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Impact of Structural Inquiry-Based Learning Approach on Future Teacher Performance

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Abstract

The study examines the impact of structural inquiry-based learning (IBL) approach on future teacher performance – their test achievements and perceived mental effort invested in completing tests. The study included 38 students at the Faculty of Education in Belgrade who were trained how to create instruments for assessing physical quantities, such as thermometer and barometer, while attending the course Geographical concepts through experiments. Focusing on interdisciplinarity, the course tasks encouraged participants to think about new problem situations and detect causal relations among physical phenomena. The results show that the IBL approach has led to higher achievement and lower values of perceived mental effort. The decrease in mental effort points to the possibility of handling larger amounts of information in working memory and processing them in long-term memory. Due to complex relationship between the variables, the model of neural networks has shown that mental effort and the cognitive complexity of the item significantly affect on the participants' achievement. The results are useful to in-service teachers as they point to the effectiveness and the guidelines for the implementation of the IBL approach.

Key words: *cognitive complexity of item; future teacher; mental effort; students' achievement; structural inquiry-based learning approach.*

Introduction

Problems related to low engagement of pupils in science classes (Angell et al., 2004; Millar, 1991; Prokop et al., 2007) and difficulties in creating argumentation based on critical and logical assessment of scientific facts (Amielia et al., 2018; Hasnunidah et al., 2020; Maine Physical Sciences Partnership, 2013, as cited in Short et al., 2020; Shinta &

Filia, 2020) have emphasized the need for changing the approach to teaching science subjects. As a result, approaches based on the constructivist theory have come into the focus of researchers, particularly with respect to the inquiry-based method of learning and teaching (Constantinou et al., 2018). According to its definition, the focus of this approach is on having students learn and understand physical phenomena and their causal relations through experimental collaborative work (Eberbach & Hmelo-Silver, 2014, as cited in Mueller & Brown, 2022, p. 13). In such a way, the approach actually incorporates positive effects of collaborative learning, particularly expressed through students' socialization and development of their communication skills (Korkman & Metin, 2021), as well as elements of the evidence-based approach used in science teaching for revealing new facts and causal relations (Cairns, 2019).

Due to the complexity of the IBL approach and its similarity with the way in which scientific phenomena are observed, researchers have often directed their research questions towards the impact of this method of learning and teaching on students' achievement (Abdi, 2014; Alachi & Ifeanyi, 2021; Aktamiş et al., 2016; Cairns, 2019). Through this approach, the teacher becomes a facilitator or coach for supporting students' learning (Anderson, 2002, as cited in Constantinou et al., 2018, p. 7). This changed role of the teacher can be achieved through three different approaches to implementing the inquiry-based method: structural, guided, and open inquiry (Yıldız-Feyzioğlu & Demirci, 2021). In the structural approach, students are given a problem and a method to use to solve it and based on this, they draw a conclusion. Contrary to this, in the guided approach students search for a suitable method on their own, while the open approach lets students work on their own in every phase of the inquiry-based method. Each of these approaches requires the accomplishment of complex learning tasks such as determining causal relations between information and integrating new ones into human cognitive structure (Marshall et al., 2017, as cited in Yıldız-Feyzioğlu & Demirci, 2021, p.401). This requirement for the accomplishment of complex learning tasks points to the complexity of viewing human cognitive architecture. During the process of learning students apply various degrees of thinking capacity and this represents their cognitive load. Accordingly, students' achievement is not any more perceived as the only measure of their success in learning. Instead, it is seen as a complex variable directly influenced by cognitive load and other factors. Cognitive load, as a complex construct, incorporates causal and assessment factors, and can be divided into intrinsic, extraneous, and germane cognitive load (Chandler & Sweller, 1991; Kalyuga, 2009a; Paas et al., 2003; Plass et al., 2010). The intrinsic cognitive load is related to the complexity of teaching material and number of elements which should be processed simultaneously, while the extraneous load is related to the environment as how the learning task is organized and presented to the students and the teachers' skills (Sweller, 2020 as cited in Maričić et al., 2022, p. 4). Germane load is related to the process of abstractness and automatization (Kalyuga, 2009b; Paas et al., 2004; Sweller et al., 2011). Because intrinsic and germane load are associated with the teaching material, they are regarded as necessary for the process of learning, although intrinsic is more important for that process than germane, while extraneous load is considered as completely unnecessary. The sum of these three loads is closely related to the capacity of working memory. If the sum is greater than the defined capacity of working memory equaling 7±2 sense units (Miller, 1956), long term acquisition of new information will not be achieved. It is therefore important to adjust the teaching approach to the capacity of working memory. In order to clearly monitor and measure the influence of the teaching approach on cognitive load, it is necessary to assess mental effort, as a measurable part of cognitive load, which is invested in solving a particular task (de Jong, 2010). The complexity of the task therefore implies defining its cognitive complexity caused by a number of relations within the problem entities, and not by the quantity of information that should be processed (Halford et al., 1998, as cited in Horvat, 2018, p. 26).

This means that the assessment of the impact of inquiry-based learning (IBL) approach on students' performance should include the effect of the approach on both, achievement and mental effort. Although the results of some studies have pointed to the positive effects of IBL approach, the approach is still insufficiently applied in the classroom due to inadequately equipped educational institutions, certain organizational problems, and insufficiently developed teacher competencies for IBL (Anderson, 2002, as cited in Gajić et al., 2021, p. 741). The teacher competencies are seen as particularly important for the application of this approach (Constantinou et al., 2018; Koutsianou & Emvalotis, 2021; Pabón-Galán et al., 2022), as they affect the level of extraneous load, and without adequate training desirable pupils' performance will never be achieved (Korkman & Metin, 2021). Having recognized the importance of this approach and the training of teachers for applying it, the Faculty of Education in Belgrade designed an elective course titled Geographical concepts through experiments. The main research question addressed in the current study is therefore related to assessing the impact of the structural IBL approach on future teacher performance defined through their achievement on knowledge test and perceived mental effort invested in test tasks. This, in turn, represents the assessment of the effects of the above-mentioned course.

