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EDUCATIONAL EFFICIENCY AND STUDENTS' INVOLVEMENT OF TEACHING APPROACH BASED ON GAME-BASED STUDENT RESPONSE SYSTEM

Branka Radulović

Abstract. *Modern approaches in Physics classes which involve the game-based student response system (GSRS) have been in use for a while, but their educational efficiency and students' involvement have not been examined. Therefore, this research's main aim was to determine the educational efficiency and students' involvement of GSRS and to assess their effect on scientific reasoning. The values of educational efficiency and students' involvement were calculated based on students' achievement and perceived mental effort. To determine these values, a pedagogical experiment with parallel groups was applied. The research was conducted on a sample of 172 secondary school students, and included material related to direct currents. The results point to positive and higher values of the educational efficiency and students' involvement for GSRS approach than the conventional approach. It means that GSRS approach causes lower mental effort, letting more space generate in the working memory to perceive and process new information. The results also show a positive effect of GSRS on higher students' engagement during the class and scientific reasoning. The obtained results undoubtedly indicate the positive effect of GSRS on the students' performance. Therefore, GSRS approach should be used often in the classroom.*

Keywords: *educational efficiency, students' involvement, GSRS, scientific reasoning, teaching physics*

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Introduction

From the moment it was created, game-based student response systems (GSRS) have attracted the attention of numerous researchers intending to determine their effect on students' performance. The primary purpose of using these tools lies in the fundamental problem observed in contemporary education: the lack of student motivation to learn and the lack of engagement during classes (Archer et al., 2020; Clark et al., 2017; Göksün & Gürsoy, 2019). GSRS provides a foundation for making the classrooms fully interactive, enabling students to interact with the teacher and learn subjects in new ways without tremendous cost and effort to administrate and maintain special devices (Wang, 2015). The teacher asks a question, which can be in the form of text, images, or videos through the projector, and students using their mobile phones or appropriate responders give a response to it (Balta et al., 2018; de Freitas, 2006; Licorish et al., 2018; McCaffrey et al., 2014). As soon as they answer, the students immediately receive feedback whether their answer is correct. Also, using the information based on students' responses, the teacher gets the information about the material taught in class, whether it is understandable to students and if there are some misconceptions. In that way, the teacher can have an insight into the transformation of students' state from naive to normative by using the scheme of concept formation (Demkanin & Kováč, 2018; Demkanin, 2018).

Some of the GSRSs are Kahoot and Socrative. According to Vick, as of 2019, over 2.5 billion people from more than 200 countries have played Kahoot, and there are 70 million monthly active unique users (Vick, 2019, according to Wang & Tahir, 2020). Because of such a large number of users, it is crucial to determine educational efficiency (E) and students' involvement (I) of GSRS. E and I's values provide information of occupancy of working memory taking into account the effectiveness of the applied teaching approach and the motivational effect that students experience in learning. Therefore, E and I's values give information on the full effect of a particular teaching approach on students' performance. For the E and I's determination, it is necessary to define standard values of students' achievement (P) and standard values of perceived mental effort as a measurable part of the cognitive load (R). The

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formula for E is: $E = \frac{P - R}{\sqrt{2}}$ (van Gog & Paas, 2008), while for I, the formula is: $I = \frac{R + P}{\sqrt{2}}$ (Paas et al., 2005). In Appendix 1 a graphical representation of these two variables is given.

Measuring the level of students' scientific reasoning is also useful in assessing GSRS approach. Scientific reasoning represents the ability to systematically explore a problem, formulate and test hypotheses, control and manipulate variables, and evaluate experimental outcomes (Han, 2013). These abilities are also necessary for practical work in the Physics laboratory and theoretical tasks (Erlina et al., 2018; Etkina et al., 2010). The scientific reasoning level can be determined by using Lawson's CTSR test (Lawson, 1978, 2004, 2005, 2010). This test includes (1) conservation of matter and volume, (2) proportional reasoning, (3) control of variables, (4) probability reasoning, (5) correlation reasoning, and (6) hypothetical-deductive reasoning (Radulović & Stojanović, 2017). The test gives a much better insight into students' knowledge as it clearly shows whether some of the content is merely memorized or adequately embedded in the student's cognitive structure (Ates & Cataloglu, 2007; Lawson & Thompson, 1988).

