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The Impact of the Blended Learning Approach on the Level of Scientific Reasoning in Physics[1]

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Abstract *The application of new technologies without changing the role of teachers and students in the education system does not necessarily mean a change in student performance. This research aims to examine the influence of active and passive engagement of high school students at the level of scientific reasoning in the e-environment during physics classes. The research sample included 128 students from two high schools in Novi Sad (Serbia), divided into two groups: experimental (E) and control (C). In group E, the active role of students was achieved by applying a blended learning approach, while in group C, where a conventional approach supported by physics education technology simulations was applied, students had a passive role. Data were collected using the Lawson Classroom Test of Scientific Reasoning (CTSR) which consisted of 24 questions comprising six dimensions: conservation of mass and volume, proportional reasoning, control of variables, probabilistic reasoning, correlational reasoning, and hypothetical and deductive reasoning. The results show that the blended learning approach leads to an increase in the level of scientific reasoning, which is reflected in the number of students at the post-formal level of scientific reasoning. Due to the importance of a proper understanding of the laws of physics, it is necessary to apply teaching approaches that encourage the development of scientific reasoning. Accordingly, the main recommendation is that the application of advanced technologies should follow a change in the role of teachers and students in the direction of peer participation and students' active participation in raising their performance.*

Keywords: *blended learning approach, teaching physics, scientific reasoning.*

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Introduction

The focus of physics as a school subject is on the different properties of energy and matter (Faridi et al., 2021). In spite of the fact that the laws of physics can be easily demonstrated in everyday life, students often have difficulties in understanding them and therefore consider physics one of the hardest and most challenging subjects (Angell et al., 2004). As they are to become experts in various fields in the future, students are considered a valuable resource of the society. Therefore, the approach to teaching and learning physics has been changed in recent decades with the aim of making physics content more comprehensible to students and more applicable in everyday life. In order to achieve greater obviousness, approaches based on simulations of physical processes and phenomena have become highly dominant in the teaching methodology. Simulations and virtual experiments allow students to control the variables, to formulate hypotheses, to interpret data and facilitate the understanding of complex phenomena (Nafidi et al., 2018, pp. 89-90). However, the impact of these approaches on students' level of scientific reasoning has remained under-researched. With this idea in mind, the current study aims to examine the impact of a blended learning approach and the conventional approach supported by Physics Education Technology (PhET simulations) on students' level of scientific reasoning. The importance of raising the level of scientific reasoning in students, and in the society globally, is reflected in understanding the cause-and-effect relationships in phenomena and the ability to draw conclusions from the observed relations. As a matter of fact, the correct formulation of questions and conclusions is recognized as the fundamental problem of teaching natural sciences (Maine Physical Sciences Partnership, 2013, as cited in Short et al., 2020). Instructional approaches for raising the level of scientific reasoning, therefore, should include the stages of problem testing, formulation and testing of hypotheses, control and manipulation of variables, as well as monitoring and evaluation of the results of the problem. The overlapping of stages in scientific reasoning with the stages of scientific method has brought about the need to evaluate the validity of Piaget's theory of formal thought and its relation to educational practice (Lawson, 1985). This re-evaluation was considered necessary because of the role of the school, not only in the presentation of scientific facts but also in the development of students' thinking skills. A general reasoning ability is the ability to question or provide a counterargument to the test causal knowledge; therefore it can be understood as a developmental cognitive construct (Ates & Cataloglu, 2007, p. 1162). Piaget's model of cognitive development of the child distinguishes several stages and levels, and for the understanding of physical concepts and phenomena, stages of concrete operations or logical thinking and formal-logical operations or abstract thinking are particularly important (Radulović & Stojanović, 2017).

According to Lawson's classification (Lawson et al., 2007), these stages are arranged on three levels: concrete, formal and post-formal. At the level of concrete operations, students master the conservation of number, volume, and mass. Students at this stage are not able to test hypotheses that include observed causative agents (Lawson et al., 2007). At the formal level, students still cannot test hypotheses but can perceive connections (Radulović & Stojanović, 2017). At the stage of post-formal level, abstract thinking is being developed. According to some researchers, the transition from one stage to the next is possible only when it is thoroughly mastered by the possibilities of the lower stage (Stepanović, 2004a, 2004b). Students can rigorously test hypotheses using observed but also unobserved agents or entities (Lawson et al., 2007). The transition from one stage to the next is possible only when it is thoroughly mastered by the possibilities of the lower stage (Stepanović, 2004a, 2004b). Approaches based on simulations and new technologies (Knie et al., 2021) support this transition. The e-environment offers a range learning formats, such as videos, texts, simulations, graphs etc. (Clark & Kaw, 2020, p. 63). Even integration of face-to-face classes with e-learning offers new possibilities (Martinez et al., 2010, p. 758).

