METODIK DIDAKTIK:
Jurnal Pendidikan Ke-SD-an

JURNAL UPI Journal homepage: https://ejournal.upi.edu/index.php/MetodikDidaktik/index

Building Future STEM Educators: How Robotics Boosts Pre-Service Teachers' Self-Efficacy

Fitri Nuraeni[1]*, Nenden Permas Hikmatunisa[1], Endah Setyowati[1], Hafiziani Eka Putri[1], Afridha Laily Alindra[1], Elvyn Kemala Azzahra[1], Tristia Layla Indriani[1], Rissa Puspita Sari[2], Norm Rorthmony[3]

[1]Universitas Pendidikan Indonesia, Bandung, Indonesia
[2]SDN 1 Nagrikidul Purwakarta, Purwakarta, Indonesia
[3]Faculty of Science Education, Battambang Teacher Education College, Cambodia
*Correspondence: E-mail: fitrinuraeni@upi.edu

ABSTRACT

Science, Technology, Engineering, and Mathematics (STEM) education in elementary schools has been developed to meet the needs of the 21st century. Despite numerous studies on strategies, media, and materials for STEM learning in elementary schools, teachers often need more support to implement them because of low self-efficacy. This issue can be addressed by incorporating robotics into preparatory courses for future elementary school teachers. This mixed-methods study investigates how integrating robotics into STEM education lectures (referred to as STEM with Educational Ro-botics, or STEM-ER) affects the self-efficacy of prospective elementary school teachers. The study involved forty-eight students in an elementary school teachers' education program. The Personal STEM Teaching Efficacy (PSTE) scale was used to measure their STEM teaching self-efficacy. The results showed that integrating robotics significantly increased the average self-efficacy of these prospective teachers. This finding suggests that a pedagogical approach with STEM-ER boosts preservice elementary teachers' confidence in teaching STEM subjects. The approach used in this study could serve as a model for elementary teacher preparation programs.

ARTICLE INFO

Article History:
Received 07 October 2025
Revised 07 November 2025
Accepted 09 November 2025

Keyword:
STEM education,
Educational Robotics,
Pre-service teachers,
Self-efficacy,
Teacher training.

1. INTRODUCTION

Primary education continues to evolve, with increasing attention to developing skills that prepare students to face the challenges of the 21st century. Science, Technology, Engineering, and Mathematics (STEM) education emerged as a strategic response to this demand (Widya et al., 2019), integrating the four disciplines into a cohesive pedagogical approach. Integrating STEM principles into primary education has attracted attention because STEM-based education is key to fostering critical thinking (Nuraeni, 2023), problem-solving skills (Alkair et al., 2023), and a deep understanding of the four disciplines (McCarthy, 2022), which can determine a country's future success in an increasingly technology-dominated environment (Nuraeni, 2023).

Despite its benefits, implementing STEM education in developing countries is often constrained (Aslam et al., 2023). One of the main obstacles in Indonesian education is teachers' difficulty designing and implementing STEM learning in the classroom (Kaniawati et al., 2016). A lack of professional training for teachers in STEM education has resulted in limited knowledge of appropriate STEM challenges and a crisis of competence in integrating the STEM disciplines (Sukiyani, 2023). In fact, the success of implementing STEM education depends heavily on educators' ability to integrate science, technology, engineering, and mathematics into a holistic learning experience. A lack of teacher understanding of STEM limits and makes STEM learning ineffective (Bell et al., 2018). Unfortunately, various studies have noted that teachers already on school duty have inadequate basic understanding of STEM (Gökçe Tekin, 2023; Twaddle & Smith, 2023; Weng et al., 2020). As a result, they have low self-confidence in STEM teaching, which leads to low STEM teaching self-efficacy (Kurup et al., 2019; Martínez-Borreguero et al., 2022). Teacher self-efficacy is vital in STEM learning (Yang et al., 2023; Yesilyurt et al., 2021). Self-efficacy strongly influences teacher behavior and, in turn, student learning outcomes (Fenton & Essler-Petty, 2019). Therefore, prospective elementary school teachers should equip themselves with adequate STEM knowledge and skills to build strong self-efficacy in implementing STEM learning.

