Teaching Innovations, Volume 38, Issue 4, pp. 1–17
DOI: 10.5937/inovacije2504001P

Katarina B. Putica[1]
University of Belgrade, Innovative Centre of the Faculty of Chemistry, Belgrade, Serbia

Original research paper

Paper received: Jan 15 2025
Paper accepted: Oct 22 2025
Article Published: Jan 20 2026

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

Extended 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. Receptive teaching that rarely considers the application of scientific knowledge in authentic contexts has been identified as one of the major causes of such results. Conversely, project-based teaching enables students to actively participate in projects initiated by real-life problems that need to be solved by using the principles of scientific methods and creating innovative products. As creativity, critical thinking, and scientific methodology process skills represent the 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.

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. Out of this number, 10 g values were used for the evaluation of H1, 13 values were included in the assessment of H2, while 12 g values were

1 puticakatarina@gmail.com;
https://orcid.org/0000-0002-5609-2368

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.

used for the evaluation of H3. The number of the computed Hedge's g values was higher than the number of the studies encompassed by this meta-analysis, as the results of some of the studies enabled the assessment of more than one research hypothesis.

It is also important to note that 65. 12% 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. In addition, 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.

As the g values used to evaluate the H1-H3 were very heterogeneous (I2 values in all three cases were over 70%), the calculation of the Hedge's g mean value for each hypothesis was based on the random effects model. In this way, the Hedge's g mean value for H1 was +1,256, for H2 it was +1,186, and for H3 it was +1.656, whereas all three values were statistically significant at the level $p < 0,001$. These results indicate that the project-based approach, in comparison to the traditional receptive approach to teaching natural sciences, has a strong and 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, confirming the high effectiveness of the project-based natural science instruction relative to the key 21st century competencies that contribute to the development of students' scientific literacy.

A detailed analysis of the g values of each hypothesis indicates that project-based science teaching has a somewhat more positive impact on the development of creativity and science process skills among secondary school and university students than on the development of their critical thinking. At the same time, further (quasi)experimental 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. Project-based teaching proved to be 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, which, in turn, has a negative impact on the development of students' creativity. 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. The development of critical thinking in chemistry education is slower due to the triplet nature of all chemical phenomena which, unlike biological and physical phenomena, students have to understand at three completely different levels (macroscopic, symbolic, and sub-microscopic). Ultimately, 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 that the positive effects of the project-based teaching on the key 21st century competencies related to the development of students' scientific literacy can be further enhanced in this manner.

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

References

- Adak, S. (2017). Effectiveness of constructivist approach on academic achievement in science at secondary level. *Educational Research and Reviews*, *12*(22), 1074–1079. https://doi.org/10.5897/ERR2017.3298
- Adewumi, G. S., & Adejoke, A. A. (2023). Effect of two instructional strategies on students science process skills in some selected abstract concepts in biology in Kwara state, Nigeria. *Journal of Science, Technology and Mathematics Pedagogy*, *1*(1), 242–258.
- Ainley, M., & Ainley, J. (2011). A cultural perspective on the structure of student interest in science. *International Journal of Science Education*, *33*(1), 51–71. https://doi.org/10.1080/.2010.518640
- Anderson, R. (2002). Reforming science teaching: What research says about inquiry. *Journal of Science Teacher Education*, *13*(1), 1–12. https://doi.org/10.1023/A:1015171124982
- Bani-Hamad, A. M. H., & Abdullah, A. H. (2019). The effect of project-based learning to improve the 21st century skills among Emirati secondary students. *International Journal of Academic Research in Business and Social Sciences*, *9*(12), 560–573.
- Barak, M. (2002). Learning good electronics, or coping with challenging tasks? Priorities of excellent students. *Journal of Technology Education*, *14*(1), 20–34. http://dx.doi.org/10.21061/jte.v14i1.a.2
- Barak, M., & Shachar, A. (2008). Projects in technology education and fostering learning: The potential and its realization. *Journal of Science Education and Technology*, *17*(3), 285–296. http://dx.doi.org/10.1007/s10956-008-9098-2
- Blumenfeld, P. C., Krajcik, J. S., Marx, R. W., & Soloway, E. (1994). Lessons learned: A collaborative model for helping teachers learn project-based instruction. *The Elementary School Journal*, *94*(5), 539–551.
  http://www.jstor.org/stable/1001838.
- Borenstein, M., Hedges, L. V., Higgins, J. P., & Rothstein, H. R. (2010). A basic introduction to fixed-effect and random-effects models for meta-analysis. *Research Synthesis Methods*, *1*(2), 97–111.
  https://doi.org/10.1002/jrsm.12
- Buroidah, H., Zubaidah, S., & Mahanal, S. (2023). Effects of project-based learning with project guide E-book on critical thinking and metacognitive skills: A case from undergraduate biology students in genetic 1 course. *Prisma Sains: Jurnal Pengkajian Ilmu dan Pembelajaran Matematika dan IPA IKIP Mataram*, *11*(2), 240–252. https://doi.org/10./ps.v11i2.6727