Research Problem

Numerous research studies have raised the problem of student motivation for learning, and in this regard, Physics as a subject and students' engagement in Physics classes have been particularly emphasized. The problem of student motivation for learning Physics seems to be worldwide, as it has been recognized in developed countries like UK, India, Japan, the USA, countries in the European Union, and also in non-developed ones (Djudin, 2018). The problem has been observed in decreasing numbers of students interested in studying Physics at university. In response to the problem of student motivation and their engagement during class, a large number of teaching approaches have been developed in recent decades. For some of them, complete information on their effect on student performance, such as educational efficiency, student involvement, and the effects on scientific reasoning, have not been established. Therefore, to ensure student science literacy and the ability to explain scientific phenomena and draw evidence-based conclusions (OECD, 2009, as cited in Demkanin, 2013), it is necessary to obtain complete information on the effects of teaching approaches on student performance. This paper focuses on educational efficiency and student involvement in GSRS approach and its effect on scientific reasoning. The obtained data was compared with the conventional approach to teaching Physics.

Research Focus

With regard to the research problem, the focus will be on the effects of GSRS approach, specifically on determining educational efficiency and student involvement and the effect on student scientific reasoning. Despite significant contributions of other researchers, these values, to the best of the author's knowledge, have not been fully examined. Therefore, the main aim was to determine the educational efficiency and students' involvement of GSRS in Physics classes, and to assess their effect on the level of scientific reasoning. This aim was operationalized through the following research questions:

- Does the GSRS approach reduce the students' mental effort?
- Does the GSRS approach increase the students' understanding of the content related to the electrical current, as measured by DIREC test?
- Which applied teaching approach results in higher value of educational efficiency and students' involvement?
- Does the GSRS approach increase students' scientific reasoning?

Research Methodology

General Background

The fundamental research question is related to determining educational efficiency and student involvement for GSRS approach and its effect on scientific reasoning. This approach uses game elements such as scores, badges, rankings, and rewards in gamification. As such, it leads to student engagement in the learning environment and enforces their behavior to reach targets (Glover, 2013, according to Göksün & Gürsoy, 2019). GSRS combines text,

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audio, and video material which can differently affect student performance, from negative (Mendelson, 2004), slightly positive (Wang & Tahir, 2020), to positive effect (All et al., 2017; Lynch & Keenan, 2018; Tsai & Hsu, 2020). Also, there is a large number of GSRS users in the world. Bearing this in mind, it appears crucial to determine the effect of this approach on students' performance.

To determine educational efficiency and students' involvement and to assess GSRS effect on the level of scientific reasoning, a pedagogical experiment with parallel groups was applied. The research was conducted in the period from March to May 2018, on a convenience sample of 172 students. The preparation of GSRS group students lasted one year in order to obtain the most reliable data on the effects of GSRS approach. The purpose of introducing students to GSRS was to direct their attention on the teaching content rather than the functions of these tools and to find the appropriate number and type of questions. The teaching topic Electric Current was chosen for this research, due to its complexity and abstractness.

Procedure

In this research, a pedagogical experiment with parallel groups, experimental (GSRS) and control (C), was applied. The groups were formed based on already created classes in one secondary school. The principal, the school administration, the students, and their parents were all briefed on the research's conduct. The students who did not agree to participate in the research participated equally in all activities, but their tests were not evaluated and not taken into statistical data processing.

During the first grade of secondary school, the GSRS group of students started working with electronic educational games in their Physics classes. In this way, GSRS was introduced to the students. They mostly used Kahoot and Socrative. The preparation had two aims: to introduce students to GSRS functions, after which they would be more focused on the teaching content, and to find the appropriate number and type of questions. According to All et al. (2017), poor slide-based lectures can cause students lower satisfaction with the learning experience. Therefore, the preparation of questions and other materials should be given a special attention.

For this research, the topic of DC was chosen, as it is one of the most crucial parts of Physics and, at the same time, the most difficult for students. This topic includes high abstraction concepts that are not familiar to students, such as short circuits. According to the curriculum prescribed by the Ministry of Education in the Republic of Serbia, primary school students (13-14 years) learn basic concepts of electric field and electric current. Therefore, before the pedagogical experiment started, a pre-test was performed to determine the initial state.

