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Impact of blended learning approach on students' achievement and mental effort

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Impact of blended learning approach on students' achievement and mental effort

Abstract. Most researchers are interested in investigating the impact of a blended learning approach (BLA) on students' performance, yet this approach's instructional efficiency has not yet been quantified. Therefore, this research aims is to determine the impact of teacher-created online Moodle-based materials in combination with face-to-face learning on student achievement and mental effort, i.e., to determine the instructional efficiency of applied teaching approaches at physics classes in high school. For this research, we chose to teach students physical principles of direct current, which involves abstract concepts. Using BLA, students can prepare better for a real experiment in the lab, and this approach also creates a safe environment for the student while providing the ability to demonstrate the learned physical phenomena. The Moodle platform course is developed for this purpose and implemented in a BL environment. Students are gradually guided from easier to more difficult concepts in this research, considering the working memory's capacity and the teaching material requirements. Our results show that the students who used BLA achieved higher scores on the knowledge test, and they also used less mental effort than students that used a conventional teaching approach. We also show that instructional efficiency for BLA is positive and significantly higher than the instructional efficiency of the conventional approach. This research's results are primarily designed for physics teachers to understand the effects of the BLA better and apply teaching approaches that respect the principles of cognitive development of a child.

Keywords: Blended learning approach, Physics, Direct Current, Mental Effort.

1. Introduction

Students view physics as a subject that is interesting but complicated and work-intensive [1]. Therefore, the researchers' task is to find the best teaching approach that will cause less difficulty. Students and teachers believed that physics is not easy to learn because it requires an understanding of abstract ideas. Therefore, teachers should apply such teaching approaches, which contribute to reducing the unnecessary student's mental effort. Angell et al. also reported that students preferred active participation using class scenarios that involved more opportunities for interaction and discussions [1]. Sometimes it is not easy to achieve this kind of interaction because there is a vast amount of material that the teacher should go through with the whole class in a specific period (teaching time). That is especially hard to accomplish with large classes (30 and more students). With Learning Management Systems (LMS) [2], teachers could shift some part of theoretical lecturing to online homework and some experimental work as the core of physics, using virtual laboratories. When students work in a real laboratory, they spend much time preparing instruments and experimenting [3]. A real-life laboratory experiment includes vast amounts of distractors that the expert instructor filters out without even thinking about it (e.g., plastic insulation on the wires, the ampere meter or voltmeter, etc.). However, a student who works on some experiments with computer simulations could spend more time thinking, analyzing, and discussing [4]. According to [5-6], aspects of the virtual experiment that increase students learning outcomes are that some physics phenomena are more visible to students [7] (e.g., charge flow or some phenomena that are not visible for a human eye). This approach allows students to perform and repeat an experiment enable more comfortable and faster manipulation of variables than a real experiment, and provides immediate feedback (e.g., about errors) throughout the process of experimenting. However, virtual experiments cannot replace real-life physical experiments. Some concepts in physics are better understood

empirically with data from real experiments. According to [8], physical experimentation is likely to have more advantages in domains requiring “physical manipulation and tactile sensation”, for instance, Newtonian mechanics. However, the same authors [8] investigated the effects of an Interactive Computer-Based Simulation before Performing a Laboratory Inquiry-Based Experiment on Students’ Conceptual Understanding of Physics [6]. They concluded that simulations could enhance physics learning when adequately integrated within a substantial physics curriculum emphasizing conceptual understandings. Therefore, the best way of teaching physics concepts should be with a combination of virtual and real-life experiments.

Most researchers have found that digital technology positively impacts student performance [9-10], pointing out that learning material presented through words and images is easier for students. However, some researchers [11] argue that multiple representations, especially in that case, do not help to form mental schemes in learning. Therefore, in this research, the blended learning approach (BLA) on the students’ achievement and perceived mental effort were investigated. Mental effort refers to the cognitive capacity allocated to the task [12] and determines the instructional efficiency of BLA. By combining the values of the standardized students’ performance (P) and the mental effort (R) invested in solving tasks on a knowledge test, it is possible to estimate the instructional efficiency (E) of the applied teaching approach [13-14]. The formula that counts instructional efficiency is $E = \frac{P - R}{\sqrt{2}}$. Figure 1 presents a Mental Effort-Performance coordinate system based on which instructional efficiency can be determined.

Figure 1. The instructional efficiency determination.