Methodology

The aim of this research was to determine the impact of the structural IBL approach on future teacher performance, through their achievement on a knowledge test and perceived mental effort, which represents the effectiveness of the applied course. The aim is accomplished through setting the following research tasks:

1. Determine the change in students' achievement on pre- and post-tests of knowledge of physical and geographical contents.
2. Determine the correlation between the cognitive complexity of the items and perceived mental effort on the pre-test.
3. Determine the change in perceived mental effort in completing the pre- and post-tests.
4. Determine the importance of cognitive complexity of the items and perceived mental effort to achieve the highest results on the post-test.

Procedure

The objective of the course *Geographical concepts through experiments* is to train students in the application of the IBL approach in the classroom. The course covers 47 school experiments divided into five topics. Each topic is devoted to one geosphere (Atmosphere, Lithosphere, Hydrosphere, Biosphere and Earth and Cosmos), i.e. to notions in disciplines dealing with processes in these geospheres. All experiments cover teaching contents of the first cycle of primary education (grades 1-4) and can therefore be considered entirely applicable.

The experiments conducted as part of the course include the following:

– For the topic Atmosphere, students are trained to create a thermometer, barometer, rain gauge or an anemometer; how to measure air pressure and air weight; how much oxygen is in the air; what evaporation and condensation are; how fog, clouds and rain are created;

– The Lithosphere section is about the movement and displacement of lithospheric plates and how earthquakes and volcanic eruptions are created; isohypsesand how they are used to represent relief; what prints are left by plants and shells; what glacial erosion is; how stalactites are formed, of the structure of rocks and how to differentiate them;

– The Hydrosphere section describes how water circulates and what it contains, how to determine its salinity and how salt water sedimentation is performed; waves and icebergs; what kinds of water there are (in relation to the source, purity, type of application and admixture);

– The section Biosphere focuses on acid rain and its impact on environmental pollution; how plants and animals 'choose' their habitats in comparison with humans; what solar energy serves for and how plants produce oxygen;

– The Earth and Cosmos section explains the compass and how it's used for orientation; how we know that the Earth rotates on its axis and around the Sun (Foucault pendulum, alternation of day and night, succession of seasons).

At the beginning of the course students were familiarized with the topics, the roles of the teacher and student were explained and the assessment criteria described. The first task for students was to organize themselves in groups of 5 to6 members. Letting students decide who they would group with makes them create their own surroundings based on their sensibility and the learning style. All groups worked on the same topic applying different tasks. This enabled discussion and exchange of experiences and opinions between the groups, which was intended for better and wider understanding of the topic. Each group selected one member who was responsible for collecting the necessary tools and equipment for the experiment. The group as was then supposed to set an appropriate hypothesis, conduct the experiment, support or discard the starting hypothesis and draw conclusions. Following that, the group's spokespersons presented the experiments and obtained results and discussed the task. Group spokespersons changed from task to task, while groups remained the same throughout the coursework.

This concept enabled each student to present a task, i.e. the conducted experiment and obtained results. This cyclical change of group spokespersons was also intended to prepare students for their teaching career. Through brief and short presentations students enhanced their communication skills while hands-on activities improved their practical inquiry skills.

The role of the teacher was to monitor and assess the engagement of students, supply and organize the needed material and answer students' questions during their task completion. In this way the role of the teacher was twofold: collaborative, so that the structural IBL approach could be applied, and observational, to support the quantitative findings of this study.

Instruments

Due to the complexity of the research problem, both quantitative approach and observation were applied. The teacher had the role of an observer. The quantitative approach included knowledge tests and scales for assessing mental effort and cognitive complexity of the items. The same knowledge test was applied in pre- and post-tests each comprising 10 items. Each item included a 5-point Likert scale to determine the level of perceived mental effort. Point 1 on the scale denoted the lowest level of mental effort, implying that the item was very easy for students, while point 5 implied the highest level of mental effort, i.e., students perceived this item as very difficult. Cronbach's Alpha for knowledge test was 0.781, while for mental effort it was 0.939. Cognitive complexity of the items was defined by two researchers, the authors of the current study, by means of the rubric for cognitive complexity. The assessment of cognitive complexity was conducted in two stages. The first stage included the assessment of the number of concepts needed for completing the item applying the scale 1 – 7. Defined concepts should be classified according to the level of difficulty on the scale ranging from easy to difficult. In the following stage the interactivity between the concept and needed skills was assessed on the scale 0 (insignificant interactivity) to 2 (complex interactivity). Accordingly, cognitive complexity of items can range from 1 to 9. The Cronbach's Alpha for cognitive complexity was 0.771.

Sample

The sample consisted of 38 third-year students of the undergraduate studies at the Teacher Education Faculty in Belgrade, who attended the course *Geographical concepts through experiments*. The sample size was limited by specific aspects of the subject – the size of the group for conducting experiments and the maximum number of 40 students per an elective course, as prescribed by the Faculty of Education. The research was conducted in the period from February to July 2021.

Data Analysis

Based on the values of skewness and kurtosis, non-parametric analysis was used for further data analysis (Table 1). Therefore, for the interpretation of the obtained results descriptive statistics, ordinal regression and Wilcoxon-test for paired samples were applied. The *r*-indicator was used as an estimator of the size of the variables' effect. The neural network model was applied to determine the importance and the normalized importance of each predictor for the highest achievement on the post-test.

