UDK 371.314.4:159.955-057.874(497.11)

Иновације у настави, XXXVIII, 2025/4, стр. 1–17
DOI: 10.5937/inovacije2504001P

Рад примљен: 15. 1. 2025.
Рад прихваћен: 22. 10. 2025.

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Оригинални научни рад

Impact of project-based teaching of natural sciences on key 21st century skills that contribute to students' scientific literacy: A meta-analysis study[2]

Summary: *PISA testing results indicate that Serbian students have an unsatisfactory level of scientific literacy which is essential for successful adaptation to life changes caused by fast scientific growth in the 21st century. As creativity, critical thinking, and science process skills represent key 21st century skills that contribute to students' scientific literacy, the present study aimed to determine whether project-based teaching of natural sciences could be used for their enhancement. The three research hypotheses stating that the project-based approach is more effective than the traditional approach to teaching of natural sciences in promoting students' creativity (H1), critical thinking (H2), and science process skills (H3) were evaluated through meta-analysis. The meta-analysis encompassed 32 studies published between 2004 and 2024, whose results enabled the calculation of 35 Hedge's g values. Following the application of the random effects model, the weighted mean Hedge's g value higher than +1.000, which indicates a strong positive effect of the project-based approach, was obtained for each hypothesis. Consequently, it was concluded that all hypotheses posed in this study are correct, which confirms the high effectiveness of the project-based teaching of natural sciences in terms of the promotion of the key 21st century skills that contribute to students' scientific literacy.*

Keywords: *project-based teaching of natural sciences, meta-analysis, creativity, critical thinking, science process skills*

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2 This study was funded by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, Contract number: 451-03-136/2025-03/200288. The study refers to Sustainable Development Goal 4 (Quality Education) of the 2030 United Nations Agenda for Sustainable Development.

Introduction

Life in the 21st century is characterized by constant changes in our professional and social environments, many of which are induced by fast scientific growth (Mejlgaard & Bloch, 2012). Since scientific literacy is essential for successful adaptation to changes of this type (Turiman et al., 2012), it is highly concerning that, within the most recent round of PISA (Programme for International Student Assessment) testing conducted by the Organization for Economic Co-operation and Development (OECD) in 2022, students from Serbia produced a scientific literacy score that was significantly below the OECD average (OECD, 2023).

Along with a thorough understanding of scientific concepts, scientific literacy also presupposes the students' ability to act and think in the manner of professional scientists and apply scientific knowledge to overcome various challenges that arise in their daily lives (OECD, 2023). Due to such characteristics, scientific literacy is inherently linked to several 21st century skills (Haryani et al., 2021). One of these skills is creativity, which refers to students' ability to overcome real-life difficulties through the creation of innovative products (Mulyani et al., 2021). Science process skills represent another core component of scientific literacy which enables students to resolve daily-life problems like professional researchers, i.e. through the application of the scientific method. This presupposes the collection of important information about the problem of interest, the use of this data for the formulation of research hypotheses, and the undertaking of appropriate experimental procedures for their evaluation (Ploj Virtič, 2022; Yalcinkaya-Onder et al., 2022). Ultimately, to select the most suitable experiments for the assessment of the posed hypotheses, draw adequate conclusions about their correctness based on the obtained experimental findings (Santos, 2017), and properly determine the extent to which a certain scientific product is effective in overcoming of a particular real-life problem (Carvalho et al., 2015), students need to be equipped with critical thinking skills.