Positive instructional efficiency values will have that teaching approach whose coordinates build an intersection in the upper left quadrant or if the point is above the curve. Therefore, the positive value of instructional efficiency indicates that students achieved higher achievement with less mental effort invested. If the teaching approach coordinates build an intersection in the lower right quadrant, or if the point is below the curve, the instructional efficiency of that approach will be negative.

Blended learning approach

Graham describes BLA as a combination of face-to-face instructions and computer-mediated instruction [15-16]. Moskal et al. [17] emphasize that BLA emerged as the dominant label for an educational platform that represents some combination of face-to-face (F2F) and online learning. BLA is a mechanism that bridges the old and the new by impacting policy and strategic initiatives in (higher) education at virtually every level [17-18]. BLA can enhance the quality of F2F meetings provided that students can benefit from the online learning activities and resources (Köse, 2010, according to [16]). When academics offer rich and engaging online materials, an opportunity is provided for students to learn differently at a place and time of their choosing [19]. Numerous studies have shown that BLA positively influences learning outcomes in the sense of learning gains [20-21]. According to [20], BLA combines a modular object-oriented dynamic learning environment (Moodle) with F2F teaching achieved good results in students' e-learning attitudes and practices. By shifting some instruction online, teachers could devote more of their limited time to F2F coaching a small-group instruction [21], which is applicable in many physics courses. Specific physics courses may take upwards of 50 % of the usual classroom activity and convert F2F activity into online learning [15,22]. The BLA model can transform higher education [23-25], providing pedagogy "to enhance both the effectiveness and efficiency of meaningful learning

experiences” [24]. The observed benefits of applying this type of teaching approach are also supported by the decreased number of traditional courses from 14.1 million down to 4.1 million [17] during the period from 2010 to 2015.

2. Methodology

The widespread adoption and availability of digital learning technologies have led to increased integration of computer-mediated instructional elements into the traditional face-to-face [F2F] learning experience [26]. Instructional designers must know that working memory is limited to seven $\pm$ two items or information elements [27-28]. It depends on two-mode components: a visuospatial sketchpad and a coordinated phonological loop. If students get more information to process than this, the teaching will be less effective. Therefore, this research aims to determine the impact of teacher-produced online Moodle-based materials in combination with F2F learning on students' achievement and mental effort, i.e., determining the instructional efficiency of applied teaching approaches in high school physics classes. According to the authors, the instructional efficiency of BLA was not identified in earlier literature.

BLA can accurately present physical phenomena and replace a realistic experiment and provide a safe student research environment. Determination of the impact of BLA on mental effort is an essential determinant for defining the future direction of education policies in all countries, emphasizing countries with reduced teaching resources such as laboratory equipment.

Research questions

In order to determine the impact of BLA on learner's mental effort, the following research questions are asked:

1. What is the impact of applied teaching approaches on student's achievement?
2. What is the impact of applied teaching approaches on self-perceived mental effort?
3. Determine the instructional efficiency of applied teaching approaches.

Methods and Materials

A pedagogical experiment was carried out using parallel groups of high school students over six weeks to determine the impact of BLA on the teaching topic Direct current. The research included two high schools in Novi Sad, Serbia. The equipment provided to the students, such as the laboratory conditions for carrying out the curriculum's experiments, was the same in both schools. In addition to lectures and computational exercises, the students of both groups performed laboratory exercises.

In the control group (C), teaching content was presented using a conventional approach, F2F, with teachers' dominant role. Students of the C group were prepared in F2F classes to perform the intended experiments using the textbook's content. The C group of students did not have any specific preparation, and the students also had traditional homework that involved solving physics problems from textbooks. Both groups dedicated the same amount of time for F2F as well as for home learning.

In the experimental group (E), the Enriched-Virtual blended learning approach to teaching was applied. The Enriched-Virtual model is a whole-school experience where within each course (e.g., math) students divide their time between attending a brick-and-mortar campus for F2F learning and learn remotely using online delivery of content and instruction [26].

Students are usually used to work with their teachers, and they have an emotional connection with them. Our students had the same physics teacher for 16 months before our experiment; therefore, they already had some emotional connections. Toward avoiding an emotional change of students' perception of their teacher, we did not want to change them. Therefore, every group kept their teachers, but the author supervised all the teaching process in both groups. Materials, experiments' choices, and tasks' order one of the authors of this research created.