- Can, B., Yildiz-Demirtas, V., & Altun, E. (2017). The effect of project-based science education programme on scientific process skills and conceptions of kindergarten students. *Journal of Baltic Science Education*, *16*(3), 395–413. https://doi.org/10.33225/jbse/17.16.395
- Carvalho, C., Fiuza, E., Conboy, J., Fonseca, J., Santos, J. S., Gama, A. P., & Salema, M. H. (2015). Critical thinking, real life problems and feedback in science classroom. *Journal of Turkish Science Education*, *12*(2), 21–31. https://doi.org/10.36681/
- Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education*, *86*(2), 175–218. https://doi.org/10.1002/sce.10001
- Corbano-Reyes, R. R. (2023). Project-based learning in science: effects on students' science process and 21st-century skills. *Psychology and Education: A Multidisciplinary Journal*, *10,* 1010–1019.
  https://doi.org/10.5281/zenodo.8166219
- Cortazar, C., Nussbaum, M., Harcha, J., Alvares, D., Lopez, F., Goni, J., & Cabezas, V. (2021). Promoting critical thinking in an online, project-based course. *Computers in Human Behavior*, *119*, Article 106705.
  https://doi.org/10.1016/j.chb.2021.106705
- DeOliveira Biazus, M., & Mahtari, S. (2022). The impact of project-based learning (PjBL) model on secondary students' creative thinking skills. *International Journal of Essential Competencies in Education*, *1*(1), 38–48. https://doi.org/10.36312/ijece.v1i1.752
- Ebenezer, J. V., & Zoller, U. (1993). Grade 10 students' perceptions of and attitudes toward science teaching and school science. *Journal of Research in Science Teaching*, *30*(2), 175–186. https://doi.org/10.1002/tea.3660300205
- Field, A. P., & Gillett, R. (2010). How to do a meta-analysis. *British Journal of Mathematical and Statistical Psychology*, *63*(3), 665–694. https://doi.org/10.1348/000711010X502733
- Gresnigt, R., Taconis, R., Van Keulen, H., Gravemeijer, K., & Baartman, L. (2014). Promoting science and technology in primary education: A review of integrated curricula. *Studies in Science Education*, *50*(1), 47–84. https://doi.org/10.1080/03057267..
- Guzzo, R. A., Jackson, S. E., & Katzell, R. A. (1987). Meta-analysis analysis. *Research in Organizational Behavior*, *9*(1), 407–442.
- Haryani, E., Coben, W. W., Pleasants, B. A., & Fetters, M. K. (2021). Analysis of teachers' resources for integrating the skills of creativity and innovation, critical thinking and problem solving, collaboration, and communication in science classrooms. *Jurnal Pendidikan IPA Indonesia*, *10*(1), 92–102.
  https://doi.org/10.15294/jpii.v10i1.27084
- Hasni, A., & Potvin, P. (2015). Student's interest in science and technology and its relationships with teaching methods, family context and self-efficacy. *International Journal of Environmental and Science Education*, *10*(3), 337–366. https://files.eric.ed.gov/fulltext/EJ1069261.pdf
- Hasni, A., Bousadra, F., Belletete, V., Benabdallah, A., Nicole, M. C., & Dumais, N. (2016). Trends in research on project-based science and technology teaching and learning at

K-12 levels: a systematic review. *Studies in Science Education*, *52*(2), 199–231. https://doi.org/10./.2016.1226573