The development of scientific literacy is also strongly affected by the way in which scientific content is taught to students (Holbrook & Rannikmae, 2009; Ploj Virtič, 2022). Thus, receptive teaching that rarely considers the application of scientific knowledge in authentic contexts has been identified as one of the major causes of the low scientific literacy (Adak, 2017; Ebenezer & Zoller, 1993; Jufrida et al., 2019). As opposed to this teaching approach that is traditionally used in natural sciences classrooms throughout the world (Hassard, 2005), project-based teaching enables students to actively participate in the learning process and the work on each project is initiated by the driving question which represents a real-life problem that needs to be solved (Ainley & Ainley, 2011; Barak, 2002; Gresnigt et al., 2014; Hasni & Potvin, 2015). Driving questions are commonly open-ended, due to which they can be successively addressed in several different ways (Hasni et al., 2016). Furthermore, students are expected to explore them in a manner that reflects the work of professional scientists, i.e. through taking part in a scientific inquiry (Chinn & Malhotra, 2002; Pedaste et al., 2015). Since scientific inquiry is highly time-consuming, project-based teaching of natural sciences is commonly implemented over an extended period of time, such as one or several months, or the entire school semester (Barak & Shachar, 2008). Given that social interactions greatly contribute to successful learning, students engage in scientific inquiry through collaboration with their classmates, teachers, and members of society (Anderson, 2002; Krajcik & Blumenfeld, 2006). Furthermore, to ensure effective communication with their collaborators, obtain various information of interest (Blumenfeld et al., 1994; Lam et al., 2009), and take part in activities that under ordinary circumstances are beyond their reach (e.g. perform simulations of experiments that could not be conducted in the classroom due to their complexity or the use of expensive equipment and chemicals), students are encouraged to implement information communication technologies as scaffolding tools (Krajcik & Blumenfeld, 2006). Finally, as previous research established that learning is more effective in this way (Anderson, 2002; Barak, 2002; Hasni & Potvin, 2015), responses to each driving question need to be produced through the creation of artifacts, i.e. tangible products that reflect the knowledge that was acquired within the project. When it comes to projects from the field of natural sciences artifacts could, for example, come in the form of new pathways for the synthesis of useful biological and chemical compounds, structural models of compounds in physical or digital form, reports, new forms of laboratory equipment, or even new scientific theories (Krajcik & Blumenfeld, 2006). All artifacts should adequately address the driving question around which the project was organized and reflect a thorough understanding of the scientific concepts that were elaborated within it (Blumenfeld et al., 1994). Therefore, teachers' feedback on whether and to what extent these requirements are met by the artifacts that the students produced is of vital importance for the successful completion of the given project (Krajcik & Blumenfeld, 2006).

Research Methodology

Research aim and research hypotheses

The present study aimed to determine whether the project-based approach is more effective than the traditional approach to teaching of natural sciences in terms of the promotion of key 21st century skills that contribute to students' scientific literacy. According to this aim, the following research hypotheses have been posed:

H1. The project-based approach is more effective than the traditional approach to teaching of natural sciences in promoting students' creativity;

H2. The project-based approach is more effective than the traditional approach to teaching of natural sciences in promoting students' critical thinking;

H3. The project-based approach is more effective than the traditional approach to teaching of natural sciences in promoting students' science process skills.

The correctness of the three research hypotheses was assessed by means of a meta-analysis.

Selection of studies for the present meta-analysis

Meta-analysis is a research technique that seeks to provide a quantitative estimate of the effectiveness of a novel teaching approach based on the results of the previously published (quasi-) experimental studies that already compared how this approach and the approach that is traditionally used in the classroom affect a learning outcome of interest (Field & Gillett, 2010; Guzzo et al., 1987).

The studies included in this meta-analysis were selected through the use of the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) procedure (Moher et al., 2010). To begin with, the citation database Google Scholar was searched to find studies published in peer-reviewed journals in the English and Serbian language in the last 20 years (2004-2024) that compared the impact of the project-based and traditional teaching of natural sciences on students' creativity, critical thinking, and science process skills. The full contents of 114 studies found in this way were then carefully assessed to determine which of these studies were eligible for the present meta-analysis. The eligible studies had to have experimental or quasi-experimental design, use valid and reliable assessment instruments, and provide enough quantitative data for the calculation of the effect size value. Of the above-mentioned 114 studies, only 32 met the given criteria. An overview of these studies is presented in Table 1.