The Moodle platform course was developed for this purpose and implemented in a mixed learning environment. Instructions for students working on the Moodle platform and the software environment were implemented in one teaching unit before starting the pedagogical experiment. Students were taught how to change parameters, do measurements and handle PhET (Physics Education Technology, University of Colorado Boulder) virtual laboratories using topics they had met before, so they were familiar with the virtual simulation environment. PhET has simulations for most physics concepts and is already widely used in classrooms. Students were in their second grade, so that they had used PhET simulations for over a year already. Thus, the students could change the physics parameters and build their experiments in the PhET environment. Students receive a compact homework course by integrating virtual PhET labs into the Moodle Platform without exiting the portal. They do not have to use any external websites, which reduces the number of distractions and unnecessary information from other sites.

The content of the students' homework in the textbooks was the same for all groups. The difference between the groups was how the students were supposed to do the homework activity. In other words, both groups had to solve the same physics problems with the same given parameters. Students from the E group used the virtual PhET laboratory integrated with the Moodle course to visualize how these given parameters' values affect the result. In

comparison, students in the C group do the calculation and visualize the process without using the virtual laboratory. In this research, we applied the most complex tool on the Moodle platform called "Lessons". Lessons and tasks on the PhET laboratory are graded from more leisurely activities to more complicated, considering the working memory's capacity and the cognitive requirements imposed by the teaching topic's choice and the teaching approach. Inside the lesson, students are systematically guided through the course to not switch to a new page until they give the correct answer to the problem. Therefore, the difference in student's preparation was that students in the E group had teacher-guided BLA with integrated PhET simulations into the Moodle course for preparing for class and experimental work in a real laboratory. Students in the C group experienced only the F2F teaching approach, which included homework in a textbook and F2F real laboratory experiments.

Example of Moodle course

The first part of the online homework course for "direct current" consists of PhET simulations of conductor resistance and problems. Using the PhET simulation, students are asked to test and calculate the dependence of conductor resistance on its length, cross-section, and specific resistance, Figure 2. This way, the student learns dependence between physical quantities one by one. Visualization of physical quantities causes mental effort reduction.

Figure 2. Wire resistance PhET simulation embedded into the Moodle course.

When students completed their simulation task, they received a series of problems and provided the correct answer to move to the next lesson. As the simulation reduces the abstractness of concepts such as resistance and specific conductors' resistance, students in

90 % of cases give the correct answers to the problems and quickly remembered the dependence between the given physical quantities. With the same approach, the lectures Ohm's law, short circuit, and direct current (DC) are created.

Participants

A total of 128 students participated in the research. The experimental group consisted of 64 students in the natural-mathematical cohort in the high school "Isidora Sekulić". The control group C consisted of 64 students of the natural-mathematical cohort of the high school "Jovan Jovanović Zmaj"; both schools are in Novi Sad, Republic of Serbia. Using the application <http://www.raosoft.com/samplesize.html>, a sample size of 128 students from a maximum of 250 students could be considered appropriate with a confidence level of 90 %. The study was conducted for six weeks during May and June 2017.

Instruments

A standardized *Inventory of Basic Conceptions - DC Circuits* (IBCDC) developed by Ibrahim Halloun was used for a pre-test and a post-test. Students in Serbia learn the topic of DC for the first time in primary school; therefore, it was necessary to assess students' initial knowledge of the subject. The test was translated into the Serbian language and applied to students from other high schools to ensure the test was accurate for Serbian ambiance and Serbian terms. The test consisted of 29 problems of multiple choices. The data is encoded with 1 for a correct answer and with 0 for an incorrect answer. Students are self-assessing their mental effort by a five-point Likert scale for each problem. Standardized Cronbach's Alpha for the knowledge test was 0.735 and for the self-perceived mental effort was 0.971. After equalization of groups, a pedagogical experiment with parallel groups was started. After the pedagogical experiment had been conducted, the final measurement was identified.

The final test was identical to the initial, which provided the possibility of comparing student achievement differences.

Data analysis

ANOVA and t-test of paired samples were used to determine the impact of applied teaching approaches on student performance. The analyses were done using the IBM SPSS 20.0 Statistics program. The eta-square indicator was used to determine the strength of the variability amongst the variables, while the Pearson's r coefficient was used to determine the variables' correlations.

The appropriate and necessary calculations (as Skewness and Kurtosis) were performed to fulfill conditions for ANOVA and t-test.

Limitations of research

This research is limited to the topic of DC circuits. Therefore future empirical research should focus on determining the possibilities for implementing the BLA in other Physics topics in high school and on a larger sample. Likewise, the duration of any future study may be at least one semester. It would be interesting to determine how the BLA influences higher-order thinking of secondary high school students or on knowledge retention.