- Hassard, J. (2005). *The art of teaching science: Inquiry and innovation in middle school and high school*. Oxford University Press.
- Hedges, L. V., & Vevea, J. L. (1998). Fixed- and random-effects models in meta-analysis. *Psychological Methods*, *3*(4), 486–504. https://doi.org/10.1037/1082-989X.3.4.486
- Higgins, J. P. T., Thompson, S. G., Deeks, J. J., & Altman, D. G. (2003). Measuring inconsistency in meta-analysis. *British Medical Journal*, *327*(7414), 557–560. https://doi.org/10.1136/bmj.327.7414.557
- Hikmah, N., Febriya, D., Asrizal, A., & Mufit, F. (2023). The impact of the project-based learning model on students' critical and creative thinking skills in science and physics learning: A meta-analysis. *Journal of Research in Science Education*, *9*(10), 892–902. https://doi.org/.29303/jppipa.v9i10.4384
- Holbrook, J., & Rannikmae, M. (2009). The meaning of scientific literacy. *International Journal of Environmental and Science Education*, *4*(3), 275–288. https://files.eric.ed.gov/fulltext/EJ884397.pdf
- Husamah, H. (2015). Thinking skills for environmental sustainability perspective of new students of biology education department through blended project based learning model. *Indonesian Journal of Science Education*, *4*(2), 110–119.
- Ijirana, I., Aminah, S., Supriadi, S., & Magfirah, M. (2022). Critical thinking skills of chemistry education students in team project-based stem-metacognitive skills learning during the COVID-19 pandemic. *Journal of Technology and Science Education*, *12*(2), 397–409. https://./10.3926/jotse.1697
- Issa, H. B., & Khataibeh, A. (2021). The effect of using project based learning on improving the critical thinking among upper basic students from teachers' perspectives. *Pegem Journal of Education and Instruction*, *11*(2), 52–57. https://files.eric.ed.gov/fulltext/EJ1302127.pdf
- Jufrida, J., Basuki, F. R., Kurniawan, W., Pangestu, M. D., & Fitaloka, O. (2019). Scientific literacy and science learning achievement at junior high school. *International Journal of Evaluation and Research in Education*, *8*(4), 630–636. http://doi.org/10.11591/ijere.v8i4.20312
- Koes-Handayanto, S., & Putri, N. D. (2021). The effect of project-based learning in STEM on students' scientific reasoning. *Journal of Physics: Conference Series (2nd International Annual Meeting on STEM education 2019, Thai Nguyen, Vietnam)*, *1835*, 012006. https://doi.org/10.1088/1742-6596/1835/1/012006
- Kraft, M. A. (2020). Interpreting effect sizes of education interventions. *Educational Researcher*, *49*(4), 241–253. https://doi./.3102/0013189X20912798
- Krajcik, J. S., & Blumenfeld, P. C. (2006). Project-based learning. In R. K. Sawyer (Ed.). *The Cambridge handbook of the learning sciences* (pp. 317–334). Cambridge University Press. https://doi.org/10.1017/CBO9780511816833.020

- Lam, S. F., Cheng, R. W.-Y., & Ma, W. Y. K. (2009). Teacher and student intrinsic motivation in project-based learning. *Instructional Science: An International Journal of the Learning Sciences*, *37*(6), 565–578. https://doi.org/10.1007/s11251-008--9
- Lou, S.-J., Chou, Y.-C., Shih, R.-C., & Chung, C. C. (2017). A study of creativity in CaC_2 steamship-derived STEM project-based learning. *Eurasia Journal of Mathematics Science and Technology Education*, *13*(6), 2387–2404. https://doi.org/10.12973/.2017.01231a
- Mejlgaard, N., & Bloch, C. (2012). Science in society in Europe. *Science and Public Policy*, *39*(6), 695–700. https://doi.org/10.1093/scipol/scs087
- Metin, S., Aral, N., Uyun, H., & Hamiden, N. (2023). The effects of project approach-based education on cognitive abilities and scientific process skills of six-years children. *Cukurova University Faculty of Education Journal*, *52*(1), 71–98. https://dergipark.org.tr/en/download/article-file/2277561.
- Mihardi, S., Harahap, M. B., & Sani, R. A. (2013). The effect of project based learning model with KWL worksheet on student creative thinking process in physics problems. *Journal of Education and Practice, 4*(25), 188–200. https://www.iiste.org/Journals/index.php/JEP/article/view/9086.
- Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & Prisma Group. (2010). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *International Journal of Surgery*, *8*(5), 336–341. https://doi.org/10.1371/journal.pmed.1000097
- Mulyani, S., Madjdi, A. H., Lovika, A. R., & Gung, Y. T. (2021). The design of development of context and creativity based teaching materials to improve scientific literacy for grade V elementary school students. *Asian Pendidikan*, *1*(2), 31–36. https://doi.org/10.53797/aspen.v1i2.5.2021
- Nurulwati, N., Herliana, F., Elisa, E., & Musdar, M. (2021). The effectiveness of project-based learning to increase science process skills in static fluids topic. *AIP Conference Proceedings (The 9th National Physics Seminar 2020, Jakarta, Indonesia)*, *2320*, 020037. https://doi.org/.1063/5.0037628
- Okoye, M. N., & Osuafor, A. M. (2021). Effects of project-based learning method on students' acquisition of science process-skills in Awka education zone. *African Journal of Science, Technology and Mathematics Education*, *6*(2), 10–20.
- Organisation for Economic Co-operation and Development [OECD] (2023). *PISA 2022 Results (Volume I): The State of Learning and Equity in Education*. https://doi.org/10.1787/53f23881-en
- Pedaste, M., Maeots, M., Siiman, L. A., De Jong, T., Van Riesen, S. A. N., Kamp, E. T., Manoli, C. C., Zacharia, Z. C., & Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational Research Review*, *14*(3), 47–61. https://doi.org/10.1016/j.edurev.2015.02.003
- Ploj Virtič, M. (2022). Teaching science & technology: components of scientific literacy and insight into the steps of research. *International Journal of Science Education*, *44*(12), 1916–1931. https://doi.org/10.1080/09500693.2022.2105414