The pedagogical experiment lasted for 26 hours or 13 weeks. Out of the total number of hours, 22 were for the chosen content, and 4 were devoted to testing. During 22 hours, the GSRS group repeated the material for 10-15 minutes using Kahoot and Socrative. The teacher had previously carefully selected the questions. The same questions were presented to students in the C group but in a conventional way, through an oral examination. In this way, the teacher asked the whole class and only one student could answer, leaving the others without an opportunity to answer the same question. The same teacher taught all the teaching units in both groups to reduce the teacher's influence (such as his/her communication abilities, for example). For this reason, only one secondary school was chosen for the experiment. The experiment was conducted from March to May 2018.

Sample

The sample consisted of 172 students of the second grade of the general-type secondary school in Novi Sad, Republic of Serbia. According to ISCED classification this level corresponds to upper-secondary school. In Serbia there are four types of secondary school (Natural Science and Mathematics, Socio-Linguistic, General, and Specialized). Based on empirical data, the lowest interest in Physics is observed among students of a general-type secondary school. This was the reason why these students participated in the research. The problem of student engagement and interest in Physics has been expressed in decreasing numbers of students interested in studying Physics at university. As this problem is recognized as global, it is crucial to obtain complete information about the teaching approaches. The entire population of all second-grade students of secondary school, all types, from Vojvodina region, was around 3,500 students. For the value of margin of error between 5% and 10%, the research sample of 172 students represented a convenient sample. Both experimental and control groups consisted of 86 students. The age of the second-grade students was from 16 to 17.

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Instrument

In this research, standardized tests were applied. Determining and Interpreting Resistive Electric Circuit Concepts Test (DIRECT) developed by Paula Engelhardt and Robert Beichner was used to assess the degree of knowledge and understanding of terms in the field of Electricity. The pre- and post-tests were the same. DIREC test had 29 items with multiple choices. Data were coded with 1 if the answer was correct and with 0 if it was not. Validation of this test has been confirmed in several papers. The test is available at https://www.physport.org/assessments/assessment.cfm?I=24&A=DIRECT. Cronbach Alpha was 0.861.

The 5-point Likert-type scale followed each item on the knowledge test with descriptors ranging from very easy (code 1) to very difficult (code 5). The students were asked to evaluate how much mental effort they invested. This subjective self-assessment of mental effort has been widely accepted as a reliable method (de Jong, 2010; Milenković et al., 2014; Paas et al., 2003). Cronbach Alpha for the assessment of mental effort was 0.962.

Lawson Classroom Test of Scientific Reasoning (CTSR), developed by Anton Lawson, was applied to determine the level of scientific reasoning. The test was used after the pedagogical experiment. It had 13 questions and 11 sub-questions. Data were coded with 1 if the student answered correctly and gave the correct explanation and 0 if (s)he gave incorrect answers or explanations. The maximum score on this test was 13. The validation of this test has also been confirmed in numerous papers, and the test is available at https://www.physport.org/assessments/assessment.cfm?I=61&A=CTSR. Cronbach Alpha was 0.958. Since the values of Cronbach Alpha for knowledge test, mental effort and scientific reasoning were higher than 0.7, the tests proved as reliable.

Data Analysis

Descriptive statistics, ANOVA, t-test, chi-square, and the neural network model were used to determine the difference in students' knowledge and perceived mental effort. The neural network model was used to determine the contribution of predictors to the explanation of the student achievement variable. The neural networks model determines each predictor's importance without the possibility of multicollinearity between the predictors. This model is based on the training and testing samples. Eta-square indicator was used as an estimator of the size of the variables' effect. Educational efficiency and students' involvement were calculated using appropriate formulas. SPSS.20 program was used for statistical data processing.

Research Results

Students' Achievement on DIREC Test

ANOVA showed that there was no statistically significant difference among students on pre-test, F ($df = 1$) = 1.26, $p > .05$. Students' achievement in GSRS group was $M = 6.28$, $SD = 1.96$, while in C group the values were $M = 5.97$, $SD = 1.70$. After equalization of the groups, a pedagogical experiment with parallel groups was applied. The main characteristic of this experiment is that the same teaching contents are processed using different approaches, while the measuring instruments are identical. After the experiment was completed, a post-test (DIRECT) was applied to determine the effect of the applied teaching approach on students' achievement. ANOVA showed that there was a statistically significant difference in students' achievement depending on the applied approach, F ($df = 1$) = 55.235, $p < .001$, $\eta^2 = 0.25$. In the GSRS group, the mean achievement was $M = 13.21$, $SD = 6.70$, while for the C group students, it was $M = 7.29$, $SD = 3.11$. To better understand the effect of applied approaches, t-test of paired samples was applied (Table 1).