3. Results

Before introducing a pedagogical experiment with parallel groups, an initial measurement was carried out to ensure the groups were equal. Groups were equalized on the essential two

criteria: achievements on the pre-test and self-perceived mental effort during the initial measuring.

Students' achievement

ANOVA showed no statistically significant difference in students' achievement on pre-test, $F (df = 1) = 0.093$, $p = 0.761$ between the C and E groups. Students in the E and C groups achieved approximately the same number of points in the knowledge test (Table 1). The table of obtained results shows that students possessed a certain level of knowledge related to the topic of DC having retained some basic concepts from primary school teaching.

After pedagogical experiment, ANOVA showed that there is a statistically significant difference in the achievements of students in the E and C group on post-test, $F (df = 1) = 4.508$, $p = 0.036$, $\eta^2 = 0.035$. In order to better understand the differences in student achievements, a paired-samples t-test was made. The results of this test are shown in Table 1.

Table 1. Descriptive statistics and value of t-test of the paired samples for the knowledge test.

As shown in Table 1, both groups' students increased their achievement in the test of knowledge. However, a higher level of achievement was observed in the E group students. So, both teaching approaches contributed to student achievement, yet BL contributed more. Our analysis showed that the E group students had significantly better success in answering the knowledge test problems. The highest difference in students' achievement was for the highest level of abstract physical concepts. That could be explained by the fact that the E group students had the opportunity to assemble different electrical circuits independently in the virtual environment, which are not allowed in the real laboratory, for example, short

circuits. Through their work in the PhET lab, E group students thoroughly understood how to connect the electric circuits, and they acquired a more profound conceptual knowledge than C group students.

Self-perceived mental effort

In terms of the self-perceived mental effort during initial measuring, ANOVA showed no statistically significant difference between the groups' results on the pre-test, $F(df = 1) = 0.077$, $p = 0.782$. The students used almost the same mental effort to solve the knowledge test, Table 2. After pedagogical experiment, ANOVA showed a statistically significant difference between the two groups in terms of student self-perceived mental effort, $F(df = 1) = 9.939$, $p = 0.002$, $\eta^2 = 0.074$. The eta-square indicator's value indicates the mean strength of the applied teaching approach on the self-perceived mental effort. To determine the difference between each group, a t-test of paired samples was applied, Table 2.

Table 2. Descriptive statistics and paired samples t-test self-perceived value.

As can be seen from Table 2, the students of both groups decreased their mental effort. However, the E group achieved a higher reduction in the mental effort reported by the C group. These results indicate a benefit of BLA because the teaching method caused students to self-report using less mental effort, i.e., less occupation of working memory. Therefore students can more easily adopt given information. The instructional efficiency for each approach was calculated to determine which teaching approach is more convenient for students.

Instructional efficiency

Figure 3 presents the instructional efficiency for each teaching approach. Instructional efficiency takes into account students' self-perceived mental effort and achievements on the post-test.

Figure 3. The instructional efficiency of applied teaching approaches.

As shown in Figure 3, the E group's instructional efficiency is in the upper left quadrant, while for the C group, the instructional efficiency is located in the lower right quadrant. The E groups' instructional efficiency is $E_E = 0.33$, and the C groups' instructional efficiency is $E_C = -0.32$. The obtained data undoubtedly demonstrates that the BLA teaching method is more convenient for students than the conventional approach.

4. Discussion and conclusions

This research aimed to determine the impact of BLA on students' achievement in the knowledge test and self-perceived mental effort. A Moodle online course for teaching students about DC circuits, using PhET simulations embedded in the lessons, was developed to determine the impact of BLA. All required material was located in one place and presented consistently to the students. The obtained results show that BLA in physics teaching positively impacts students' achievement. Students who have teaching material presented using the BLA approach (students in the E group) have more accurately provided correct answers on the post-test than students who have been provided with the same material but presented only using a conventional F2F teaching approach (students of the C group).

