STEM Education with Robotics Activities: A Task-Centered Teachers Professional Development Program

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Abstract

This study explores the impact of a Task-Centered Robotics Professional Development (PD) on teachers' self-efficacy, anxiety, and attitudes toward integrating robotics activities into STEM education. A 30-hour PD included direct instruction in the context of three tasks based on the Task-Centered Instructional Strategy, focusing on developing the pedagogical, technological, and content competencies needed to implement robotics activities into STEM classes. Data were collected through three questionnaires consisting of closed and open-ended questions. Sixteen Israeli Arab middle school teachers participated in a PD, utilizing LEGO Mindstorms EV3 robots' kits. Results revealed a significant increase in teachers' self-efficacy regarding robotics activities and a significant decrease in anxiety, with attitudes also improving, though not significantly. This study supports the potential of Task-Centered PD in training science teachers with no prior technological knowledge to incorporate robotics activities into their classrooms.

Keywords

Robotics Activities, STEM Education, Professional Development [1]

1. Introduction

Robotics allow students to see, touch, and interact with the principles they learn in class. This hands-on experience deepens understanding and sparks curiosity and engagement, making complex topics more accessible and enjoyable [1], [2]. Integrating robotics enables teachers to bridge theoretical and practical applications, fostering deeper conceptual understanding while fostering 21st-century skills such as problem-solving and computational thinking [3]. Despite these benefits, many STEM teachers hesitate to integrate robotics due to perceived competency gaps and low self-efficacy [4]. This gap emphasizes the need to equip STEM teachers with the necessary competencies to integrate robotics into their curricula effectively. This involves proficiency in the operation of robots and a pedagogical understanding of how to incorporate them into teaching practices.

This study presents a Task-Centered PD Program to foster middle school teachers' competencies for effective robotics integration into STEM. Grounded in the Task-Centered Instructional Strategy [5], which combines direct instruction with real-world task progression, the study examines how can a Task-Centered PD influence teachers' self-efficacy and attitudes toward integrating robotics activities into STEM education?

2. Methodology

2.1. Participants

Sixteen Israeli Arab middle school teachers participated in the PD in 2021-2022 (mean age=39, SD=6.5, teacher's seniority=15, SD=6.5, ten females and six males). Six teach computer science and mathematics, while ten teach science. Eleven (~69%) of the teachers had no prior experience with

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robots, either as a user or a teacher. The participants signed a consent form approved by the Institutional Ethical Committee.

2.2. Materials

2.2.1. LEGO Mindstorms EV3 robots' kits

During the program, teachers engaged in hands-on activities using LEGO Mindstorms EV3 robots, chosen for their robustness and classroom suitability [6]. The kits include sensors and a block-based interface that reduces syntax errors, enhancing accessibility. Their modular design allows easy model creation for teaching key STEM concepts.

2.2.2. STEM Education with Robotics Activities – a Task-Centered Teacher PD

The STEM Education with Robotics Activities PD was designed to foster STEM teachers' needed competencies to develop and implement robotics-based STEM lessons. It follows the Task-Centered Instructional Strategy [5], which emphasizes complex learning through direct instruction embedded in real-world task progression. Unlike traditional instruction, which often lacks relevance, this approach ensures meaningful experiences that build novice learners' confidence through cognitive-affective positive feedback loops [7]. The program included ten 3-hour sessions (30 hours total) designed around three tasks incorporating technological, pedagogical, and scientific knowledge [8] (see Fig. 1).