Table 1
Difference between Pre- and Post-test Within Groups

	M(SD)	***t***	***η^2***	***df***
Cpost - Cpre	1.33 (3.29)	3.739**	0.141	85
$GSRS_{post}$ - $GSRS_{pre}$	6.93 (6.38)	10.080**	0.544	85

* $p < .05$, ** $p < .01$

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As it can be seen, the highest difference between students' achievement on pre- and post-test was obtained in the GSRS group. Eta-square coefficient indicated a large effect size of GSRS on students' achievement. It can be assumed that GSRS approach caused higher students' engagement and their active involvement in the teaching process resulted in higher achievement. The more agile students of the GSRS group were encouraged to develop a competitive spirit, and those introverted were given a chance to express their cognitive potentials. In this way, more students are actively involved in the teaching process, which is especially important for classes with a larger number of students. In this particular case, classes with 30 students were included in the research. With the conventional approach a small number of students could answer the teacher's questions, while GSRS offered that possibility to everyone. Knowing that they will not have the opportunity to express their cognitive potentials, introverted persons in the conventional approach remain unrecognizable, i.e., unnoticed by the teacher. In such a situation, the teacher cannot correct his/her approach and may not respond to students' cognitive demands or eliminate certain misconceptions.

Looking at DIRECT items, the GSRS group students gave significantly better answers to all of the items than their C group peers. A problem that resulted in a more considerable difference between the groups referred to calculating the power of a resistor. The students got a starting situation; a simple circuit made up of a power source and one resistor. Then another resistor was placed in the circuit. The students were to decide if the electric current's power brought into the resistor changed; whether it increased/decreased or there were no changes. The proportion of correct answers of students in the GSRS group was 57%, while in the C group it was 1%. There were also some other examples with an electric circuit, including parallel-connected light bulbs or where a light bulb replaced the resistor.

The most challenging question for both groups of students was the question related to the creation of the electric field. The students had to answer whether the electric field inside the bulb fiber equaled zero or was different from zero. The percentage of correct answers to this question was 24% and 9%, for the GSRS and C group, respectively.

To assess GSRS approach in relation to student performance, it is necessary to determine its effect on students' cognitive load and mental effort as a measurable part. The mental effort information points to the cognitive capacity allocated to the task and the working memory occupancy. Depending on its size, the process of learning can be interrupted.

Perceived Mental Effort

ANOVA showed that there was no difference between the groups in perceived mental effort on pre-test, F ($df = 1$) = 3.136, $p > .05$. Mental effort in C group was $M = 2.59$, $SD = 0.85$, while for GSRS group it was $M = 2.83$, $SD = 0.95$. After the pedagogical experiment ANOVA pointed to a difference between the groups, F ($df = 1$) = 5.537, $p < .05$, $\eta^2 = 0.03$. The students in the C group reported slightly less mental effort $M = 2.09$, $SD = 0.82$, while in the GSRS group a considerably lower mental effort was reported in comparison with the values before the experiment $M = 1.80$, $SD = 0.77$. Table 2 presents t-test of paired samples.

Table 2
Difference in Perceived Mental Effort on Pre- and Post-test

	***M*(*SD*)**	***t***	***η²***	***df***
C_{post} - C_{pre}	0.50 (1.05)	4.418**	0.187	85
$GSRS_{post}$ - $GSRS_{pre}$	1.03 (1.10)	8.688**	0.470	85

* $p < .05$, ** $p < .01$

A decrease of perceived mental effort was obtained in both groups, but there was a difference in the size effect. Eta-square showed a moderate effect of GSRS approach on the decrease of perceived mental effort. Viewed by categories (Figure 1), in the GSRS group, a significant reduction in category (difficult) was detected by about 25%, and a significant increase of the lowest perceived effort (very easy) by about 30%. There were also changes in the C group's perceived mental effort, but these changes were less intense than in the GSRS group.