SPSS.20 program was used for statistical data processing

Table 1

Skewness and Kurtosis values

	Skewness	Kurtosis
students' achievement on the pre-test	-.186	-.478
students' achievement on the post-test	-2.789	7.114
perceived mental effort on the pre-test	1.559	2.418
perceived mental effort on the post-test	2.346	3.846

Results

Based on the defined research tasks, the results are presented in three parts.

Students' achievement on the knowledge tests

Table 2 shows Wilcoxon-test for paired samples of students' achievement on the knowledge tests.

Table 2

Students' achievement on the knowledge pre- and post-tests

	M	SD	*z*	*r*
pre-test	4.92	1.26	5.047**	.5789
post-test	9.32	1.89		

** $p < .001$

The obtained values, especially the *r*-indicator value, indicate a large impact of the applied approach on students' achievement. Student achievement almost doubled. The largest change was observed in items related to heat transfer, purpose of anemometer, and definition of artesian water. The item related to heat transfer has a negation; therefore, it can be assumed that the students overlooked it and thus got a lower result on the pre-test. The smallest change is obtained for temperature and pressure, which indicates that students are familiar with basic concepts of natural sciences.

During the coursework students showed additional interest in course content. Thus, apart from the obtained results, students were curious to know how the experiment results would change if certain parameters were changed. For example, while assessing the salinity of liquid, students decided to extend the task and examine the change in the experiment results by changing the diameter and the weight of a little ball placed at the end of a straw immersed in liquid. They also showed additional interest in assessing the effect of liquid thickness on the results of the experiment. In the experiment that included the construction of an anemometer students were expected to calculate the area and circumference of a circle and determine the wind speed based on the number of cycles per unit time, i.e. the circular frequency. Although the teacher observation suggested that students showed a greater interest in the course content and readiness to deepen their knowledge, the current study focuses on students' perceived mental effort and cognitive complexity of the items.

Perceived mental effort and cognitive complexity

The obtained results show a positive correlation between cognitive complexity and perceived mental effort on pre-test, *Pearson* $r = .798$, $p < .001$. The relevant values of cognitive complexity are M = 4.70, SD = 1.83, while the values referring to mental effort are given in Table 3. The relationship between cognitive complexity and perceived mental effort was confirmed by ordinal regression, χ^2 ($df = 10$) = 38.309, $p < .001$, with pseudo R-Square = .988.

Table 3 shows Wilcoxon-test for paired samples of students' perceived mental effort on pre- and post-tests.

Table 3

Perceived mental effort on pre- and post-test

	M	SD	*z*	*r*
pre-test	2.02	.31	5.035**	.5775
post-test	1.22	.58		

** $p < .001$

The obtained value of the *r*-indicator points to the large impact of the applied approach on decreasing perceived mental effort. Decreasing mental effort is detected in nearly every item. Lower mental effort values suggest that a larger space in working memory was obtained so students could adopt and process more information.

Neural network model

The obtained results show a very strong negative correlation between perceived mental effort and student achievement, *Pearson* $r = -.940$, $p < .001$. As predictors of perceived mental effort and cognitive complexity of items are also in positive correlation, the neural network model was applied. The overall percentage of the training sample is 85.7%, while the test sample is, 100.0%. The AUROC (area under the ROC curve) provides the accuracy of the model, which in our case is 0.967. Table 4 shows the importance and normalized importance of perceived mental effort and items' cognitive complexity on the achievement on the post-test.

Table 4
Importance and normalized importance of perceived mental effort and cognitive complexity of items

	Importance	Normalized Importance (%)
perceived mental effort	.416	71.3
cognitive complexity of items	.584	100.0

As shown in Table 4, both predictors significantly contribute to the variance of student achievement. The findings point to the necessity of including students' mental effort and cognitive complexity levels in lesson design processes and education policy making.

Discussion

In the study whose participants were future teachers, the impact of structural IBL approach on participants' performance, i.e. their test achievement and perceived mental effort invested in test completion, was examined. The structural IBL approach was selected with the aim of preparing future teachers for their work with pupils as there are numerous reports in the literature recommending the training of student teachers for applying this approach in the primary school classroom (Aktamiş et al., 2016; Letina, 2019; Purnawati et al., 2021; Zudaire et al., 2021). It has been reported that the IBL approach contributes to better student performance (Aktamiş et al., 2016; Alachi & Ifeanyi, 2021; Letina, 2016; Panasan & Nuangchalerm, 2010; Wu & Hsieh, 2006), greater interest in science at school (Swarat et al., 2012, as cited in Mueller & Brown, 2022, p.18) and improved critical thinking and creativity in fourth-grade primary school students (Purnawati et al., 2021). Recognizing the significance of IBL approach, as well as issues reported by researchers, the Faculty of Education in Belgrade created a course titled *Geographical concepts through experiments*. The course encompasses five topics within which students are given specific tasks. Students receive detailed information on the stages and activities of problem-based education, so that the issues reported by Perković Krijan et al. (2017) could be avoided. The development of competencies for the IBL approach is expected to increase future teachers' confidence in the classroom (Kadijević & Mandić, 2019; Letina, 2019) and change in pupils' attitudes towards sciences (Baber & Qureshi, 2021; Bozkurt, 2015).

The course tasks were completed in groups of 5 to6 members. The students decided between themselves on whom they would group with, based on their sensibility, learning styles, and way of thinking. In such micro environments each student was expected to present a task to other students. In this way the students had a public presentation through which they enhanced their communication and practical inquiry skills. This concept is also believed to improve socialization of potentially introvert students, as evidenced in the research by Mueller and Brown (2022).