Table 1. Overview of studies included in the present meta-analysis.

Study number	Author(s) of the study	Publication year	Educational level	Subject area	Geographic region	Sample size
S1	Adewumi & Adejoke	2023	Secondary school	Biology	Africa	120
S2	Bani-Hamad & Abdullah	2019	Secondary school	Science	Asia	12
S3	Buroidah et al.	2023	University	Biology	Asia	28
S4	Can et al.	2017	Kindergarten	Science	Europe	26
S5	Corbano-Reyes	2023	Secondary school	Science	Asia	23
S6	Cortazar et al.	2021	University	Science	South America	834
S7	deOliveira Biazus & Mahtari	2022	Secondary school	Physics	Asia	50
S8	Husamah	2015	University	Biology	Asia	95
S9	Ijirana et al.	2022	University	Chemistry	Asia	130
S10	Issa & Khataibeh	2021	Secondary school	Science	Asia	111
S11	Koes-Handayanto & Putri	2021	Secondary school	Science	Asia	66
S12	Lou et al.	2017	Secondary school	Chemistry	Asia	60
S13	Metin et al.	2023	Kindergarten	Science	Europe	38
S14	Mihardi et al.	2013	University	Physics	Asia	126
S15	Nurulwati et al.	2021	Secondary school	Physics	Asia	40
S16	Okoye & Osuafor	2021	Secondary school	Biology	Africa	284
S17	Pramashela et al.	2023	Secondary school	Science	Asia	70
S18	Putranta et al.	2019	Secondary school	Physics	Asia	62
S19	Putri et al.	2019	Elementary school	Biology	Asia	45
S20	Rengkuan et al.	2023	University	Biology	Asia	67
S21	Sekar et al.	2024	Secondary school	Biology	Asia	135
S22	Sembiring & Jahro	2024	Secondary school	Chemistry	Asia	58
S23	Setiawan et al.	2021	Secondary school	Chemistry	Asia	25
S24	Siew & Ambo	2018	Elementary school	Science	Asia	60
S25	Sitanggang & Haryanto	2023	Secondary school	Science	Asia	50
S26	Suastra & Ristiati	2019	Secondary school	Science	Asia	60
S27	Tuanany et al.	2023	Secondary school	Science	Asia	78
S28	Tuaputty et al.	2023	University	Biology	Asia	32
S29	Viana et al.	2019	Secondary school	Physics	Asia	48
S30	Wahyudiati et al.	2022	University	Chemistry	Asia	50
S31	Wakumire et al.	2022	Secondary school	Physics	Africa	50
S32	Yalcin et al.	2009	University	Physics	Europe	90

As can be seen, 65.62% of the studies included in this meta-analysis were published after the year 2020, which shows that the exploration of the impact of the project-based teaching of natural sciences on key 21st century skills that contribute to students' scientific literacy currently represents a very active field of research. It can also be observed that 59.38% of the studies were conducted at the secondary school level, 28.12% of them included university students, 6.25% of the studies were conducted in elementary school, while the remaining 6.25% of the studies included kindergarten students. Furthermore, 37.50% of the studies referred to science teaching, 25% of them were related to biology, 21.88% of the studies referred to physics, while 15.62% of the studies focused on chemistry teaching. Additionally, 78.12% of the studies were conducted in Asia, while 68.75% of them had 50 or more participants.

Computation and interpretation of the effect size values

The magnitude of the impact that a novel teaching approach has on the learning outcome of interest is expressed through the value of the effect size. The two types of effect size indices that are most frequently used in educational research are Cohen's *d* and Hedges' *g* (Kraft, 2020). While the effect of the implementation of a novel teaching approach tends to be overestimated when Cohen's *d* is applied in regard to studies with less than 50 participants, the accuracy of Hedge's *g* is not affected by the sample size (Turner & Bernard, 2006). For this reason, within the present meta-analysis which encompassed 10 studies with less than 50 participants and 22 studies with 50 or more participants (Table 1), Hedge's *g* index was used as a measure of the effect size.