For example, the E group students achieved significantly better results than the C group students on problems related to the current intensity in points 1 and 2 at different parts of the circuit. Also, the example is a simple electric circuit with the source and the bulb as a consumer. Students were asked if there any difference between electric current before or after the consumer is turned on. To this problem, 81.5 % of the E group students and 58.5 % of the C group students gave the correct answers. There is another example where we had a significant difference between C and E groups: In the first circuit, there are two parallel consumers and one source, and in another circuit, there is one source and one consumer. Students were supposed to define in which circuit the electric current has the higher intensity. Both consumers and sources have the same characteristics. To this problem, 70.9 % of the E group students and 39.6 % of the C group students have the correct answer. In the third example, students investigated in which of given circuits the power that came out of the resistor is higher. As expected, students in the E group scored 16 % higher than students in the E group. We then focused on problems where there is a significant difference in scores between groups, and we concluded that those problems were always related to real-life problems. For example, if the problem was how much light the bulb would give, as a prerequisite, students are supposed to know that the more electric current goes through the bulb, the bulb will be brighter.

Another example would be with pictures of real-life circuits that students cannot find in a regular schoolbook, but they can in the lab or the virtual lab. As students in the E group had plenty of experience playing in the virtual lab, they created a cognitive connection between electric circuit schemes and real-life wires, bulbs, resistors, and sources. Students could also play with PhET simulations and, for example, see that the bulb is brighter if they increase the current. Therefore, better success on knowledge tests is that they did all experiments with their “own” hands, so they memorized it better. Therefore, students from the E group could

easier find correct answers to this kind of real-life problem. According to the results, we can conclude that BLA gave a better understanding of these physical concepts. Similar results were observed previously. Sulisworo et al. [30] have found that the value of learning achievement is significantly different between students who were taught F2F and cooperative-blended learning. Suana et al. [31] researched the impact of BLA on Basic Physics I course on vectors, linear motions, and translational dynamics, founding significant difference in students' achievement which took BLA course.

Compared to using textbooks and lectures solely, a learning environment that incorporates computer simulations has the advantage that students can systematically explore hypothetical situations [32]. The E group students also interact with a simplified version of a process or system, change the time-scale events, practice tasks, and solve problems in a realistic environment without stress [32]. In addition to the established positive impact of BLA on student achievement, this research determined the impact of BLA on self-perceived mental effort.

It was found that students of the E group perceived less mental effort than the C group students. The obtained value indicates that BLA is a more convenient approach for students because it causes less mental effort, i.e., causing less occupancy of the working memory. Accordingly, [33] for topics with high complexity, instructional designers must consider the cognitive requirements of processing their materials and reducing any unnecessary mental effort. Reduced mental effort and less occupancy of working memory give the learner the possibility to connect more information to existing ones in long-term memory by recombining existing ones.

By actively involving students in exploring and discovering, computer simulations can be powerful learning tools, as learning then involves something more than learning through listening, reading, or seeing [32]. However, the application of new technologies in the teaching process does not necessarily produce better student results because it is only a tool that needs to be targeted to a precisely defined problem. Therefore, this research's results are primarily intended for physics teachers to understand BLA's impact better and encourage them to implement this approach into their classes. In order to complete the picture of the impact of BLA, the direction of future research will be oriented towards not only determining the impact of BLA in other areas of physics but also within other natural sciences. After analyzing the results, we have gained experience, which has generated further ideas for future research. One idea is to use the "Workshop" option within the Moodle course, and after the completion of the PhET simulation activity, students should evaluate each other's work. Thus further engaging in work is stimulating peer learning. That could help with managing large class sizes and having students learning more actively. Due to this study's limitation – applying only to teaching one topic on the DC circuits, we propose carrying out further research in different physics fields. That will provide clear guidance for determining educational policies' future directions in countries with a lower economy. It is also essential to consider some limitations of this research related to the pedagogical experiment's sample and duration. Although the research results are very encouraging, this research does not look at the BLA's impact on knowledge retention.

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Table 1. Descriptive statistics and value of t-test of the paired samples for knowledge test.

Groups	pre-test		post-test		<i>t</i>	<i>p</i>	<i>η</i>
	M	SD	M	SD			
C	8.05	3.18	9.70	3.36	3.435	0.001	0.158
E	8.21	2.65	10.84	2.64	6.257	0.000	0.383

For Review Only

Table 2. Descriptive statistics and value of t-test of the paired samples for self-perceived mental effort.

Groups	pre-test		post-test		t	p	η
	M	SD	M	SD			
C	2.41	0.94	2.67	1.03	1.873	0.066	0.053
E	2.35	0.85	3.13	0.61	8.476	0.000	0.533

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Figure 1. The instructional efficiency determination.

25x20mm (600 x 600 DPI)

Figure 2. Wire resistance PhET simulation embedded into the Moodle course.

323x192mm (72 x 72 DPI)

Figure 3. The instructional efficiency of applied teaching approaches.

60x43mm (300 x 300 DPI)