The course tasks encouraged students to think of new problem situations, such as how a bee would behave in a new habitat, what is required for its survival and how the change in a physical parameter (heat, light, precipitation, etc.) would affect it. A positive effect of the structural IBL approach on students' engagement was detected through observation, which is in line with other studies. Thus, Prayogi and Verawati (2020) report that conflict cognitive strategies defined within IBL tasks improve pre-service teachers' critical thinking skills and contribute to reaching higher order thinking abilities.

In order to understand the effect of the structural IBL approach more completely, changes in the level of students' perceived mental effort were also examined. The findings suggest that the IBL approach contributed to a significant lowering of the perceived mental effort, thus creating a larger space in working memory that could be used for acquiring new information. The results are in line with the findings of Maričić et al. (2022) who report that hands-on experiments reduce the extraneous cognitive load. Lowering of mental effort, as a measurable part of cognitive load, has proved to be important for reaching the highest knowledge test scores. Apart from the decrease in cognitive load, a significant contribution to excellent post-test results has been achieved by cognitive complexity, which is tightly connected with mental effort as well. Due to multiple relations among the variables, the effect of variable was assessed by the neural network model.

Further research should include a larger sample and comparison with other approaches based on the constructivist theory and e-environment. Some of the approaches have shown that e- environment can significantly affect students' performance (Mandić et al., 2017; Odadžić et al., 2017; Pribićević et al., 2017).

Conclusion

The findings of the study point to a positive effect of the structural IBL approach on students' achievement and a significant lowering of the perceived mental effort, as a measurable part of cognitive load. The significance of mental effort decrease is reflected in the quantity of information processed in working memory and further in long-term memory. The study points to a positive correlation between perceived mental effort and cognitive complexity of the item. Therefore, to determine the overall effect of the structural IBL approach on achieving excellent post-test scores, the model of neural networks was applied. The model showed that both predictors, i.e. mental effort and cognitive complexity of the item significantly affect students' achievement. The study results are therefore useful for in-service teachers as they offer a better insight into the effect of IBL approach on students' performance. Additionally, the current study offers guidelines to other institutions that train future teachers on how to implement this approach into their curricula.

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Utjecaj strukturalnoga istraživački usmjerenoga pristupa učenju na dostignuća budućih učitelja

Sažetak

Istraživanje proučava utjecaj strukturalnoga istraživački usmjerenoga pristupa učenju (IBL) na dostignuća budućih učitelja – njihova postignuća i percepciju mentalnoga napora uloženoga u rješavanje testova. Istraživanje je uključivalo 38 studenata Učiteljskog fakulteta u Beogradu koji su tijekom sudjelovanja u kolegiju Geografski pojmovi kroz eksperimente postali osposobljeni za kreiranje instrumenata za provjeru fizičkih veličina poput termometra i barometra. Usmjeren na interdisciplinarnost, kolegij je potaknuo sudionike na promišljanje o novim problemskim situacijama i na otkrivanje uzročnih veza među fizičkim pojavama. Rezultati pokazuju da istraživački usmjeren pristup dovodi do većega postignuća i smanjenih vrijednosti percepcije mentalnoga napora. Smanjenje mentalnoga napora ukazuje na mogućnost obrade veće količine informacija u radnoj memoriji i procesiranje u dugoročnom pamćenju. Zbog složenih veza među varijablama, model neuronskih mreža pokazao je da mentalni napor i kognitivna složenost čestice značajno utječu na postignuća sudionika. Rezultati su korisni za buduće učitelje jer ukazuju na učinkovitost IBL pristupa i daju smjernice za primjenu istoga.

Ključne riječi: *budući učitelji; kognitivna složenost zadatka; mentalni napor; postignuća studenata; strukturalni istraživački usmjereni pristup učenju.*

Uvod

Problemi vezani uz nisku razinu uključenosti učenika u znanstvene predmete (Angell i sur., 2004; Millar, 1991; Prokop i sur., 2007) te poteškoće u pronalaženju argumenata zasnovanih na kritičkoj i logičkoj procjeni znanstvenih činjenica (Amielia i sur., 2018; Hasnunidah i sur., 2020; Maine Physical Sciences Partnership, 2013, prema Short i sur., 2020; Shinta i Filia, 2020) naglašavaju potrebu za promjenom pristupa poučavanju prirodoslovno-znanstvenih predmeta. Kao rezultat toga, pristupi zasnovani na konstruktivističkoj teoriji postali su predmet proučavanja znanstvenika, a posebno se to odnosi na istraživački usmjereni pristup učenju i poučavanju (Constantinou i sur., 2018). Prema definiciji, fokus ovoga pristupa jest da učenici uče i razumiju fizičke pojave i njihove uzročnih odnose putem eksperimentalnoga suradničkog rada (Eberbach i Hmelo-Silver, 2014, prema Mueller i Brown, 2022, str. 13). Na taj način, ovaj pristup zapravo uključuje pozitivne učinke suradničkoga učenja, posebno izraženih kroz socijalizaciju učenika i razvoj njihovih komunikacijskih vještina (Korkman i Metin, 2021), kao i elemente pristupa utemeljenoga na dokazima koji se koristi u poučavanju znanosti kako bi se otkrivale nove činjenice i uzročni odnosi (Cairns, 2019).