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Figure 1
Difference in Perceived Mental Effort on Pre- and Post-test

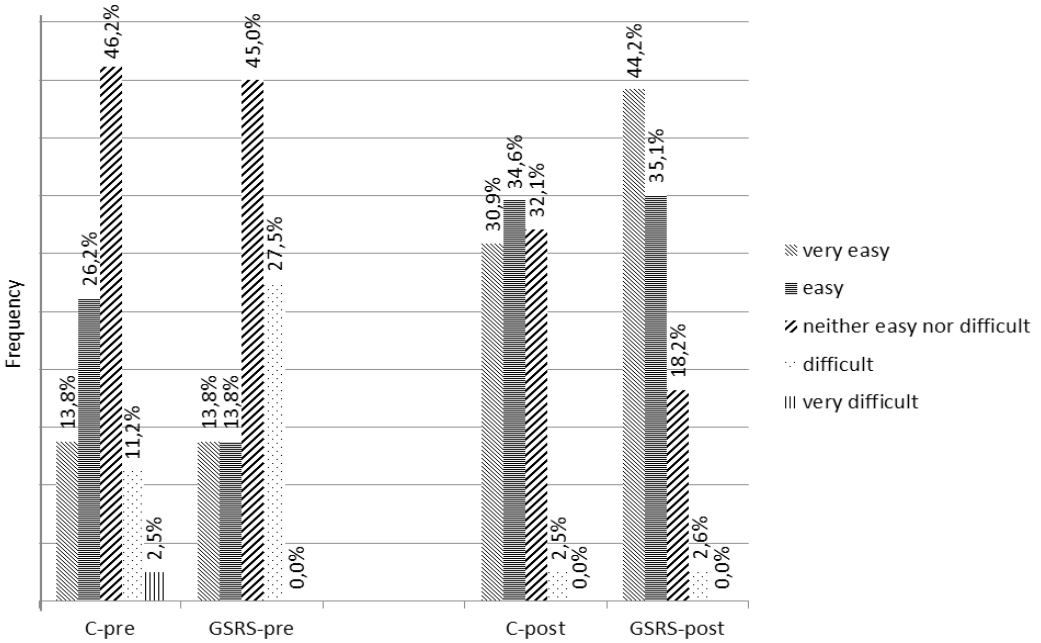
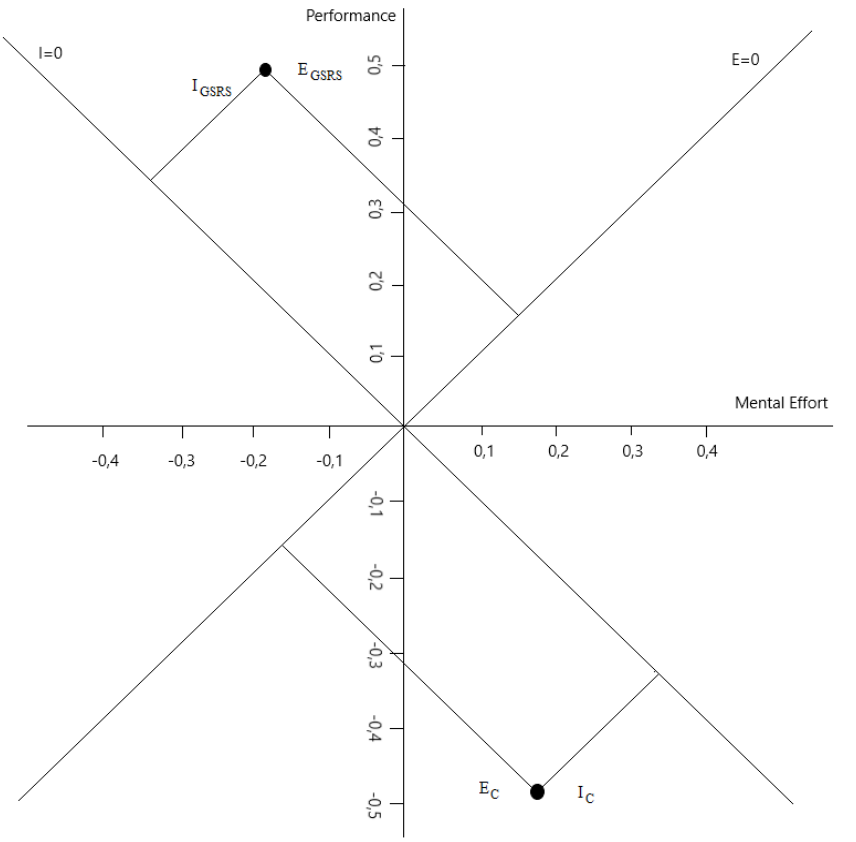


Figure 2 shown the educational efficiency (E) and students' involvement (I).