Hedge's *g* for a given (quasi-)experimental study can be calculated through the use of the results of *t* and χ^2 test, ANOVA, or mean results and standard deviations of the control and experimental groups (Turner & Bernard, 2006). To conduct a meta-analysis, a minimum of 10 effect size values per research hypothesis is required (Field & Gillett, 2010). The results of the studies included in the present-meta analysis enabled the calculation of 35 Hedge's *g* values, of which 10 were used for the evaluation of H1, 13 values were included in the assessment of H2, while 12 values were used for the evaluation of H3. The number of the computed Hedge's *g* values was higher than the number of studies encompassed by this meta-analysis, as the results of some of the studies enabled the assessment of more than one research hypothesis.

Following the computation of Hedge's *g* for all studies included in the assessment of H1-H3, the weighted mean Hedge's *g* value was obtained for each hypothesis. The selection of the appropriate model for the calculation of this value was based on the use of the I^2 index. I^2 lower than 50% indicates that Hedge's *g* values used for the assessment of the given hypothesis are homogeneous (Higgins et al., 2003), which warrants the application of the fixed effects model (Hedges & Vevea, 1998). On the other hand, I^2 higher than 50% indicates that Hedge's *g* values used to evaluate the given hypothesis are heterogeneous (Higgins et al., 2003), which requires the implementation of the random effects model (Borenstein et al., 2010). Within the present meta-analysis, the computation of I^2 values and the subsequent application of the appropriate model for the calculation of weighted mean Hedge's *g* for each of the three research hypotheses were conducted in JASP software for statistical analysis.

Weighted mean Hedge's *g* values obtained in this way were interpreted according to the following guidelines (Turner & Bernard, 2006). Thus, a positive weighted mean value of Hedge's *g* implies that the project-based approach is more effective than the traditional approach (a negative value implies the opposite). However, if such a value is lower than +0.200, the given positive effect is, in fact, negligible. On the other hand, the value between +0.200 and +0.500 indicates a small positive effect, the value between +0.500 to +0.800 implies a moderate positive effect, while a strong positive effect is indicated by the value larger than +0.800. Ultimately, all research hypotheses for which the weighted mean Hedge's *g* value was higher than +0.200 were confirmed as correct.

Results

Hedge's *g* values calculated from the results of studies included in the evaluation of the three research hypotheses are presented in Table 2.

Table 2. Overview of Hedge's g values used for the evaluation of the three research hypotheses.

Study Number	Author(s) of the study	g(H1)	g(H2)	g(H3)
S1	Adewumi & Adejoke (2023)	/	/	1.865
S2	Bani-Hamad & Abdullah (2019)	1.106	1.000	/
S3	Buroidah et al. (2023)	/	3.262	/
S4	Can et al. (2017)	/	/	0.669
S5	Corbano-Reyes (2023)	/	/	1.343
S6	Cortazar et al. (2021)	/	0.177	/
S7	deOliveira Biazus & Mahtari (2022)	1.288	/	/
S8	Husamah (2015)	2.507	1.334	/
S9	Ijirana et al. (2022)	/	0.548	/
S10	Issa & Khataibeh (2021)	/	0.380	/
S11	Koes-Handayanto & Putri (2021)	/	/	1.572
S12	Lou et al. (2017)	1.027	/	/
S13	Metin et al. (2023)	/	/	1.420
S14	Mihardi et al. (2013)	0.841	/	/
S15	Nurulwati et al. (2021)	/	/	1.328
S16	Okoye & Osuafor (2021)	/	/	3.557
S17	Pramashela et al. (2023)	0.270	/	/
S18	Putranta et al. (2019)	/	2.792	/
S19	Putri et al. (2019)	1.319	/	/
S20	Rengkuan et al. (2023)	/	0.819	/
S21	Sekar et al. (2024)	1.041	/	/
S22	Sembiring & Jahro (2024)	/	/	0.854
S23	Setiawan et al. (2021)	/	/	2.974
S24	Siew & Ambo (2018)	0.471	/	/
S25	Sitanggang & Haryanto (2023)	/	0.312	/
S26	Suastra & Ristiati (2019)	/	0.832	/