Zbog složenosti IBL pristupa i sličnosti s načinom na koji se promatraju znanstvene pojave, istraživači su često usmjeravali svoja istraživačka pitanja prema utjecaju ovoga načina učenja i poučavanja na postignuće učenika (Abdi, 2014; Alachi i Ifeanyi, 2021; Aktamiş i sur., 2016; Cairns, 2019). Kroz ovaj pristup, nastavnik postaje facilitator ili trener u davanju podrške učenicima u učenju (Anderson, 2002, prema Constantinou i sur., 2018, str. 7). Ova promijenjena uloga nastavnika može se postići kroz tri različita pristupa u primjeni metode temeljene na istraživanju: strukturalni, vođeni i otvoreni pristup (Yıldız-Feyzioğlu i Demirci, 2021). Kod strukturalnoga pristupa, učenicima je zadan problem i metoda kojom će se koristiti za rješavanje problema i na osnovi koje će doći do zaključka. Suprotno tome, u vođenom pristupu učenici sami traže odgovarajuću metodu, dok otvoreni pristup dopušta učenicima da samostalno rade u svakoj fazi metode temeljene na istraživanju. Svaki od ovih pristupa zahtijeva izvođenje složenih zadataka učenja, poput utvrđivanja uzročnih odnosa između informacija i integracije novih informacija u ljudsku kognitivnu strukturu (Marshall i sur., 2017, prema Yıldız-Feyzioğlu i Demirci, 2021, str. 401). Ova potreba za izvršavanjem složenih zadataka učenja ukazuje na kompleksnost promatranja ljudske kognitivne arhitekture. Tijekom procesa učenja, učenici primjenjuju različite razine kognitivnih sposobnosti, što predstavlja njihovu kognitivnu opterećenost. Na taj način, postignuće učenika više se ne percipira kao jedina mjera njihova uspjeha u učenju. Umjesto toga, promatra se kao složena varijabla na koju izravno utječe kognitivno opterećenje i drugi faktori. Kognitivno opterećenje, kao složeni konstrukt, uključuje faktore uzroka i procjene te se može podijeliti na intrinzično, ekstrinzično i povezano kognitivno opterećenje (Chandler i Sweller, 1991; Kalyuga, 2009a; Paas i sur., 2003; Plass i sur., 2010). Intrinzično kognitivno opterećenje povezano je sa složenošću nastavnoga materijala i brojem elemenata koji se istovremeno trebaju obraditi, dok je ekstrinzično kognitivno opterećenje povezano s okolinom, odnosno kako je zadatak učenja organiziran i predstavljen učenicima te vještinama nastavnika (Sweller, 2020 prema Maričić i sur., 2022, str. 4). Povezano kognitivno opterećenje povezano je s procesom apstrakcije i automatizacije (Kalyuga, 2009b; Paas i sur., 2004; Sweller i sur., 2011). S obzirom na to da su intrinzično i povezano opterećenje povezani s nastavnim materijalom, smatraju se nužnima za proces učenja, iako je intrinzično opterećenje važnije za taj proces od povezanoga opterećenja, dok se ekstrinzično opterećenje smatra potpuno nepotrebnim. Ukupna vrijednost ovih triju opterećenja usko je povezana s kapacitetom radne memorije. Ako je ukupna vrijednost veća od definiranoga kapaciteta radne memorije koji iznosi

7±2 jedinica (Miller, 1956), dugoročno usvajanje novih informacija neće biti ostvareno. Stoga je važno prilagoditi pristup poučavanju kapacitetu radne memorije. Za jasno praćenje i mjerenje utjecaja pristupa poučavanja na kognitivno opterećenje, važno je procijeniti mentalni napor, kao mjerljivi dio kognitivnoga opterećenja koji se ulaže u rješavanje određenoga zadatka (de Jong, 2010). Stoga, složenost zadatka implicira definiranje njegove kognitivne složenosti uzrokovane brojem odnosa unutar entiteta problema, a ne količinom informacija koje treba obraditi (Halford i sur., 1998, prema Horvat, 2018, str. 26).

Ovo znači da procjena utjecaja istraživački usmjerenoga pristupa učenju (IBL) na postignuća učenika trebaju uključivati učinak pristupa na postignuće i mentalni napor. Iako su rezultati nekih istraživanja ukazali na pozitivne učinke IBL pristupa, on se i dalje nedovoljno primjenjuje u učionicama zbog nedostatno opremljenih obrazovnih institucija, određenih organizacijskih problema te nedovoljno razvijenih kompetencija nastavnika za primjenu IBL pristupa (Anderson, 2002, prema Gajić i sur., 2021, str. 741). Kompetencije nastavnika smatraju se izrazito važnima za primjenu ovoga pristupa (Constantinou i sur., 2018; Koutsianou i Emvalotis, 2021; Pabón-Galán i sur., 2022) jer utječu na razinu ekstrinzičnoga opterećenja i bez odgovarajuće obuke nikada se neće ostvariti željeno postignuće učenika (Korkman i Metin, 2021). Prepoznajući važnost ovog pristupa i osposobljavanja učitelja za njegovu primjenu, Učiteljski fakultet u Beogradu osmislio je izborni kolegij naslovljen Geografski pojmovi kroz eksperimente. Stoga je glavno istraživačko pitanje u ovome istraživanju povezano s procjenom utjecaja strukturalnoga IBL pristupa na postignuće budućih učitelja definirano kroz njihovo postignuće na testu znanja i percipiranom mentalnom naporu uloženom u rješavanje zadataka testa. U konačnici, to predstavlja i procjenu učinka navedenoga kolegija.

Metodologija

Cilj ovoga istraživanja bio je utvrditi utjecaj strukturalnoga IBL pristupa na postignuća budućih učitelja koristeći njihove rezultate na testu znanja i percepciji mentalnog napora, što također ukazuje i na učinak primijenjenoga kolegija. Cilj se ostvaruje postavljanjem sljedećih istraživačkih zadataka:

1. Utvrditi promjenu u postignuću studenta usporedbom rezultata ostvarenih na predtestu i na posttestu znanja o fizičkim i geografskim sadržajima.
2. Utvrditi korelaciju između složenosti stavki i percipiranoga mentalnog napora na predtestu.
3. Utvrditi promjenu u percepciji mentalnoga napora u rješavanju predtesta i posttesta.
4. Utvrditi važnost kognitivne složenosti stavki i percipiranoga mentalnog napora za postizanje najboljih rezultata na posttestu.