A mere application of technologies without a change in the roles and activities of the main agents in the educational process does not necessarily lead to a higher level of scientific reasoning. This study focuses on two approaches in which face-to-face learning is integrated with simulations, with the only difference being in the role of students and teachers. The aim is to examine the effect of the two approaches on raising the level of scientific reasoning. In the conventional approach, the teacher preserved his/her dominant role, but relied on the use of PhET (Physics Education Technology) simulations, while the other approach implied the blended learning approach (BLA).

BLA is learning based on the application of face-to-face lectures, online learning, and learning supported by other technologies. The main ideas of BLA are to create an effective environment for learning, encourage students' motivation to learn, promote collaborative and project activities, and establish learning as an active and interactive process (Hoic-Bozic et al., 2009). BLA requires students' active participation during school classes and at home (Graham, 2006). Therefore, this approach enables the maximum usage of classroom time for the development of students' functional knowledge. Such a conceptualized teaching approach, however, requires the use of more complex LMS (Learning Management System) systems that allow monitoring of each student step and two-way communication between the teacher and students, as well as between students themselves. The benefits of using BLA have been documented in numerous papers (Alonso et al., 2005; Hoic-Bozic et al., 2009; Shurygin et al., 2017; Susanna et al., 2021), but according to the authors, its influence on the level of scientific reasoning has not yet been examined. Therefore, the aim of this research is to examine the impact of BLA, as an approach that supports the active role of students in the e-environment, on the students' level of scientific reasoning.

Method

Procedure

The teaching topic Direct Current was chosen for this research due to its complexity and abstractness. The topic includes 26 teaching units that aim to introduce students to the concept of the electric circuit, short circuit, how to connect ammeters and voltmeters, and all components of the circuit.

This research conducted a pedagogical experiment with parallel groups, control (C) and experimental (E). In case of C group students, the teaching content was presented by means of the conventional approach followed by PhET simulations, but with the teacher having a dominant role. The students of both groups were in the e-environment, but with different roles. Teaching materials and tasks were formulated so that students moved step by step, from easier to more complex examples. Thus, at the beginning, it was necessary to construct a circuit without resistors (short circuit) (Figure 1), then with resistors (bulbs) added (Figure 2), one by one, without changing the voltage value of the power source. The students noticed that due to the increase in the number of light bulbs, the light intensity in them decreased.

Figure 1
Short circuit: a) scheme and b) illustration in PhET simulation

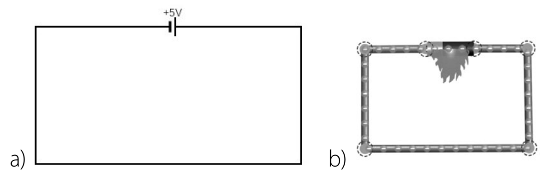
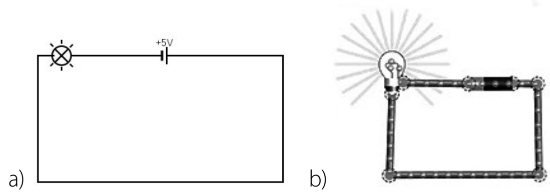


Figure 2
The simplest circuit without a switch: a) scheme and b) illustration in PhET simulation



Group C students had a passive observer role while the teacher presented the experiments that accompanied the material. In contrast, the students of Group E took an active part and constructed the circuits themselves, performed measurements, and drew conclusions in which they had to argue with each other. As the BLA requires work in the classroom and at home, all the material was available to Group E students via Moodle. Thus, the students of group E were asked to repeat the measurements at home independently and construct graphic presentations of the examined physical laws (Figure 3, Figure 4).