Limited technology and engineering content in elementary schools is another problem that makes teachers reluctant to implement STEM learning. This can be overcome by integrating robotics into the lecture program for prospective elementary school teachers, as various studies have shown that robotics is an ideal tool for making STEM learning more integrated and effective (Ahmadaliev et al., 2022; Chiazzese et al., 2019; Karaahmetoğlu et al., 2019; Mwangi et al., 2022; Nugraha & Gutami, 2020; Purnomo & Firmansyah, 2021; Shang et al., 2023; Tselegkaridis & Sapounidis, 2022). Unfortunately, the integration of robotics in the lecture program for prospective teachers remains minimal.

Various studies have shown that teachers' self-efficacy in STEM teaching can be strengthened through targeted experiences, such as structured professional development, engineering design assignments, and field experiences, typically measured with validated instruments and using pre-post or quasi-experimental designs. Compared with these designs, the STEM-ER in this study integrates educational robotics into a STEM course for prospective elementary school teachers. This integration design is less common in previous research and new in the context of the elementary teacher education program in Indonesia.

Therefore, using a descriptive qualitative method and a quasi-experimental, non-equivalent control group research design, this study aims to develop a STEM-ER strategy by integrating educational robotics into STEM Education lectures in the Elementary School Teacher

Education study program and to examine its effect on the self-efficacy of prospective elementary school teachers in teaching STEM subjects. The research questions addressed in this study are: How is the STEM with Educational Robotics (STEM-ER) strategy implemented in the STEM Learning for Elementary Schools course, and how does the implementation of the STEM-ER strategy affect the self-efficacy of prospective elementary school teachers in teaching STEM subjects?ts?

2. METHODS

This study aimed to provide an overview of the implementation and performance of the STEM-ER intervention in improving prospective elementary school teachers' self-efficacy in STEM teaching. The study used a mixed-methods experimental design in which qualitative data served as a supplementary source, integrated with the primary experimental data collected through pre- and posttests (Creswell & Creswell, 2018). The study combined a descriptive qualitative method and a quasi-experimental, non-equivalent control group design involving two groups of students in the undergraduate elementary school teacher education program at one of the universities in West Java as research samples. The two groups were selected through purposive sampling, guided by the following considerations: 1) students enrolled in an elementary teacher education program, and 2) those currently taking STEM Education courses.

The analysis compared data from the implementation of the STEM-ER strategy with those from conventional learning strategies by analyzing learning scenarios and documentation of lesson activities. The data also included results from the PSTE questionnaire, which comprises 13 statements rated on a five-point scale: strongly agree (5), agree (4), neutral (3), disagree (2), and strongly disagree (1). PSTE scores, based on these 13 items, range from 13 to 65. The PSTE items follow those in the PSTE according to Fenton & Essler-Petty (2019) and have been shown to be reliable (Nadelson et al., 2010). The PSTE was administered electronically using Google Forms. An independent sample t-test was conducted to compare prospective teacher self-efficacy data before and after completing the STEM-ER course.

Table 1. Statements in Personal STEM Teaching Self Efficacy (PSTE)

No	Statements
1.	I will continually find better ways to teach STEM
2.	Even if I try very hard, I will not teach STEM as well as I will teach most subjects
3.	I know the steps necessary to teach STEM concepts effectively
4.	I will not be very effective in monitoring STEM experiments
5.	I will generally teach STEM ineffectively
6.	I understand STEM concepts well enough to be effective in teaching elementary STEM
7.	I will find it difficult to explain to students why STEM experiment work
8.	I will typically be able to answer students' STEM questions
9.	I wonder if I will have the necessary skills to teach STEM
10.	Given a choice, I will not invite the principal to evaluate my STEM teaching
11.	When a student has difficulty understanding a STEM concept, I will usually be at a loss as to how to help the student understand
12.	When teaching STEM, I will usually welcome student's questions
13.	I do not know what to do to turn students on to STEM