S27	Tuanany et al. (2023)	/	2.458	1.560
S28	Tuaputty et al. (2023)	/	/	1.274
S29	Viana et al. (2019)	2.875	/	/
S30	Wahyudiati et al. (2022)	/	0.128	/
S31	Wakumire et al. (2022)	/	2.356	/
S32	Yalcin et al. (2009)	/	/	1.765

I^2 values computed to determine which model should be used to calculate the weighted mean Hedge's *g* for each of the three research hypotheses are provided in Table 3.

Table 3. I^2 values for the three research hypotheses.

Hypothesis	I^2(%)
H1	89.841
H2	91.514
H3	72.397

Since all I^2 values were higher than 50%, the calculation of the weighted mean Hedge's *g* for all three research hypotheses was based on the random effects model. The weighted mean Hedge's *g* values obtained in this way are presented in Table 4.

Table 4. Weighted mean Hedge's g values for the three research hypotheses.

Hypothesis	Weighted mean Hedge's g	*z*	*p*	95% confidence interval	
				Lower	Upper
H1	1.256	4.856	< 0.001	0.749	1.763
H2	1.186	4.309	< 0.001	0.729	1.642
H3	1.656	8.066	< 0.001	1.279	2.033

As can be observed, all computed weighted mean Hedge's *g* values were higher than +0.800. This implies that the project-based approach, in comparison to the traditional approach to teaching of natural sciences, has a strong positive impact on students' creativity, critical thinking, and science process skills. Based on such findings, it can be concluded that all three research hypotheses that were posed in this study are correct.

Discussion

Upon completion of a meta-analysis, it is customary to compare its findings with the results of prior studies of this type that evaluated the correctness of identical hypotheses. Thus, in terms of the impact of project-based teaching of natural sciences on students' creativity and critical thinking, based on the results of the studies published between 2016 and 2023 and the application of the random effects model, the meta-analysis of Hikmah et al. (2023) produced the weighted mean Hedge's *g* values of 1.207 and 1.308, respectively. Furthermore, when it comes to the impact of the project-based approach on the enhancement of students' science process skills, the meta-analysis of Setiyadi et al. (2024) that encompassed studies published from 2013 to 2023 and implemented the random effects model, produced the weighted mean Hedge's *g* value of 1.147. As can be seen, both of the above-mentioned prior meta-analyses, following the application of the random effects model, also produced strong weighted mean effect size values higher than +1.000. Thus, it can be concluded that the results of this meta-analysis are in full agreement with the findings of prior studies of this type that indicate the strong positive impact of project-based teaching of natural sciences on key 21st century skills that contribute to students' scientific literacy. Ultimately, it is important to examine whether the effectiveness of project-based science teaching in terms of the promotion of students' creativity, critical thinking and science process skills varies across different educational levels or different subjects in the field of natural sciences and, thus, determine under which conditions this approach produces the strongest positive effects.

Regarding the development of students' creativity, the obtained *g* values ranged between +0.270 and +2.875, with 80% of them pertaining to the category of strong positive effect size values. More specifically, all studies with university students, 83.33% of the studies at the secondary school level, and one out of two studies with elementary school students reported *g* values higher than +0.800, while studies at the kindergarten level were not conducted. Strong positive effect size values were also reported by all studies from the fields of physics, biology and chemistry, while 66.67% of the studies related to science education produced *g* values lower than +0.800. Overall, the highest *g* value was obtained in the study of Viana et al. (2019), which was conducted at the secondary school level in the field of physics. In this study, projects related to the teaching topic *Impulse and momentum* were carried out in groups of four or five students, with the use of information communication technologies as scaffolding tools.