Postupak

Cilj je kolegija Geografski pojmovi kroz eksperimente osposobiti studene u primijeni IBL postupka u razredu. Kolegij sadrži 47 eksperimenata koji se provode u školi i koji su podijeljeni u pet tema. Svaka tema posvećena je jednoj geosferi (Atmosfera, Litosfera, Hidrosfera, Biosfera te Zemlja i svemir), odnosno konceptima u disciplinama koje se bave s procesima u spomenutim temama. Svi eksperimenti pokrivaju nastavne sadržaje za prvi ciklus primarnoga obrazovanja (1. – 4. razred) te se smatraju potpuno primjenjivima.

Eksperimenti provedeni u okviru kolegija sadrže sljedeće:

– kroz temu Atmosfera, studenti se osposobljavaju za izradu termometra, barometra, mjerača oborina ili anemometra; kako mjeriti tlak zraka i težinu zraka; koliko kisika ima u zraku; što je isparavanje i kondenzacija; kako nastaju magla, oblaci i kiša

– u temi Litosfera govori se o kretanju i pomaku litosferskih ploča i načinu na koji se stvaraju potresi i vulkanski erupcije; izohipse i kako se koriste za prikaz reljefa; kakav otisak ostavljaju biljke i školjke; što je ledenjačka erozija; kako se formiraju stalaktiti, struktura stijena i razlike među njima

– u temi Hidrosfera opisuje se kako voda cirkulira i što sadrži, kako odrediti njezinu slanost i kako se provodi taloženje slane vode; valovi i ledenjaci; vrste voda (u odnosu na izvor, čistoću, vrstu primijene i primjese)

– u temi Biosfera usredotočenost je na kiselu kišu i njezin utjecaj na zagađenje okoliša; kako biljke i životinje 'biraju' svoja staništa u usporedbi s ljudima; za što služi solarna energija i kako biljke proizvode kisik

– u temi Zemlja i svemir objašnjava se kompas i kako ga koristiti za orijentaciju; kako znamo da se Zemlja okreće oko svoje osi i oko Sunca (Foucaultovo njihalo, izmjenjivanje dana i noći, smjena godišnjih doba).

Na samom početku kolegija, studenti su bili upoznati s temama, objašnjene su uloge nastavnika i studenata te su opisani kriteriji ocjenjivanja. Prvi zadatak za studente bio je organizirati se u grupe od 5 do 6 članova. Dajući studentima slobode u odlučivanju s kime će se grupirati, omogućuje im stvaranje okoline koja uzima u obzir njihovu osjetljivosti i stil učenja. Sve grupe radile su na istoj temi primjenjujući različite zadatke. Ovo je omogućilo diskusiju i razmjenu iskustava i mišljenja među grupama, a svrha je bila bolje i dublje razumijevanje teme. Svaka je grupa odabrala jednoga člana koji je bio odgovoran za prikupljanje potrebnih alata i opreme za eksperiment. Grupa je potom trebala postaviti odgovarajuću hipotezu, provesti eksperiment, podržati ili odbaciti početnu hipotezu i donijeti zaključke. Nakon toga, predstavnici grupa prezentirali su eksperimente i dobivene rezultate te su raspravljali o zadatku. Predstavnici grupa mijenjali su se iz zadatka u zadatak, dok su grupe ostale iste tijekom cijeloga kolegija. Ovaj koncept omogućio je svakom studentu prezentiranje zadatka, odnosno provedeni eksperiment i dobivene rezultate. Ovakva ciklička promjena predstavnika grupa također je bila namijenjena pripremi studenata za njihovu buduću učiteljsku profesiju. Kroz kratke i koncizne prezentacije studenti su poboljšali svoje komunikacijske vještine, dok su praktične aktivnosti unaprijedile njihove praktične istraživačke vještine.

Uloga nastavnika bila je pratiti i ocjenjivati angažman studenata, osigurati i organizirati potrebni materijal te odgovarati na pitanja studenata tijekom izvršavanja njihovih zadataka. Na taj način, uloga nastavnika bila je dvostruka: suradnička, kako bi se primijenio strukturalni pristup IBL, i promatračka, kako bi se podržali kvantitativni nalazi ovoga istraživanja.

Instrumenti

Zbog složenosti istraživačkoga problema primijenjen je kvantitativni pristup i promatranje. Nastavnik je imao ulogu promatrača. Kvantitativni pristup uključivao je testove znanja i ljestvice za ocjenjivanje mentalnoga napora i kognitivne složenosti stavki. Isti test znanja primijenjen je na predtestiranju i post-testiranju, svaki s 10 čestica. Za određivanje razine percipiranoga mentalnog napora za svaku česticu se koristila Likertova skala od 5 stupnjeva. Stupanj 1 na ljestvici označava najnižu razinu mentalnoga napora, što implicira da je čestica bila vrlo jednostavna za studente, dok stupanj 5 implicira najvišu razinu mentalnoga napora, odnosno da su studenti smatrali da je ta stavka vrlo teška. Cronbachov alfa za test znanja iznosio je 0,781, dok je za mentalni napor iznosio 0,939. Kognitivna složenost stavki definirana je od strane dva istraživača, autora trenutačnog istraživanja, putem rubrike za kognitivnu složenost. Procjena kognitivne složenosti provodila se u dva koraka. Prvi korak uključivao je procjenu broja koncepata potrebnih za izvođenje stavke primjenom skale od 1 do 7. Definirani koncepti trebali su biti razvrstani prema težini na skali koja se kretala od lakog do teškog. U sljedećem koraku ocjenjivana je interaktivnost između koncepta i potrebnih vještina na skali od 0 (neznatna interakcija) do 2 (složena interakcija). Prema tome, kognitivna složenost čestica može se kretati od 1 do 9 Cronbachov alfa za kognitivnu složenost iznosio je 0,771.