Figure 2
Educational Efficiency and Students' Involvement



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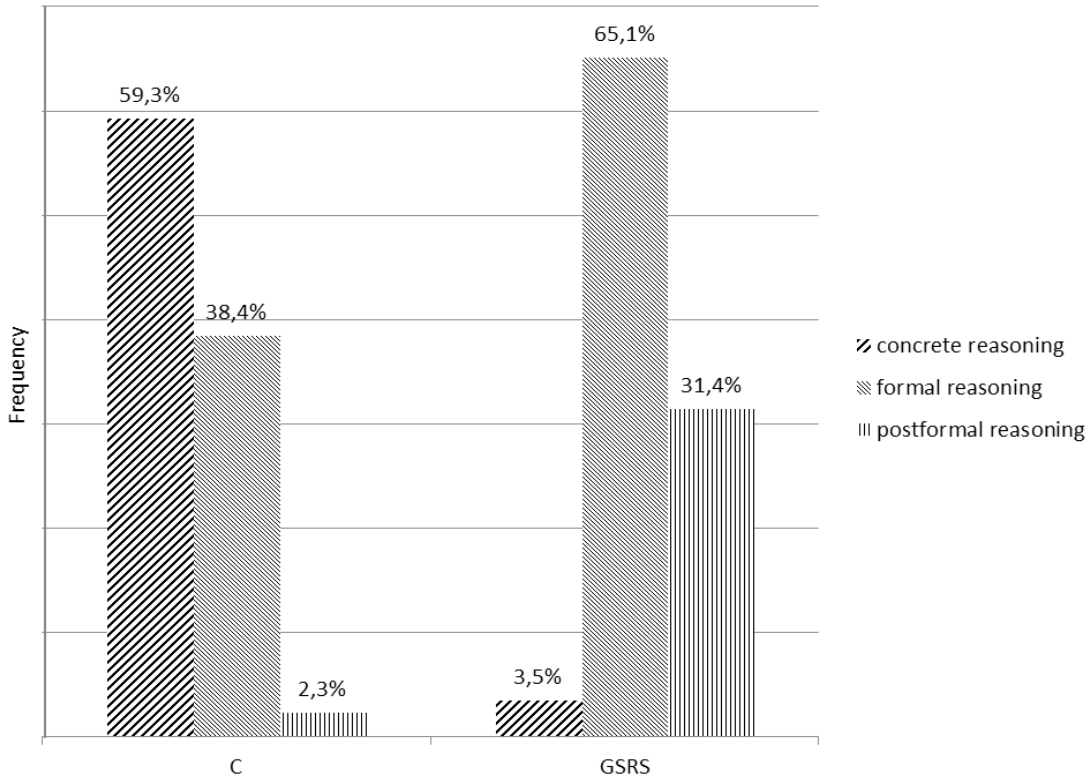
Applying the formulas by Paas and coworkers, the obtained value of educational efficiency for the GSRS group was $E_{GSRS} = 0.504$, while for the C group was $E_C = -0.705$. As for students' involvement, the values were $I_{GSRS} = 0.226$ and $I_C = -0.221$. According to the obtained values, GSRS appeared much more effective for students than the conventional approach. GSRS caused less mental effort, leaving more space in working memory to perceive and process new information.

Level of Scientific Reasoning

During the final testing, the students' scientific reasoning level was assessed. The chi-square test showed a statistically significant difference in the level of scientific reasoning depending on the applied teaching approach, $\chi^2(df = 2) = 70.162$, $p < .001$, Cramers $V = 0.639$ (Figure 3).