In terms of the development of critical thinking, the obtained *g* values ranged between +0.128 and +3.262, with 38.46% of them falling below the category of strong positive effect size values. Consequently, the mean *g* value for H2 was lower than the mean *g* values for H1 and H3, while the heterogeneity of individual *g* values, presented though I^2 index, was the highest. The strong positive *g* values in regard to H2 were reported by 71.43% of the studies with secondary school students and 50% of the studies that included university students, while studies at lower educational levels were not conducted. Furthermore, *g* values higher than +0.800 were also obtained in all studies from the fields of biology and physics, as well as 50% of the studies related to science education. On the other hand, both studies that explored the impact of project-based teaching on the development of critical thinking in the field of chemistry reported *g* values lower than +0.800. Overall, the highest *g* value was obtained in the study of Buroidah et al. (2023), in which project-based teaching was used to elaborate introductory genetics content with university students. The projects in this study were completed in groups with up to five members, whose activities were guided by means of an E-book.

Finally, when it comes to the development of science process skills, the obtained *g* values fell in the range between +0.669 and +3.557, with 91.67% of them being higher than +0.800. Thus, the mean *g* value for H3 was higher than those calculated for H1 and H2, while the corresponding I^2 value was the lowest. Strong positive *g* values were reported by all studies at the secondary school and university levels, as well as one out of two studies related to kindergarten education, while studies with elementary school students were not conducted. Effect size values higher than +0.800 were also produced by all studies from the fields of biology, chemistry and physics, as well as 80% of the studies related to science teaching. Overall, the highest *g* value was obtained in the study of Okoye & Osuafor (2021), in which the teaching topic *Animal skeleton* was elaborated with secondary school students. In this study, all projects were completed through group work, with the help of information communication technologies that were used to visualize the structure of bones and their position within the skeleton.

The previously discussed results indicate that project-based science teaching has a particularly strong positive impact on the development of creativity and science process skills among secondary school and university students, while its effectiveness in terms of the promotion of critical thinking at these educational levels appears to be slightly lower. At the same time, further studies with both the elementary school and kindergarten students are needed before more definitive conclusions about the impact of the project-based science teaching on the development of creativity, critical thinking and science process skills at these educational levels could be drawn. The above-mentioned results also show that project-based teaching is equally effective in promoting the development of students' science process skills when different scientific subjects are taught separately and in a combined manner. Conversely, in terms of the development of creativity, stronger positive effects are observed when different scientific subjects are taught separately. This can be related to the fact that combining teaching content from different subjects increases cognitive load (Xu et al., 2022) which, in turn, has a negative impact on the development of students' creativity (Rodet, 2022; Sun & Yao, 2012). Regarding the promotion of the development of critical thinking, the lower effectiveness of the project-based teaching was only observed in the field of chemistry. Previous research indicates that the development of critical thinking in chemistry education is more difficult due to the triplet nature of chemical phenomena which, unlike biological and physical phenomena, exist at the macroscopic level which can be perceived through the senses, symbolic level which refers to chemical symbols and formulas, and sub-microscopic level which cannot be observed by the naked eye (Talanquer, 2018). Ultimately, the obtained results show that all projects in the studies that produced the highest *g* values in regard to H1-H3 were conducted through group work and with the help of information communication technologies, which confirms the previous findings that collaborative activities (Anderson, 2002; Krajcik & Blumenfeld, 2006) and scaffolding thorough the use of digital technologies (Krajcik & Blumenfeld, 2006) enhance the positive effects of the project-based teaching.