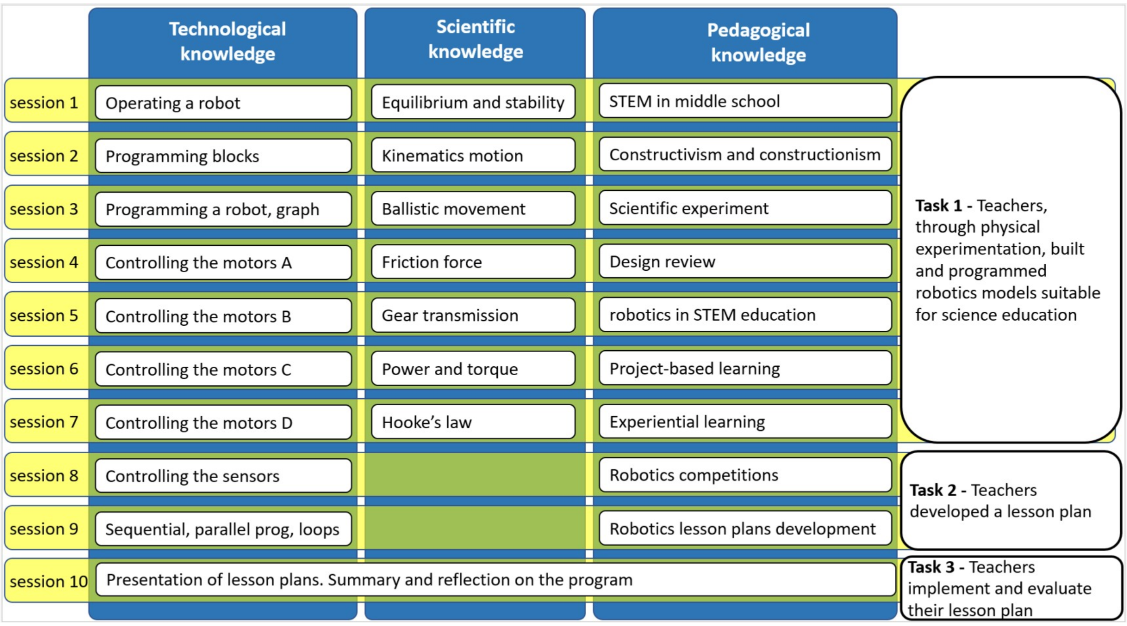

Figure 1: Outline of the Task-Centered PD.

Task 1 focused on teachers' hands-on experience with robots in science contexts, developing skills in building, programming, and troubleshooting educational robots, along with 21st-century skills like collaboration, teamwork, communication, and problem-solving. During the first seven sessions, teacher pairs built and programmed robot models and conducted physics experiments relevant to science instruction (see Fig. 2, 3).

Task 2 focused on developing a robotics-integrated STEM lesson plan, expanding teachers' technological-pedagogical knowledge (e.g., teaching students to build robots), technological-scientific knowledge (e.g., solving math and science problems using robotics), and technological-pedagogical-scientific knowledge (e.g., enriching scientific concepts through robotics). It also addresses 21st-century skills, including creativity, critical thinking, self-regulation, and decision-making.

Task 3 focused on implementing and evaluating the lesson plans. Teachers presented their plans and robotic models, enabling peers to test them as student simulations. Feedback helped refine the lesson plans and offered insights into classroom management. The session concluded with a group discussion summarizing the PD.

Figure 2: Teachers' experience during the PD. A. Tower construction and measurement. B. Robot assembling. C. Robot programming. D. Testing the robot's kinematics. E. Friction analysis.

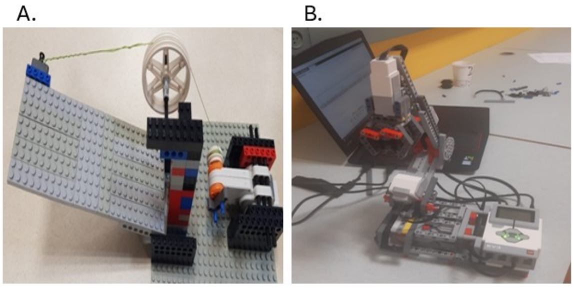

Figure 3: Examples of teachers' projects: A. Drawbridge, B. Potential energy**.**

2.3. Data Analysis

This mixed-method participatory study [9] combined quantitative and qualitative research methods. As the researcher developed and implemented the PD, this study aligns with participatory research principles, addressing a practical problem (in our case, improving STEM education through the integration of robotics) and examining teachers' experiences within that context [10]. Quantitative data analysis involved an initial examination of the normal distribution of data and homogeneity assumptions alongside a Cronbach's Alpha reliability assessment. Quantitative data were analyzed thematically [11] by two independent researchers to identify emergent themes.