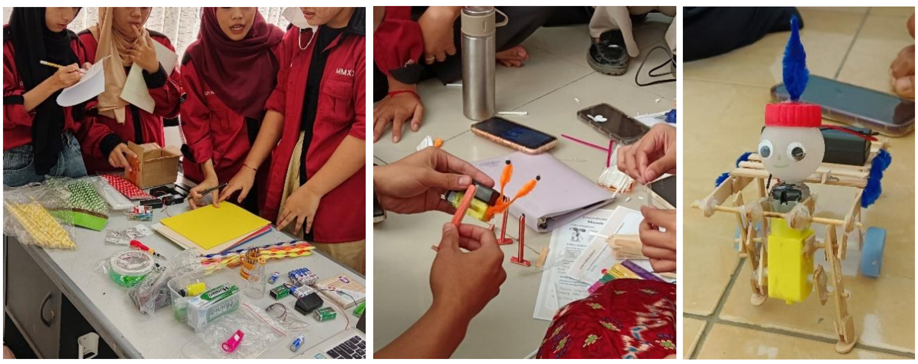
3. RESULTS AND DISCUSSION

The study investigated the impact of a STEM with Educational Robotics (STEM-ER) intervention on the self-efficacy of prospective elementary teachers over four weeks, with four 150-minute sessions. The following section will describe each session (Table 2) in detail and explain how it may affect their STEM teaching self-efficacy.

Table 2. STEM-ER intervention

Meeting	Focus	Key Learning Goals
1	Introduction to educational robotics; unplugged engineering design	Understand relevance of robotics in education; apply EDP to a human-centered problem; practice teamwork within constraints
2	Hands-on with solar-powered car kits; robot definition	Distinguish robots vs non robots (sense-think-act); assemble & test a kit; analyzed environtmental variables: connects robotics to curriculum
3	Electronics assembly: line follower robot + soldering	Develop basic electronic skills; practice precision assembly & troubleshooting;
4	Programming Arduino-based robots with visual coding	Translate logic to code; connect block-based programming to robot behavior; explore diverse applications; present & reflect

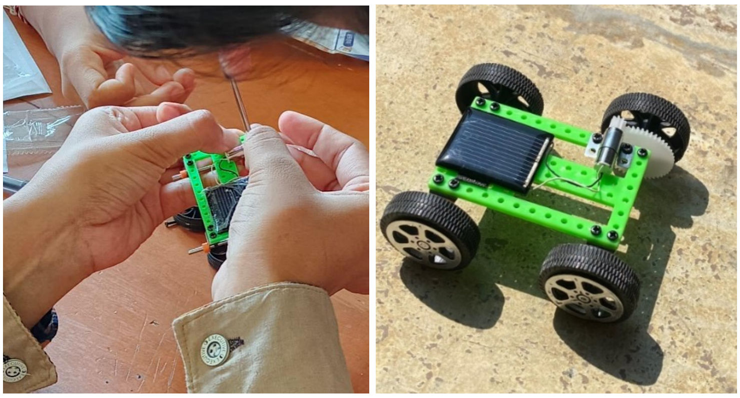
The first meeting introduced prospective elementary teachers to the fundamentals of robotics and their applications in educational settings. The session began with a class discussion highlighting the growing importance of robotics across fields and emphasizing its potential to revolutionize education by enhancing student engagement and learning. Many studies also suggest growing trends in introducing robotics at the elementary level. Participants were introduced to simple robotics activities that can be done using everyday materials. They engaged in a collaborative engineering challenge in which they designed an unplugged robot prototype to assist elderly individuals using simple materials such as a DC motor, battery, ice cream sticks, straws, etc. This activity required them to employ the engineering design process, which included identifying problems, brainstorming solutions, planning (Fig. 1a), constructing (Fig. 1b), testing (Fig. 1c), and improving their designs (Nuraeni, 2020). The exercise fostered teamwork and critical thinking as participants worked within a limited budget to create innovative solutions, reflecting real-world engineering constraints. Overall, this meeting laid the groundwork for understanding the potential of robotics in education and inspired participants to think creatively about how technology can be integrated into elementary classroom learning.