Conclusion

The present study aimed to determine whether the key 21st century skills that contribute to students' scientific literacy could be enhanced through project-based teaching of natural sciences. The three research hypotheses stating that this approach is more effective than the traditional teaching approach in promoting students' creativity (H1), critical thinking (H2), and science process skills (H3) were evaluated by means of a meta-analysis. The meta-analysis encompassed 32 (quasi-)experimental studies, whose results enabled the calculation of 35 values of Hedge's *g*. 10 of these values were used for the evaluation of H1, 13 values were included in the assessment of H2, while 12 values were used for the evaluation of H3. Following the application of the random effects model, the weighted mean Hedge's *g* higher than +1.000 was obtained for each hypothesis. Given that such strong values of the effect size indicate that the project-based approach is considerably more effective than the traditional approach to teaching of natural sciences, it was concluded that all three research hypotheses that were posed in this study are correct.

Based on these findings, which are in line with the results of prior meta-analyses that assessed the correctness of identical hypotheses (Hikmah et al., 2023; Setiyadi et al., 2024), educators in the field of natural sciences are strongly encouraged to implement the project-based approach in their classrooms. Educators should be aware that the use of this approach would not only enhance the above-mentioned 21st century skills and scientific literacy of their students but also ensure that they are adequately prepared for dealing with various challenges that may arise in their daily lives and future professional settings, due to the rapid scientific progress in the 21st century.

The greatest limitation of this meta-analysis refers to the relatively small number of Hedge's *g* values used for the evaluation of H1-H3. However, given that the exploration of the impact of the project-based teaching of natural sciences on students' creativity, critical thinking, and science process skills currently represents a very active field of research, authors of future meta-analyses should be able to include a far greater number of studies in the assessment of the above-mentioned hypotheses and, thus, fortify evidence of the strong positive impact of project-based teaching on the above-mentioned skills. Furthermore, if the formation of clusters of 10 or more studies conducted at different educational levels, regarding different subjects from the field of natural sciences, or with a different size of student groups that worked on a project becomes possible, a sub-group analysis could be used to determine how the effectiveness of the project-based teaching varies from kindergarten to university, across different scientific subjects or with the increase/decrease in the group size. Ultimately, future meta-analyses could also examine the impact of the project-based teaching of natural sciences on some additional skills that are essential for life in the 21st century, such as communication, collaboration and, given the incentive to use information communication technologies as scaffolding tools throughout the project, students' digital literacy skills.

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УТИЦАЈ ПРОЈЕКТНЕ НАСТАВЕ ПРИРОДНИХ НАУКА НА КЉУЧНЕ КОМПЕТЕНЦИЈЕ 21. ВЕКА КОЈЕ ДОПРИНОСЕ РАЗВОЈУ УЧЕНИЧКЕ НАУЧНЕ ПИСМЕНОСТИ: МЕТААНАЛИТИЧКА СТУДИЈА

Резултати ПИСА тестирања указују да ученици из Србије немају задовољавајући ниво научне писмености, која је есенцијална за успешно прилагођавање животним променама изазваним брзим научним развојем у 21. веку. Један од кључних узрока оваквих резултата јесте рецептивни приступ настави природних наука, током којег се ново градиво ретко разматра у аутентичним контекстима. С друге стране, пројектна настава подразумева активан ангажман ученика у оквиру пројеката иницираних конкретним проблемима из реалног живота, чије превазилажење захтева примену принципа научног метода и креирање иновативних продуката. Будући да креативност, критичко мишљење и компетенције везане за примену научног метода представљају кључне компетенције 21. века које доприносе развоју научне писмености, циљ овог истраживања био је да се утврди да ли се пројектна настава природних наука може применити за њихово унапређивање.