- Pramashela, A., Suwono, H., Sulisetijono, S., & Wulanningsih, U. (2023). The influence of project-based learning integrated STEAM on the creative thinking skills. *BIOEDUKASI: Journal for Biology and Biology Education*, *21*(2), 138–143.
- Putranta, H., Jumadi, J., & Wilujeng, I. (2019). Physics learning by PhET simulation-assisted using problem based learning (PBL) model to improve students' critical thinking skills in work and energy chapters in MAN 3 Sleman. *Asia-Pacific Forum on Science Learning and Teaching*, *20*(1), Article 3.
- Putri, S. U., Sumiati, T., & Larasati, I. (2019). Improving creative thinking skill through project-based-learning in science for primary school. *Journal of Physics: Conference Series (International Conference on Mathematics and Science Education (ICMScE 2018), Bandung, Indonesia)*, *1157*(2), 022052. https://doi.org/10.1088/1742-6596/1157/2/022052
- Rengkuan, M., Leasa, M., & Sumampouw, H. M. (2023). Metacognitive and critical thinking skills of genetics of biology students with project-based learning. *Cypriot Journal of Educational Sciences, 18*(2), 522–532. https://doi.org/10.18844/cjes.v18i2.7299
- Rodet, C. S. (2022). Does cognitive load affect creativity? An experiment using a divergent thinking task. *Economics Letters*, *220*, Article number 110849. https://doi.org/10.1016/j.econlet.2022.110849
- Santos, L. F. (2017). The role of critical thinking in science education. *Journal of Education and Practice*, *8*(20), 159–173. https://files.eric.ed.gov/fulltext/ED575667.pdf
- Sekar, A. D., Manalu, K., & Adlini, M. N. (2024). Investigating the influence of the project based learning model on students creative thinking during digestive system learning. *Indonesian Journal of Biology Education*, *7*(1), 15–20. https://doi.org/10.31002/ijobe.v7i1.1415
- Sembiring, N. A. E. B., & Jahro, I. S. (2024). Differences in learning outcomes and science process skills of students learned with the model project based learning and discovery learning on acid-base material. *Journal of Educational Technology: Journal of Learning Research and Development*, *9*(2), 314–326. https://doi.org/10.33394/jtp.v9i2.11245
- Setiawan, R. R., Suwondo, S., & Syafii, W. (2021). Implementation of project-based learning student worksheets to improve students' science process skills on environmental pollution in high schools. *Journal of Educational Sciences*, *5*(1) 130–140. https://doi.org/10.29303/jpm.v17i5.3710
- Setiyadi, M. W., Sudiatmika, A. A. I. A. R., Suma, K., & Suardana, N. (2024). Meta-analysis: the effect of project based learning on science process skills. *Jurnal Pembelajaran Dan Biologi Nukleus*, *10*(1), 52–62. https://doi.org/10.36987/jpbn.v10i1.5227
- Siew, N. M., & Ambo, N. (2018). Development and evaluation of an integrated project-based and stem teaching and learning module on enhancing scientific creativity among fifth graders. *Journal of Baltic Science Education*, *17*(6), 1017–1033. https://doi.org/10.33225/jbse/18.17.1017