(a) (b) (c)

Figure 1. Participants Performing Engineering Design Process: a) Planning, b) Constructing, c) Testing Robot Prototype

The second meeting provided participants with hands-on experience using educational robotic kits, specifically focusing on a solar-powered car. The session began with a discussion of the characteristics that define a robot, such as the ability to sense, think, and act autonomously. This foundational understanding was crucial for distinguishing between robots and non-robots. Participants assembled the solar-powered car kits in groups (Fig. 2a), applying their knowledge of mechanical and electrical components. After assembly, they conducted outdoor tests to observe the cars in action (Fig. 2b), noting how variables such as sunlight intensity affected performance. This practical activity allowed participants to analyze the differences between the solar-powered car and typical robots, reinforcing their understanding of robotics concepts. Additionally, the meeting included a group discussion on integrating robotics into the elementary school curriculum, emphasizing its relevance to the emancipated curriculum currently implemented in Indonesia. Participants brainstormed ways to incorporate robotics into various subjects, considering the potential benefits for student engagement and learning outcomes. By the end of the session, participants had gained practical experience in assembling and testing robotic kits, enhancing their analytical skills and creativity in applying robotics to educational contexts. Pre-service teachers need practical experience through various exercises and the execution of hands-on project activities during their STEM preparation program (Sungur Gul et al., 2023). Engaging in these kinds of activities encourages them to think critically and anticipate problems related to their future STEM teaching.



(a) (b)

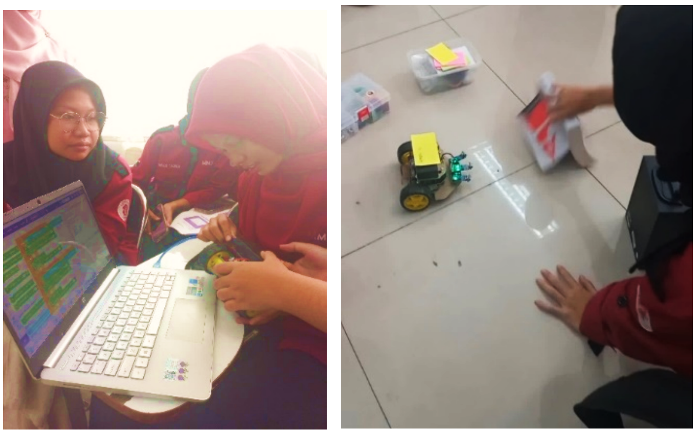
Figure 2. Participants Assembled (a) and Test (b) Educational Robotic Kit: Solar Powered Car

In the third meeting, participants assembled line follower robots to further develop their technical skills and understanding of electronic components. The session began with an explanation of line follower robots, focusing on how sensors and algorithms enable these robots to follow a path autonomously. Participants were introduced to the electronic components used to build these robots, such as sensors, motors, and microcontrollers. For many participants, this was their first soldering experience (Fig. 3a), adding complexity and excitement to the task. Working in groups, participants applied their soldering skills to assemble the line follower robots, emphasizing the importance of precision and attention to detail. The hands-on activity provided valuable experience in troubleshooting and problem-solving, as some robots encountered issues (Fig. 3b) due to poor solder joints or incorrect wiring. Despite these challenges, participants reflected positively on the learning experience, appreciating the opportunity to deepen their understanding of electronics and circuits. The session highlighted the value of resilience and perseverance in STEM projects, reinforcing the importance of technical skills in educational robotics.