Три истраживачке хипотезе у којима је наведено да је пројектна настава ефективнија од традиционалне рецептивне наставе природних наука у погледу унапређивања ученичке креативности (Х1), критичког мишљења (Х2) и компетенција везаних за примену научног метода (Х3) проверене су путем метаанализе. У метаанализу су биле укључене 32 (квази)експерименталне студије публиковане између 2004. и 2024. године, чији су резултати омогућили израчунавање 35 вредности Хеџесовог g. Од тога је 10 g вредности искоришћено за проверу Х1, 13 за проверу Х2, док је 12 g вредности примењено за проверу Х3. Број израчунатих g вредности био је већи од укупног броја студија укључених у ову метаанализу пошто су резултати појединих студија омогућили проверу више од једне истраживачке хипотезе. Такође је важно истаћи да је 65,12% поменутих студија објављено након 2020. године, што указује да испитивање утицаја пројектне наставе природних наука на унапређивање кључних компетенција 21. века које доприносе развоју ученичке научне писмености тренутно представља веома актуелну област истраживања. Притом је 59,38% студија било изведено са ученицима средњих школа, 28,12% на нивоу универзитета, у 6,25% студија су били укључени ученици основних школа, док је преосталих 6,25% студија спроведено на предшколском нивоу. Истовремено, 37,50% студија било је везано за наставу природних наука, 25% за наставу биологије, 21,88% студија односило се на физику, док је 15,62% студија био фокусирано на наставу хемије.

Услед високог степена хетерогености g вредности које су коришћене за проверу Х1–Х3 (I^2 вредности у сва три случаја биле су веће од 70%), израчунавање средње вредности Хеџесовог g за сваку од хипотеза било је засновано на моделу случајних ефеката. Тако је за Х1 добијена средња вредност Хеџесовог g од +1,256, за Х2 средња g вредност била је +1,186, а

за X3 +1.656, при чему су све три вредности биле статистички значајне на нивоу p<0,001. Поменути резултати указују да, у односу на традиционалну рецептивну наставу природних наука, пројектна настава има јак, позитиван и статистички значајан утицај на развој ученичке креативности, критичког мишљења и компетенција везаних за примену научног метода. На основу тога се може закључити да су све хипотезе постављене у овом истраживању тачне, чиме се потврђује висока ефективност пројектне наставе природних наука у погледу унапређивања кључних компетенција 21. века које доприносе развоју ученичке научне писмености.

Коначно, детаљна анализа g вредности у вези са сваком од хипотеза показала је да на нивоу средње школа и универзитета пројектна настава природних наука има нешто позитивнији ефекат на развој креативности и компетенција за примену научног метода него на развој критичког мишљења. Истовремено, за извођење сличних закључака на нижим образовним нивоима неопходно је спровести додатне (квази)експерименталне студије у вези са датом проблематиком. По питању развоја компетенција за примену научног метода, пројектни приступ показао је једнаку ефективност у ситуацијама када је настава била фокусирана на градиво само једне научне дисциплине, као и у ситуацијама када је градиво различитих научних дисциплина комбиновано. С друге стране, у погледу развоја креативности, већа ефективност установљена је у ситуацијама када је настава била фокусирана на градиво само једне научне дисциплине. Ово се може објаснити чињеницом да комбиновање градива различитих дисциплина доводи до повећања когнитивног оптерећења, што представља један од важних фактора који негативно утичу на развој креативности. Када је у питању развој критичког мишљења, нешто нижа ефективност пројектне наставе установљена је само у области хемије. Спорији развој критичког мишљења у овој области повезан је са чињеницом да све хемијске појмове ученици истовремено морају да сагледају на три потпуно различита нивоа (макроскопском, симболичком и субмикроскопском), што није случај са наставним појмовима из физике и биологије. Коначно, у свим студијама које су дале највеће индивидуалне g вредности у вези са X1–X3 ученици су пројекте изводили у групама и уз коришћење информационо-комуникационих технологија, што указује да се на овај начин додатно могу појачати позитивни ефекти пројектне наставе на кључне компетенције 21. века у вези са развојем ученичке научне писмености.

***Кључне речи**: пројектна настава природних наука, метаанализа, креативност, критичко мишљење, компетенције за примену научног метода*