Figure 3
Effect of Teaching Approaches on the Level of Scientific Reasoning



More students in the GSRS group were at the highest post-formal level than in the C group. At this level, abstract thinking develops. It means that students become able to reason in abstract categories and make conclusions by using deduction. On the other hand, the students of group C at a concrete level use inductive reasoning. They can memorize teaching content, but not generalize physical laws and principles. In other words, it means that the C group students were unable to do items related to conducting experiments. These students were unable to notice the existence of dependence between the presented variables.

Model of Neural Networks

A model of neural networks was used to determine the predictor's contribution: applied teaching approach, perceived mental effort, and the level of scientific reasoning on the variance in student achievement. The training

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sample for the applied model's validity was 93.5%, while the test sample was 80.0%. The AUROC (area under the ROC curve) that gives the model's accuracy was 0.923. Table 3 shows both the importance and the normalized importance of each predictor in determining the neural network.

Table 3
Importance and Normalized Importance of Each Predictor

	Importance	Normalized importance (%)
Teaching approach	0.439	100.0
Scientific reasoning	0.315	71.8
Mental effort	0.246	56.0

The obtained data indicate that all predictors were significant, with normalized importance of more than 50%. Accordingly, to increase students' achievement, it is necessary to apply such a teaching approach that will cause an increase in the level of scientific reasoning and, at the same time, decrease the perceived mental effort.

Discussion

The interest in using digital games as educational tools has increased enormously over the past decade (All et al., 2017; Lynch & Keenan, 2018), which demands better teachers' knowledge and skills in using the modern technology (Demkanin, 2020; Demkanin & Novotná, 2021). This approach combines the entertaining power of digital games and teaching content. The positive effect of the approach on students' engagement and achievement has been observed, but still, to the best of the author's knowledge, its educational efficiency and students' involvement have not been fully assessed.

The obtained results have pointed to a considerably positive effect of GSRS approach on students' achievement. The GSRS group students achieved higher values on the knowledge test than their C group peers. This suggests that students better understand the teaching content and appear more focused on it when they use GSRS. Differences were particularly noticed for the group of items related to the brightness of parallel bulbs in some current or with the bulb's resistance after the switch is open. More students in the GSRS group gave correct answers to almost every item than it was the case with the C group students.

Dervan (2014) found that using Socrative, one of the used GSRS in this research, lectures became more interactive and highlighted students' gaps in knowledge. Also, Socrative improved students' engagement during lectures and helped the teacher understand where students had a difficulty. According to Caldwell, some students said that they paid more attention and focused more on content because they knew they had to use this knowledge at the end of the lecture to compete in a knowledge competition (Caldwell, 2007, according to Wang, 2015). Those very competitive ones had even read the textbook more carefully before coming to lectures to beat the classmates. Raising students' motivation to learn positively affects their interest in the subject and their achievements (Habgood & Ainsworth, 2011; Olić et al., 2016). Also, higher results on the knowledge tests cause increasing student motivation to learn. Due to the complex correlation between motivation and achievement, the researchers' task is to find ways to increase one variable, which will cause an increase in the other one. However, some studies report the positive effect of electronic games (Supercharged) in teaching Physics, but still students' knowledge of the topic was rated lower than in the control group (Anderson & Barnett, 2011). Kao et al. (2017) found that post hoc comparisons show that the scaffolding group's marking critical features scored significantly higher than both the demonstration and the non-scaffolding groups. Positive effects of game-based learning were also shown in a research by Sengupta et al. (2015). Their study showed the design of conceptually integrated games for learning Newtonian physics. According to Clark et al., well-designed games can scaffold student learning (Clark et al., 2009, according to Sengupta et al., 2015).

According to the present results, GSRS approach had a considerably positive effect on decreasing the students' perceived mental effort. After determining the perceived mental effort and achievement, educational efficiency and students' involvement were calculated. The results undoubtedly indicate that the values for educational efficiency and students' involvement for GSRS approach are positive. The results point out and

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confirm the positive effect of GSRS approach on students' performance. The students were more engaged and focused on the content, and the classroom atmosphere was more dynamic compared to the conventional approach classes.