Uzorak

Uzorak je činilo 38 studenata treće godine prijediplomskoga studija na Učiteljskom fakultetu u Beogradu, koji su upisali kolegij Geografski koncepti kroz eksperimente. Veličina uzorka bila je ograničena specifičnim aspektima predmeta - veličinom grupe za izvođenje eksperimenata i maksimalnim brojem od 40 studenata po izbornom predmetu, kako je propisano na Učiteljskom fakultetu. Istraživanje je provedeno u razdoblju od veljače do srpnja 2021. godine.

Analiza podataka

Na temelju vrijednosti asimetrije (*skewness*) i spljoštenosti (*kurtosis*), za daljnju analizu podataka korištena je neparametrijska analiza (Tablica 1). Stoga su za interpretaciju dobivenih rezultata primijenjene deskriptivne statistike, ordinalna regresija i Wilcoxonov test za uparene uzorke. R-indikator korišten je kao procjena veličine učinka varijabli. Neuronski model mreže primijenjen je kako bi se odredila važnost i normalizirana važnost svakog prediktora za postizanje najvećega rezultata na posttestu. Za statističku obradu podataka korišten je program SPSS 20.

Tablica 1

Rezultati

Na temelju definiranih istraživačkih zadataka, rezultati su prikazani u tri dijela.

Postignuća studenata na testovima znanja

Tablica 2

Dobivene vrijednosti, posebno *r*-vrijednost, ukazuju na veliki utjecaj primijenjenoga pristupa na postignuća studenata. Postignuće studenata gotovo se udvostručilo. Najveća promjena zabilježena je u česticama koje se odnose na prijenos topline, svrhu anemometra i definiciju arteške vode. Čestica koja se odnosi na prijenos topline sadrži negaciju, stoga se može pretpostaviti da su studenti to previdjeli i tako dobili niži rezultat na predtestu. Najmanja promjena postignuta je za temperaturu i tlak, što ukazuje da su studenti upoznati s osnovnim pojmovima prirodnih znanosti.

Tijekom nastave, studenti su pokazali dodatni interes za sadržaj predmeta. Stoga su, osim za dobivene rezultate, htjeli otkriti mijenjaju li se rezultati eksperimenta ako se promijene određeni parametri. Na primjer, dok su ocjenjivali slanost tekućine, studenti su odlučili proširiti zadatak i istražiti promjenu rezultata eksperimenta mijenjajući promjer i težinu male kuglice postavljene na kraju slamke uronjenu u tekućinu. Također su pokazali dodatni interes za procjenu utjecaja gustoće tekućine na rezultate eksperimenta. U eksperimentu koji je uključivao izradu anemometra od studenata se očekivalo da izračunaju površinu i opseg kruga te odrede brzinu vjetra na temelju broja ciklusa po jedinici vremena, odnosno cirkularnu frekvenciju. Iako su opažanja nastavnika sugerirala da su studenti pokazali veći interes za sadržaj predmeta i spremnost za produbljivanje svojega znanja, trenutačno istraživanje usmjereno je na percipirani mentalni napor i kognitivnu složenost stavki kod studenata.

Percipirani mentalni napor i kognitivna složenost

Dobiveni rezultati ukazuju na pozitivnu korelaciju između kognitivne složenosti i percipiranoga mentalnog napora na predtestu, *Pearson* $r = .798$, $p < .001$. Relevantne vrijednosti za kognitivnu složenost su M = 4,70, SD = 1,83, dok su vrijednosti koje se odnose na mentalni napor prikazane u Tablici 3. Povezanost između kognitivne složenosti i percipiranoga mentalnog napora potvrđena je ordinalnom regresijom, χ^2 ($df = 10$) = 38,309, $p < .001$, sa pseudo R-kvadratom = .988.

Tablica 3 pokazuje Wilcoxonov test za uparene uzorke percipiranoga mentalnog napora studenata na predtestu i posttestu.

Tablica 3

Dobivena *r*-vrijednost ukazuje na veliki utjecaj primijenjenoga pristupa na smanjenje percipiranoga mentalnog napora. Smanjenje mentalnoga napora primijećeno je gotovo u svakoj čestici. Niže vrijednosti mentalnoga napora sugeriraju da je dobiveno više prostora u radnoj memoriji, što omogućava studentima usvajanje i obradu većega broja informacija.

Model neuronskih mreža

Dobiveni rezultati pokazuju vrlo snažnu negativnu korelaciju između percipiranoga mentalnog napora i postignuća studenata, Pearson $r = -.940$, $p < .001$. S obzirom na to da su prediktori percipiranoga mentalnog napora i kognitivne složenosti čestica također u pozitivnoj korelaciji, primijenjen je neuronski model. Ukupni postotak uzorka za osposobljavanje iznosi 85,7 %, dok je testni uzorak 100,0 %. AUROC (površina ispod ROC krivulje) pruža točnost modela, koja u ovom slučaju iznosi 0,967. Tablica 4 prikazuje važnost i normaliziranu važnost percipiranoga mentalnog napora i kognitivne složenosti čestica na postignuće na posttestu.

Tablica 4

Kao što je prikazano u Tablici 4, oba prediktora značajno doprinose varijabilnosti postignuća studenata. Rezultati ukazuju na potrebu uključivanja mentalnoga napora studenata i razine kognitivne složenosti u procese dizajniranja nastave i donošenja obrazovnih politika.