(a) (b)

Figure 3. Creating Line Follower: (a) Soldering Process and (b) Testing On Lined Track

The fourth meeting introduced participants to programming and coding with Arduino-based robots, highlighting how coding can be integrated into educational practices. The session began with an overview of Arduino, a popular open-source platform for building electronic projects, and its applications in robotics. Participants were introduced to Pictoblox, a visual programming application that translates block-based programming into C++ code, enabling users to program Arduino-based robots easily. For this session, participants were provided with pre-assembled robots, each designed to perform a specific task, such as a human-following robot, an obstacle-avoiding robot, or a robot controllable via Android devices. Working in groups, participants used Pictoblox to program their robots (Fig. 4a), learning to translate logical instructions into functional code. This hands-on activity allowed participants to experiment with different programming strategies and observe how their code affected the robot's behavior. The session concluded with a showcase in which each group demonstrated its programmed robots (Fig. 4b), highlighting the diversity of applications achievable through coding. Participants received feedback on their projects, discussing the challenges faced and the strategies used to overcome them. This meeting emphasized the growing importance of coding skills in modern education, preparing participants to integrate coding into their teaching practices and to inspire future generations of students.



(a) (b)

Figure 4. Participant (a) Program The Robot and (b) Showcase Obstacle Avoider Robot

After completing the four-session STEM with Educational Robotics (STEM-ER) program, the prospective elementary teachers' self-efficacy in teaching STEM was evaluated using the

Personal Science Teaching Efficacy (PSTE) questionnaire. The analysis compared the experimental group, which participated in the STEM-ER activities, with the control group, which received conventional STEM lectures.

The Shapiro-Wilk test assessed the normality of the pretest scores for both groups, and the results indicated non-significant p-values ($p > 0.05$), suggesting that the scores were normally distributed for both groups. This normal distribution was vital because it validated the use of parametric tests in subsequent analyses. In addition, Levene's test for homogeneity of variances in pretest scores consistently showed non-significant results ($p > 0.05$), implying that the variances between the two groups were similar, allowing for a fair comparison using parametric tests, such as the independent t-test, to compare the groups' self-efficacy scores. The Levene's test for equality of variances results ($F = .370$, $p = .546$) indicated equal variances between the control and experimental groups' N-gains at the 0.05 significance level. This finding supported the assumption of equal variances required for the independent t-test, further validating the robustness of the analysis. The independent t-test revealed a significant difference between the means (t-value = -3.845, df = 46, $p = .000$), indicating that the experimental group had a higher mean self-efficacy score than the control group (Table 3). The negative t-value suggested that the mean self-efficacy score of the control group was lower than that of the experimental group, implying that participating in the STEM-ER program positively impacted the experimental group's self-efficacy in teaching STEM.

Table 3. Group Comparison on self-efficacy

Outcome	Groups compared	t	df	p-value
Self-Efficacy	Control vs Experiment	-3.845	46	0.000

Several critical factors in the STEM-ER program's design and execution contributed to the experimental group's higher self-efficacy in teaching STEM. First, the program provided hands-on learning experiences that fostered deeper understanding and increased confidence in teaching STEM subjects. By engaging in hands-on activities such as assembling robots and solving real-world problems, participants experienced active learning, which encouraged them to explore, experiment, and apply their knowledge, thereby enhancing understanding and retention. Studies such as Campbell & Damico (2023) highlight that an active, hands-on STEM education approach promotes teachers' self-efficacy in implementing such lessons in future classrooms.

Second, the collaborative learning environment fostered teamwork and communication, essential skills for effective STEM teaching. Participants learned to work together to solve problems, share ideas, and support one another's learning, creating a positive, empowering environment. Working in groups provided peer support, boosting confidence in tackling complex tasks and reinforcing the ability to teach STEM concepts collaboratively. Research by W. Johnson & T. Johnson (2019) emphasizes the positive impact of cooperative learning on students' academic performance and self-efficacy.