The obtained results point to the positive effect of GSRS approach on increasing scientific reasoning. More students in the GSRS group achieved a higher level of scientific reasoning than in the C group. It means that students can consistently test the hypotheses using observed or unobserved agents or entities (Lawson et al., 2007). Therefore, the starting point is not in the observed agents or entities, but in theoretical (hypothetical) relations that establish or verify real relations between phenomena (Stepanović, 2004a, 2004b). Postformal reasoning level is essential for understanding physics concepts and phenomena. Therefore, researchers are searching for different teaching approaches which will positively affect scientific reasoning and have positive values of E and I. Some of these approaches are based on using modern technology. Technology can play a significant role in helping learners use higher-order thinking skills to plan and conduct research, manage projects, and solve problems through appropriate digital tools and resources (ISTE, 2007, according to Lee & Choi, 2017). However, it is vital to use digital tools properly because they are just tools, not a goal by themselves. According to Lee and Choi (2017), when technology-enhanced learning for higher-order thinking is well-designed, it may not produce desired outcomes, as this also depends on learner factors. In this particular case, the familiarization of the GSRS students with GSRS work lasted the whole year to find an acceptable way of presenting questions and introducing students to GSRS.

Psycharis (2013) confirmed the positive effect of computational models on students' performance. Moreover, students' active role in their classrooms positively affects scientific reasoning (Erlina et al., 2018). The potentials of digital games can be used to promote collaborative problem-solving, to provide effective learning environments, and to facilitate science learning for younger students (Li & Tsai, 2013). To enhance learning and teaching, game designers should embed meta-cognitive activities, such as reflective opportunities into educational video games to provide scaffolds for students and reinforce that they are engaged in an educational learning experience (Anderson & Barnett, 2013).

Conclusions and Implications

Although GSRS approach has been in use in Physics lessons for a while, there is limited empirical evidence on its effect on student performance. The present study contributes to this lack of evidence by assessing the educational efficiency, students' involvement, and the level of students' scientific reasoning of GSRS in relation to the conventional approach in Physics classes. It has been found that GSRS results in better students' performance on DIREC test and causes less mental effort in solving tasks than the conventional approach. The obtained values for the estimated educational efficiency, students' involvement, and the level of scientific reasoning have also confirmed that GSRS approach is more appropriate for students than the conventional teaching and learning. On the basis of the overall results, it can be concluded that the present study offers a sound empirical evidence on the positive effects of the implementation of GSRS approach. Physics teachers are now given a better insight into GSRS application and the findings are intended to encourage more and more teachers to apply GSRS in their classrooms. Further research, however, should compare GSRS approach with other student-centered approaches to find the most suitable way of teaching and learning. It would also be necessary to apply a retention test in future studies.

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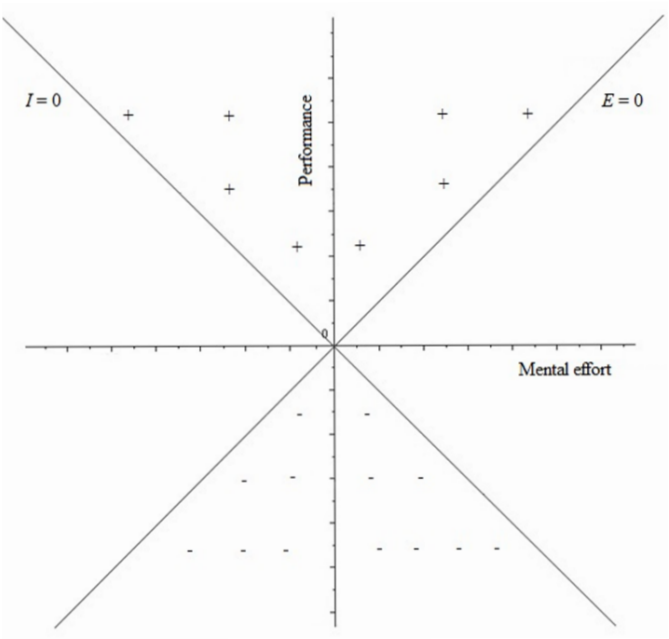
Appendix 1

Figure 4
Graphical presentation of educational efficiency and students' involvement (adapted according to Cerniglia, 2012)



If the point representing one teaching approach is above the curves, then that approach has positive values for E and I, i.e., if the point is below the curves, the applied approach has negative values. Therefore, the teaching approach with positive E, and I cause higher achievement and lower mental effort.

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