Diskusija

U istraživanju u kojem su sudjelovali budući učitelji, ispitivan je utjecaj strukturalnoga IBL pristupa na postignuće sudionika, odnosno njihovo postignuće na testu i percipirani mentalni napor uložen u izvršenje testa. Strukturalni IBL pristup odabran je s ciljem pripreme budućih učitelja za rad s učenicima, s obzirom na to da postoje brojni izvještaji u literaturi koji preporučuju osposobljavanje studenata, budućih učitelja, za primjenu ovoga pristupa u osnovnoj školi (Aktamiş i sur., 2016; Letina, 2019; Purnawati i sur., 2021; Zudaire i sur., 2021). Izvješća pokazuju da IBL pristup doprinosi boljem postignuću učenika (Aktamiş i sur., 2016; Alachi i Ifeanyi, 2021; Letina, 2016; Panasan i Nuangchalerm, 2010; Wu i Hsieh, 2006), većem interesu za znanost u školi (Swarat i sur., 2012, citirano u Mueller i Brown, 2022, str. 18) te poboljšava kritičko razmišljanje i kreativnost kod učenika četvrtoga razreda osnovne škole (Purnawati i sur., 2021). Uzimajući u obzir važnost IBL pristupa, kao i probleme koje su prijavili istraživači, Učiteljski fakultet u Beogradu kreirao je kolegij pod nazivom Geografski pojmovi kroz eksperimente. Kolegij obuhvaća pet tema u okviru kojih studenti dobivaju određene zadatke. Studenti dobivaju detaljne informacije o fazama i aktivnostima problemskoga pristupa obrazovanju kako bi se izbjegli problemi koje su istaknuli Perković Krijan i sur. (2017). Očekuje se da će razvoj kompetencija za IBL pristup povećati samopouzdanje budućih učitelja u učionici (Kadijević i Mandić, 2019; Letina, 2019) i promijeniti stavove učenika prema znanosti (Baber i Qureshi, 2021; Bozkurt, 2015).

Zadatci kolegija izvršeni su u grupama od 5 do 6 članova. Studenti su sami odlučivali s kim će se grupirati, temeljem svojih senzibilnosti, stilova učenja i načina razmišljanja. U takvim mikrosredinama očekivalo se da će svaki student prezentirati zadatak drugim studentima. Na taj su način studenti imali javnu prezentaciju kojom su unaprijedili svoje komunikacijske vještine i praktične vještine istraživanja. Vjeruje se da ovaj koncept također poboljšava socijalizaciju potencijalno introvertnih studenata, kako je dokazano u istraživanju Muellera i Browna (2022).

Zadatci kolegija poticali su studente na razmišljanje o novim problematičnim situacijama, poput toga kako bi pčela reagirala u novom staništu, što je potrebno za njezino preživljavanje i kako bi promjena nekog fizičkog parametra (toplina, svjetlost, oborine itd.) utjecala na nju. Pozitivan učinak strukturalnoga IBL pristupa na uključenost studenata uočen je putem promatranja, što je u skladu s drugim istraživanjima. Tako Prayogi i Verawati (2020) izvješćuju da kognitivne strategije konflikta definirane unutar IBL zadataka poboljšavaju kritičko razmišljanje budućih učitelja i doprinose postizanju sposobnosti razmišljanja višega reda.

Za potpuno razumijevanje učinka strukturalnoga IBL pristupa, također smo istraživali promjene u razini percipiranoga mentalnog napora studenata. Rezultati ukazuju da je IBL pristup značajno smanjio percipirani mentalni napor, stvarajući tako veći prostor u radnoj memoriji koji se mogao koristiti za usvajanje novih informacija. Rezultati su u skladu s nalazima Maričić i sur. (2022) koji su pokazali da praktični eksperimenti smanjuju nepotreban kognitivni teret. Smanjenje mentalnoga napora, kao mjerljivoga dijela kognitivnoga opterećenja, pokazalo se važnim za postizanje najviših rezultata na testu znanja. Osim smanjenja kognitivnoga opterećenja, značajan doprinos izvrsnim posttest rezultatima ostvaren je kroz kognitivnu složenost, koja je čvrsto povezana s mentalnim naporom. Zbog višestrukih odnosa između varijabli, učinak varijable procijenjen je pomoću neuronskoga modela.

Daljnja istraživanja trebala bi uključivati veći uzorak i usporedbu s drugim pristupima temeljenima na konstruktivističkoj teoriji i e-okružju. Neki od pristupa pokazali su da e-okružje može značajno utjecati na postignuće studenata (Mandić i sur., 2017; Odadžić i sur., 2017; Pribićević i sur., 2017).

Zaključak

Nalazi istraživanja ukazuju na pozitivan učinak strukturalnoga IBL pristupa na postignuće studenata i značajno smanjenje percipiranoga mentalnog napora, kao mjerljivoga dijela kognitivnoga tereta. Značaj smanjenja mentalnoga napora odražava se u količini informacija koje se obrađuju u radnoj memoriji i dalje u dugoročnoj memoriji. Istraživanje pokazuje pozitivnu korelaciju između percipiranoga mentalnog napora i kognitivne složenosti čestice. Stoga je, kako bi se odredio ukupni učinak strukturalnoag IBL pristupa na postizanje izvrsnih rezultata na posttestu, primijenjen model neuronskih mreža. Model je pokazao da oba prediktora, odnosno mentalni napor i kognitivna složenost stavke, značajno utječu na postignuće studenata. Stoga su rezultati istraživanja korisni za nastavnike u službi jer pružaju bolji uvid u učinak IBL pristupa na postignuće studenata. Osim toga, ovo istraživanje daje smjernice za implementiranje ovoga pristupa u kurikule drugih institucija koje osposobljavaju buduće učitelje.