Figure 3
Dependence of current on voltage

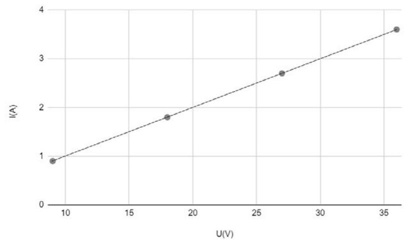
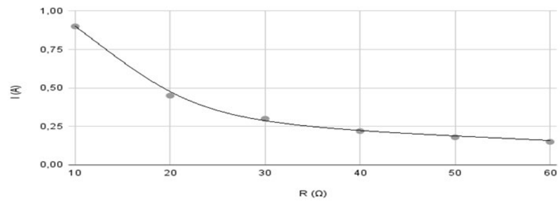
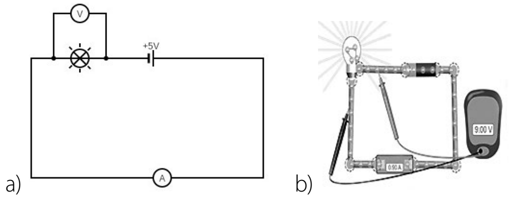


Figure 4
Dependence of current on resistance



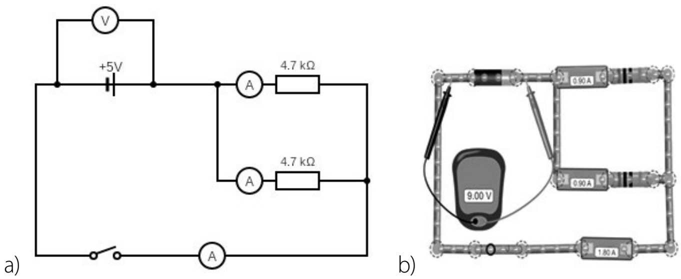
In so doing, the students used ammeters and voltmeters to measure the currents and voltages of each light bulb in the circuit and made conclusions about the connection between the observed attenuation of light intensity due to an increase in the number of light bulbs in the circuit (Figure 5).

Figure 5
Determining the current and voltage for a given circuit element: a) scheme and b) illustration in PhET simulation



Also, the students changed the way of connecting light bulbs (in series and parallel) and watched how the current and voltage changed (Figure 6).

Figure 6
Influence of different ways of connecting light bulbs in a circuit on voltage and current values



The students had to submit their homework in the appropriate folder on the Moodle platform. The students had the task of writing a report based on the measured physical quantities, which they were asked to present tabularly and graphically, using the relations obtained. After submitting the homework, the students had the opportunity to continue discussing the obtained results and critically evaluate each other. The students were randomly given other students' work for evaluation. They graded the works by giving a percentage from 0% to 100% with a detailed explanation of why they scored the way they scored. Thus, the homework did not have the role of just repeating the material but aimed to encourage students to critically analyze the values of other students' experimental measurements, as well as the way of performing and formulating conclusions based on the obtained values. To avoid favoring someone's work, negative points were introduced if incorrectly drawn conclusions or poorly measured results were highly valued. Although the students were critical when grading other people's work, knowing that they would also be graded on their assessment of other people's work, the teacher's task was to check the objectivity of the given grades and assess the quality of the homework.

The functional tasks of the classroom were focused on developing logical thinking, the ability to recognize cause-and-effect relationships and draw conclusions, connecting already acquired knowledge with new knowledge, and enabling students to connect a circuit. Working at home emphasized the ability to think critically, present information, and argue conclusions.

Participants

The research included 128 students from two grammar schools in Novi Sad, Serbia. The participants were divided into two groups: 64 in the experimental group (E) and 64 in the control group. The groups were formed on the basis of already existing classes. The goal of the research was presented to all students, both principals and the school pedagogy and psychology services. The students voluntarily participated in the research.

In order to determine the sample size, the Raosoft application was used, based on which it was estimated that the sample of 128 students was appropriate with a confidence level of 90%.

Instruments

Lawson's Classroom Test of Scientific Reasoning (CTSR), developed by Anton Lawson and translated into Serbian, was used in the initial and final testing. Lawson's test consists of 24 questions grouped in 12 pairs, thus representing six dimensions, i.e. components of scientific reasoning: conservation of mass and volume, proportional reasoning, control of variables, probabilistic reasoning, correlational reasoning, and hypothetical and deductive reasoning (Radulović & Stojanović, 2017).

The first 10 pairs of questions of Lawson's test are made up of the main question and sub-questions in which an explanation is sought as to why the answer to the main question is correct. The last two pairs of questions, 21-22 and 23-24, have a slightly different form. The first question is the central one, and the second question is an experiment that would prove that the answer to the first question is incorrect. This examines students' complete understanding of the problem situation because it is much more difficult to assume an opposite solution and explain it appropriately. Scoring of the Lawson test required students to give the correct answer to both questions in one pair of questions in order to win a point. Accordingly, the maximum number of points that students could score is 12. Students who score from 0 to 4 points are at a specific level; from 5 to 9 points is the formal level, while if they score 10 or more points, they are at the highest, post-formal level (Radulović & Stojanović, 2017). Standardized Cronbach's Alpha for the scientific reasoning test was 0.790.