Third, the program's focus on real-world problem-solving allowed participants to connect theoretical knowledge to practical applications. By addressing real-world problems, such as designing robots to assist older adults, participants could contextualize their learning and demonstrate the relevance of STEM subjects, increasing self-efficacy. The engineering design process mirrored real-world engineering challenges, equipping participants with skills and confidence to teach STEM subjects effectively. Hynes & Swenson (2013) discuss how incorporating real-world problem-solving in STEM education enhances students' understanding and motivation.

Finally, the program exposed participants to cutting-edge technology, enhancing their technological literacy and confidence in integrating technology into teaching practices. Working with modern tools and programming languages developed 21st-century skills crucial for STEM education, such as digital literacy, critical thinking, and problem-solving. Voogt & Roblin (2012) explore the importance of developing 21st-century skills in education and how technology integration can support this goal.

Several areas for future research include: 1) Conduct longitudinal studies to assess the long-term impact of STEM-ER programs on teachers' self-efficacy and teaching practices by tracking participants over time to provide insights into how these experiences influence their classroom instruction and student engagement. Investigating the effectiveness of similar STEM-ER programs in diverse educational settings, including different grade levels and socio-cultural contexts, will also help educators design more inclusive and effective programs. In addition, future research can focus on the effectiveness of various technological tools and platforms in supporting teachers and students in integrating robotics into the STEM learning process.

4. CONCLUSION

The results demonstrate the positive impact of the STEM with Educational Robotics (STEM-ER) program on prospective elementary teachers' self-efficacy in teaching STEM subjects. The significant difference in self-efficacy scores between the experimental and control groups underscores the effectiveness of hands-on, collaborative, and technology-integrated learning experiences. By fostering a deeper understanding of STEM concepts, promoting teamwork, and equipping participants with modern technological skills, the STEM-ER program prepares future educators to teach STEM subjects confidently and effectively.

6. REFERENCES

Ahmadaliev, D., Saleh Metwally, A. H., Mohamed Fahmy Yousef, A., & Shuxratov, D. (2022). The effects of educational robotics on STEM students’ engagement and reflective thinking. *2022 IEEE Frontiers in Education Conference (FIE)*, 1–7. https://doi.org/10.1109/FIE56618.2022.9962498

Alkair, S., Ali, R., Abouhashem, A., Aledamat, R., Bhadra, J., Ahmad, Z., Sellami, A., & Al-Thani, N. J. (2023). A STEM model for engaging students in environmental sustainability programs through a problem-solving approach. *Applied Environmental Education & Communication*, *22*(1), 13–26. https://doi.org/10.1080/1533015X.2023.2179556

Aslam, S., Alghamdi, A. A., Abid, N., & Kumar, T. (2023). Challenges in implementing STEM education: Insights from novice STEM teachers in developing countries. *Sustainability*, *15*(19), 14455. https://doi.org/10.3390/su151914455

Bell, D., Morrison-Love, D., Wooff, D., & McLain, M. (2018). STEM education in the twenty-first century: Learning at work—an exploration of design and technology teacher perceptions and practices. *International Journal of Technology and Design Education*, *28*(3), 721–737. https://doi.org/10.1007/s10798-017-9414-3

Campbell, L. O., & Damico, N. (2023). Investigating an instructional model for integrated STEM in teacher education. *Journal of STEM Teacher Education*, *58*(1).

https://doi.org/10.61403/2158-6594.1512

Chiazzese, Arrigo, Chifari, Lonati, & Tosto. (2019). Educational robotics in primary school: Measuring the development of computational thinking skills with the bebras tasks. *Informatics*, *6*(4), 43. https://doi.org/10.3390/informatics6040043

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE Publications, Inc.