- Sitanggang, R. P., & Haryanto, H. (2023). The influence of project-based learning models on critical thinking ability and basic science learning outcomes. *Proceedings Series on Social Sciences & Humanities*, *12*, 436–444. https://doi.org/10./pssh.v12i.831
- Suastra, I. W., & Ristiati, N. P. (2019). Developing critical thinking, scientific attitude, and self-efficacy in students through project based learning and authentic assessment in science teaching at junior high school. *Journal of Physics: Conference Series (International Seminar on Science Education 2018, Yogyakarta, Indonesia)*, *1233*(1), 012087. https://doi.org/10.1088/1742-6596/1233/1/012087
- Sun, G., & Yao, S. (2012). Investigating the relation between cognitive load and creativity in the conceptual design process. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *56*(1), 308–312. https://doi.org/.1177/1071181312561072
- Talanquer, V. (2018). Chemical rationales: Another triplet for chemical thinking. *International Journal of Science Education*, *40*(15), 1874–1890. https://doi.org/10.1080/09500693.2018.1513671
- Tuanany, N., Wael. S., & Tuaputty, H. (2023) Integration of project based learning (PjBL) and picture and picture (PaP) learning models on process skills, critical thinking and learning outcomes of class X IPA students at SMA Muhamadiyah Masohi and SMA Negeri 15 Maluku Tengah. *Rumphius Pattimura Biological Journal*, *5*(1), 7–11. https://doi.org/10.30598/rumphiusv5i1p007-011
- Tuaputty, H., Alimudi, S., Irene, I., Latuperissa, L. N., & Donkor, A. K. (2023). Project-based learning using a laboratory approach on learning outcomes and critical thinking in marine biology. *Jurnal Pendidikan Biologi Indonesia*, *9*(1), 103–114. https://doi.org/10.22219/jpbi.v9i1.24551
- Turiman, P., Omar, J., Daud, A. M., & Osman, K. (2012). Fostering the 21st century skills through scientific literacy and science process skills. *Procedia-Social and Behavioral Sciences*, *59*, 110–116. https://doi.org/10.1016/j.sbspro.2012.09.253
- Turner, H. M. I., & Bernard, R. M. (2006). Calculating and synthesizing effect sizes. *Contemporary Issues in Communication Science and Disorders*, *33*(Spring), 42–55. https://doi.org/10.1044/cicsd_33_S_4
- Viana, R. V., Jumadi, J., Wilujeng, I., & Kuswanto, H. (2019). The influence of project based learning based on process skills approach to student's creative thinking skill. *Journal of Physics: Conference Series (International Seminar on Science Education 2018, Yogyakarta, Indonesia)*, *1233*(1), 012033. https://doi.org/10.1088/1742-6596/1233/1/012033
- Wahyudiati, D., Irwanto, I., & Ningrat, H. K. (2022). Improving pre-service chemistry teachers' critical thinking and problem-solving skills using project-based learning. *World Journal on Educational Technology: Current Issues*, *14*(5), 1291–1304. https://doi.org/10.18844/wjet.v14i5.7268
- Wakumire, R., Nkundabakura, P., Mollel, A. D., Nazziwa, C., & Wakhata, R. (2022). Impact of project-based learning on students' critical thinking skills in kinematics in Mbale district,

Uganda. *East African Journal of Education and Social Sciences*, *3*(3), 160–170. https://dx.doi.org/10.4314/eajess.v3i3.191

- Xu, C., Chih-Fu, W., Dan-Dan, X., Wen-Qian, L., & Kai-Yi, W. (2022). Challenges to student interdisciplinary learning effectiveness: An empirical case study. *Journal of Intelligence*, *10*, 88. https://doi.org/10.3390/jintelligence10040088
- Yalcin, S. A., Turgut, U., & Buyukkasa, E. (2009). The effect of project based learning on science undergraduates' learning of electricity, attitude towards physics and scientific process skills. *International Online Journal of Educational Sciences*, *1*(1), 81–105. https://www.ajindex.//makale/acarindex-1423904510.pdf
- Yalcinkaya-Onder, E., Zorluoglu, S. L., Timur, B., Timur, S., Guvenc, E., Ozergun, I., & Ozdemir, M. (2022). Investigation of science textbooks in terms of science process skills. *International Journal of Contemporary Educational Research*, *9*(2), 432–449. https://doi.org/10.33200/ijcer.1031338