Data analysis

Mixed analysis of variance (ANOVA) and independent samples t-test were used to determine the impact of applied teaching approaches on scientific reasoning, while eta-square indicator showed the strength of the variability amongst the variables. The analyses were performed using the JASP.

Results

To test how similar the C and E groups were in the pre-test, the independent samples t-test was applied. The obtained results (Table 1) show that the difference in the students' achievement is not statistically significant.

Table 1
Statistical difference in pre-test achievement of the C and E group students

Group	*M*	*SD*	*t (df)*	*d*
C	7.83	1.99	1.407 (124)	0.251
E	7.35	1.81		

Note. M – Mean, *SD* – standard deviation, *t* – t-test value, *df* – degrees of freedom, *d* – Cohen's d

The average values obtained show that the students of both groups are at the formal level of scientific reasoning, because they scored about 7 points out of a maximum of 12. After the pre-test was completed, the C group had classes with PhET simulations with the dominant role of the teacher while in the E group the approach was student-centered. After that, the participants were tested again. The difference in the students' achievement was examined by the mixed ANOVA in two periods of measurement (prior and after the treatment) (Table 2).

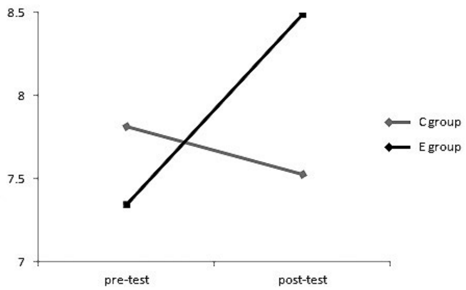
Table 2
The effect of group and testing (time) on the students` achievement

	F	*df*	η_p^2
Group	0.615	1	.005
Testing	3.896	1	.030
Testing x group	10.822**	1	.080

Note. F- F-test value, df – degrees of freedom, η_p – partial eta squared, ***p* < .001

The results suggest that the difference in the two test scores is dependent on group membership. The graphs given below (Figure 7) show that the E group had a higher score in the post-test than in the pre-test, while the opposite situation was recorded in the case of the C group. The independent samples t-test indicates that the difference in the post-test achievement is statistically significant when the two groups of students are compared (t = -2.350, df = 124, p = 0.02, d = -0.419).

Figure 7
Difference on pre-and post-test for both groups



The analysis suggests that the E group students were higher achievers than their C group peers. The obtained negative value of the C group should therefore be understood as stagnation in the recognition and prediction of problem solutions, and not as a simple reduction of scientific reasoning. This further implies that the active role of students in physics classes contributes to their better achievement.

In order to better illustrate the impact of BLA on the level of scientific reasoning in students, Table 3 presents the results of the mixed ANOVA. The analysis encompasses the interactions between the instructional approach, the levels of scientific reasoning (concrete, formal and post-formal) and the testing period.

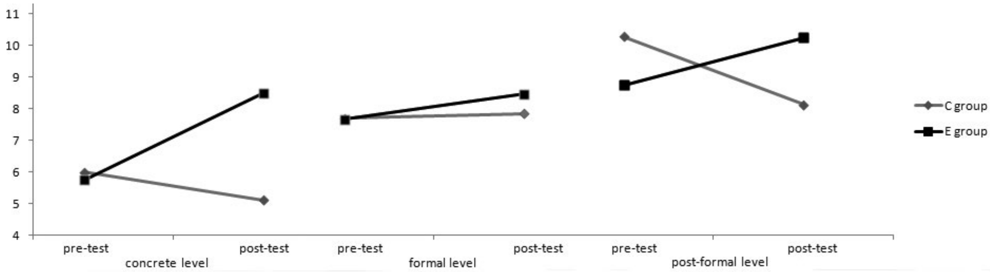
Table 3
Effects of interaction between non-repeated group factors of testing and repeated factors of testing and level of scientific reasoning

	F	df	η_p^2
Group x Testing	0.271	1	.002
Group x Level	11.548**	1	.091
Level x Testing	4.620*	1	.039
Group x Testing x Level	5.329*	1	.044

Note. F- F-test value, df – degrees of freedom, η_p – partial eta squared, ***p* < .001, **p* < .05, ** *p* < .001

The above results suggest that the effect of the interaction between the factors Group and Level is significant, implying that the Group effect is not identical in students with different levels. The effect of Level and Testing variables also proved significant, indicating a different pace in students' progress between the two tests. The means of scientific reasoning in relation to the given levels are shown in Figure 8.