Fenton, D., & Essler-Petty, S. (2019). Self-efficacy and STEM: An integrated pedagogical approach for pre-service elementary teachers. *International Journal for Cross-Disciplinary Subjects in Education*, *10*(4), 4160–4168. https://doi.org/10.20533/ijcdse.2042.6364.2019.0508

Gökçe Tekin, Ö. (2023). Teachers' basic knowledge level of STEM education. *African Educational Research Journal*, *11*(4), 580–587. https://doi.org/10.30918/AERJ.114.23.092

Hynes, M., & Swenson, J. (2013). The humanistic side of engineering: Considering social science and humanities dimensions of engineering in education and research. *Journal of Pre-College Engineering Education Research (J-PEER)*, *3*(2). https://doi.org/10.7771/2157-9288.1070

Kaniawati, I., Suwarma, I. R., Hasanah, L., Rustaman, N. Y., & Nurlaelah, E. (2016). Challenges in developing engineering class design at middle classroom to improve science, technology, engineering, and mathematics (STEM) education. *Proceedings of the 2015 International Conference on Innovation in Engineering and Vocational Education*. 2015 International Conference on Innovation in Engineering and Vocational Education, Bandung, Indonesia. https://doi.org/10.2991/icieve-15.2016.23

Karaahmetoğlu, K., Korkmaz, Ö., & Amasya University, Technology Faculty, department of computer engineering, Amasya, Turkey. (2019). The effect of project-based arduino educational robot applications on students' computational thinking skills and their perception of Basic Stem skill levels. *Participatory Educational Research*, *6*(2), 1–14. https://doi.org/10.17275/per.19.8.6.2

Kurup, P. M., Li, X., Powell, G., & Brown, M. (2019). Building future primary teachers' capacity in STEM: Based on a platform of beliefs, understandings and intentions. *International Journal of STEM Education*, *6*(1), 10. https://doi.org/10.1186/s40594-019-0164-5

Martínez-Borreguero, G., Naranjo-Correa, F. L., & Mateos-Núñez, M. (2022). Development of STEM Instructional resources for teaching optics to teachers-in-training: Influence on learning and teacher self-efficacy. *Education Sciences*, *12*(3), 186. https://doi.org/10.3390/educsci12030186

McCarthy, D. L. (2022). A STEM Experiential Learning Experience: A Five-Year Synthesis of Lessons Learned. *Experiential Learning and Teaching in Higher Education*, *2*(1), 17. https://doi.org/10.46787/elthe.v2i1.3382

Mwangi, P. N., Muriithi, C. M., Professional Engineer and Associate Professor, Department of Electrical Engineering, Dean School of Engineering and Technology, Murang'a University of Technology, Kenya., Agufana, P. B., & Senior Lecturer, Founding Dean School of Education, Murang'a University of Technology (MUT), Kenya. (2022). Exploring the benefits of Educational Robots in STEM Learning: A Systematic Review. *International Journal of Engineering and Advanced Technology*, *11*(6), 5–11.

https://doi.org/10.35940/ijeat.F3646.0811622

Nadelson, L., Hay, A., Pyke, P., Callahan, J., & Schrader, C. (2010). Teaching inquiry based stem in the elementary grades using manipulatives: A systemic solution report. *2010 Annual Conference & Exposition Proceedings*, 15.1176.1-15.1176.18. https://doi.org/10.18260/1-2--16395

Nugraha, B. E., & Gutami, R. S. (2020, November 1). *LOGARITHMUS: kit robot edukasi science, technology, engineering and mathematics (STEM) untuk menyongsong "Merdeka Belajar"*. https://www.semanticscholar.org/paper/LOGARITHMUS%3A-KIT-ROBOT-EDUKASI-SCIENCE%2C-TECHNOLOGY%2C-Nugraha-Gutami/ef78232c58c8ab9658e8a32af3394dddf9056771

Nuraeni, F. (2020). *Aktivitas desain rekayasa untuk pembelajaran berbasis STEM di sekolah dasar*. UPI Sumedang Press.