Figure 8
Difference on pre- and post-tests for three levels of scientific reasoning



As shown in Figure 8, there is a noticeable increase in the mean of each scientific level of E group students while such changes did not occur in C group students. Thus, the BLA approach based on the active role of students in the educational process to a greater extent encourages the development of higher levels of scientific reasoning. Therefore, the obtained results can be understood as encouraging E group students to be creative and take a critical approach to the problem.

To better understand the contribution of this teaching approach, one-way ANOVA was applied to compare student achievement on the post-test between groups for the six components of reasoning (Table 4).

Table 4
Influence of applied teaching approaches on the observed components of reasoning

	F	*df*	η^2
conservation of mass and volume	2.808	1	-
proportional reasoning	5.603*	1	.050
control of variables	10.252*	1	.088
probabilistic reasoning	7.361*	1	.065
correlational reasoning	6.730*	1	.060
hypothetical-deductive reasoning	1.890	1	-

Note. F- F-test value, df – degrees of freedom, η_p –eta squared, * $p < .05$

In four of the six components, the E group students achieved a statistically higher score than their C group peers.

Discussion

STEM subjects (science, technology, engineering, and mathematics) are seen as a meaningful context for embedding scientific reasoning, critical thinking (Faridi et al., 2021) and computational thinking (Knie et al., 2022). However, it has been observed that students do not understand certain concepts and as a result, new approaches to teaching and learning physics, as one of the STEM subjects, have been created in the last decades. One of the approaches that has gained a lot of attention is the one based on simulations. Although a number of studies have pointed to the positive effects of employing simulations in classes (Martinez et al., 2010; Freeman et al., 2014, as cited in Kaw et al., 2019), there are still some open questions, such as the impact of this method on scientific reasoning.

The present results point to a more positive impact of BLA as an approach that involves active student engagement on the level of scientific reasoning than the conventional approach followed by online simulations, but with the passive role of students. The results show that a higher percentage of E group students than C group students are at the post-formal level. According to Lawson et al. (2007), students at the post-formal level of reasoning can consistently test hypotheses using observed but unnoticed agents or entities. Students are trained to empirically verify theoretical laws and to draw conclusions about the relationships between variants based on empirical values (Stepanović, 2004b). The value of the obtained result is reflected in the data of several researches reporting that many high school students, as well as university students, have not developed post-formal reasoning (Lawson, 2006). Also, the results obtained by Huitt and Hummel (2003) show that only 35% of high school graduates have developed formal reasoning, and many people do not develop it even in adulthood. Failure to achieve the highest post-formal level of reasoning results in difficulties in solving computational problems, understanding theoretical concepts, and rejecting misconceptions related to sciences and mathematics.

In addition to their higher average achievement, the students in group E achieved better results on four of the six observed components of scientific reasoning. These components are proportional reasoning, conrol of variables, and probabilistic and correlational reasoning. Bitner and Valanides identified these components with critical thinking skills as essential for success in advanced high school science and math courses (Radulović & Dorocki, 2018). The component of scientific reasoning the control of variables is essential because it follows the way of thinking and concluding. Students are given a task where they have one dependent and one independent physical unit (current, voltage, and resistance). These univariable designed experiments help students construct data that influence their conceptual representations of a single cause and effect (Rind & Ning, 2020, p. 365). Students of both groups, using PhET simulations, performed univariable experiments to observe changes in the electric current depending on voltage and then on the applied resistance in the circuit; with the difference that in group C the teacher had the dominant role, while in group E the BLA with the dominant role of students was applied. During the school classes, the students of the E group created the same circuits as the teacher in the C group. During school classes and work at home, the students in the E group discussed possible situations, measurement results, drew conclusions, applied argumentation, etc. The active engagement of the E group students in discussing and giving arguments related to their assumptions was aimed at developing critical thinking skills and the ability to present information appropriately. Lack of arguments has been identified as one of the main problems in science teaching (Maine Physical Sciences Partnership, 2013, as cited in Short et al., 2020). The BLA offers an opportunity to overcome this problem (Greenlaw & DeLoach, 2003, as cited in Sukma & Priatna, 2021). The students in the E group had the opportunity to evaluate other students' work and explain their grades, which followed the development of students' argumentation and critical thinking. Ling and Loh (2020) have shown that the deduction indicator for critical thinking has significant relationships with sequence logic. Accordingly, drawing the right conclusions encourages critical thinking (Wannapiroon, 2014, as cited in Prafitasari et al., 2021) and scientific reasoning.

Although no statistical significance was obtained for the hypothetical and deductive reasoning component, the E group students showed slightly higher achievement than their C group peers. Within this component, students should notice complex relationships among variables, combine them systematically, and arrive at the set of all possible combinations (Radulović & Stojanović, 2018). The complexity of the tasks is reflected in the need to explain the diametrically opposite result of the experiment. By noticing all the connections, students can make a hypothesis about the experiment and explain its result.

Conslusions

This research aimed to examine the impact of the blended learning approach (BLA) on the level of scientific reasoning. The approach applied as the one that supports the active role of students in the educational process was the blended learning approach, while the passive role of students was achieved through the conventional approach followed by simulations. The results showed that the application of new technologies without changing the roles of teachers and students in the educational system does not cause a significant improvement in the students' level of scientific reasoning. The application of BLA, based on the active role of students during school classes and work at home, led to an increase in the level of scientific reasoning. The number of students at the post-formal level in the E group was twice as high as in the C group. An increase in the number of students at the post-formal level is an increase in the number of students who can think in abstract categories to draw conclusions based on abstract assumptions that are very important in learning physics. These students fully understand the physical concepts and phenomena they learn and thus achieve better results on the knowledge test. Post-formal reasoning is more flexible, logical, accepts moral and intellectual complexity, where dialectics are at a much higher level than at previous stages. Therefore, it can be concluded that new technologies can encourage the development of post-formal reasoning but it is necessary to change the roles of teachers and students in the teaching and learning process.

Finally, it is necessary to state the limitations of the research regarding the choice of a specific topic for the implementation of BLA and the consideration of its impact on the level of scientific reasoning. Namely, this paper focused exclusively on the complex and abstract topic of direct current. Consequently, the findings derived from this research may not be universally applicable to other branches of physics. To improve the generalizability of the results, future research could investigate the effectiveness of BLA at the level of scientific reasoning in solving challenges within different physics disciplines. In addition, the inclusion of participants from different age groups and educational levels would provide a more comprehensive understanding of the impact of BLA on the level of scientific reasoning and, in general, on the teaching and learning of physics. In this way, the limitations of this research, which concerns a sample of the same age with the same educational profile, would be overcome.

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Uticaj pristupa kombinovanog učenja na nivo naučnog rezonovanja u nastavi fizike

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Apstrakt *Primena novih tehnologija bez promene uloga nastavnika i učenika u obrazovnom sistemu ne znači nužno promenu u postignućima učenika. Ovo istraživanje ima za cilj da ispita uticaj aktivnog i pasivnog angažovanja srednjoškolaca na nivou naučnog rasuđivanja u e-okruženju tokom časova fizike. Uzorak istraživanja obuhvatio je 128 učenika iz dve srednje škole u Novom Sadu (Srbija), podeljenih u dve grupe: eksperimentalnu (E) i kontrolnu (K). U grupi E, aktivna uloga učenika postignuta je primenom kombinovanog pristupa učenju, dok su u grupi K, gde je primenjen konvencionalni pristup podržan simulacijama tehnologije za edukaciju fizike, učenici imali pasivnu ulogu. Podaci su prikupljeni korišćenjem Losonovog testa naučnog rezonovanja u učionici (CTSR) koji se sastojao od 24 pitanja koja obuhvataju šest dimenzija: konzervacijom materije i zapremine, rezonovanje zasnovano na proporcijama, kontrola varijabli, rezonovanje zasnovano na predviđanju, rezonovanje zasnovano na korelacijama i hipotetičko-deduktivno rezonovanje. Rezultati pokazuju da kombinovani pristup učenju dovodi do povećanja nivoa naučnog rezonovanja, što se odražava u broju učenika na postformalnom nivou naučnog rezonovanja. Zbog važnosti pravilnog razumevanja zakona fizike, neophodno je primeniti nastavne pristupe koji podstiču razvoj naučnog rezonovanja rezonovanja. U skladu s tim, glavna preporuka je da primena naprednih tehnologija treba da prati promenu uloga nastavnika i učenika u pravcu vršnjačkog učešća i aktivnog učešća učenika u podizanju njihovih postignuća.*

Ključne reči: *kombinovani pristup, nastava fizike, naučno rezonovanje.*