Nuraeni, F. (2023). *STEM play with Fathar* (Vol. 1–). Taqaddum Press.

Purnomo, F. E., & Firmansyah, M. A. (2021). Wheeled robot with ardublock programming for elementary school students. *JEECS (Journal of Electrical Engineering and Computer Sciences)*, *6*(1), 985–990. https://doi.org/10.54732/jeecs.v6i1.187

Shang, X., Jiang, Z., Chiang, F.-K., Zhang, Y., & Zhu, D. (2023). Effects of robotics STEM camps on rural elementary students' self-efficacy and computational thinking. *Educational Technology Research and Development*, *71*(3), 1135–1160. https://doi.org/10.1007/s11423-023-10191-7

Sukiyani, F. (2023). Investigating Elementary school teachers' challenges and needs in implementing STEM education: The case of nusa tenggara barat indonesia. In F. Nurhasanah & R. S. Padmi (Eds.), *Proceedings of the 7th International Symposium on Mathematics Education and Innovation (ISMEI 2022)* (Vol. 9, pp. 77–84). Atlantis Press International BV. https://doi.org/10.2991/978-94-6463-220-0_9

Sungur Gul, K., Saylan Kirmizigul, A., Ates, H., & Garzon, J. (2023). Advantages and challenges of STEM education in k-12: Systematic review and research synthesis. *International Journal of Research in Education and Science*, *9*(2), 283–307. https://doi.org/10.46328/ijres.3127

Tselegkaridis, S., & Sapounidis, T. (2022). Exploring the Features of educational robotics and stem research in primary education: A systematic literature review. *Education Sciences*, *12*(5), 305. https://doi.org/10.3390/educsci12050305

Twaddle, J., & Smith, T. (2023). STEM pedagogical content knowledge of preservice teachers. *International Journal of Multidisciplinary Perspectives in Higher Education*, *8*(1), Article 1. https://doi.org/10.32674/jimphe.v8i1.4820

Voogt, J., & Roblin, N. P. (2012). A comparative analysis of international frameworks for 21stcentury competences: Implications for national curriculum policies. *Journal of Curriculum Studies*, *44*(3), 299–321. https://doi.org/10.1080/00220272.2012.668938

W. Johnson, D., & T. Johnson, R. (2019). Cooperative learning: the foundation for active learning. In S. Manuel Brito (Ed.), *Active Learning—Beyond the Future*. IntechOpen. https://doi.org/10.5772/intechopen.81086

Weng, X., Jong, M., & Chiu, T. K. F. (2020). *Implementation challenges of STEM education:*

From teachers' perspective.

Widya, Rifandi, R., & Laila Rahmi, Y. (2019). STEM education to fulfil the 21 st century demand: A literature review. *Journal of Physics: Conference Series*, *1317*(1), 012208. https://doi.org/10.1088/1742-6596/1317/1/012208

Yang, W., Wu, R., & Li, J. (2023). Development and validation of the STEM Teaching Self-efficacy Scale (STSS) for early childhood teachers. *Current Psychology*, *42*(9), 7275–7283. https://doi.org/10.1007/s12144-021-02074-y

Yesilyurt, E., Deniz, H., & Kaya, E. (2021). Exploring sources of engineering teaching self-efficacy for pre-service elementary teachers. *International Journal of STEM Education*, *8*(1), 42. https://doi.org/10.1186/s40594-021-00299-8

Zhan, Z., Shen, W., Xu, Z., Niu, S., & You, G. (2022). A bibliometric analysis of the global landscape on STEM education (2004-2021): Towards global distribution, subject integration, and research trends. *Asia Pacific Journal of Innovation and Entrepreneurship*, *16*(2), 171–203. https://doi.org/10.1108/APJIE-08-2022-0090