2.4. Research Tools

We utilized three questionnaires, which included closed and open-ended questions, administered before and at the end of the PD. The questionnaires were adapted for robotics education by refining phrasing for STEM teachers and adding items on robotics-related competencies and attitudes. Experts in STEM and robotics validated these modifications.

2.4.1. Competencies Self-Efficacy Toward Robotics Activities Rating Questionnaire

To assess the program's impact on teachers' competencies in integrating robotics activities into STEM education, teachers rated their perceived competency of 22-item on a 5-point Likert scale from 1="very low level" to 5="very high level", which included three categories (TK, TPK, and TPACK) [12]. Cronbach's alpha test indicated high reliability; technological knowledge (TK) category α=0.80 (e.g., "Basic ability to build an educational robot"), technological pedagogical knowledge (TPK) category α=0.89 (e.g., "Know how to teach the programming aspects of robotics."), and technological pedagogical content knowledge (TPACK) category α=0.92 (e.g., "Ability to design appropriate robotics activities for STEM education."). The questionnaire also included an open-ended question: "How do you currently feel about your competencies to facilitate student learning with the robotics kits?".

2.4.2. Anxiety in Performing Robotics Activities Questionnaire

This questionnaire, adapted from Malik et al. [13], included six items to assess teachers' anxiety in performing different aspects of robotics activities (e.g., "redesign and construct a new robot"). Responses were ranked on a 5-point Likert scale from 1="very low level" to 5="very high level". A Cronbach's alpha test indicated high reliability (α=0.93). Furthermore, the questionnaire included an open-ended question: "How anxious do robotics tasks make you?".

2.4.3. Attitude Toward Integrating Robotics Activities into STEM Education Questionnaire

This questionnaire contains 11 items based on [14] (e.g., "integrating robotics into STEM education should be mandatory") and addresses teachers' attitudes toward using robotics in STEM education. Responses were ranked on a 5-point Likert scale from 1="strongly disagree" to 5="strongly agree". A Cronbach's alpha test indicated high Results (α=0.91).

3. Results

At the beginning of the program, teachers were hesitant to disassemble robot models or modify code without supervisor approval, strictly following instructions. As the program progressed, they became more independent and creative, confidently experimenting, making changes, and testing new scenarios without guidance. Next, we present the influence we found on self-efficacy, anxiety, and attitudes.

3.1. The Influence of the Task-Centered PD on Teachers' Self-Efficacy Toward Robotics Activities

Before and after the program, teachers reported their self-efficacy toward robotics activities on a scale of 1="very low level" to 5="very high level" (see Table 1). Teachers' TPK self-efficacy significantly increased $t(16)=2.13$, $p<.05$. Likewise, teachers' TPACK self-efficacy significantly increased $t(16)=2.13$, $p<.05$. Although teachers' TK self-efficacy improved, the difference was only marginally significant, $t(16)=2.13$, $p=0.071$. After the program, we also asked the teachers: "Do you need additional training to teach new robotics topics in your STEM classes?". Teachers reported that they would be interested in such training. Specifically, teachers were interested in more scientific activities (e.g., "*I need to be* exposed to *additional scientific activities in robotics*") and in a community of practice (e.g., "*If I want to receive advice, I will have someone to turn to*").

3.2. The Influence of the Task-Centered PD on Teachers' Anxiety Levels in Performing Robotics Activities

Before and after the program, teachers rated their anxiety when performing robotics tasks on a scale from 1="very low" to 5="very high". We found that anxiety levels significantly decreased by the end of the program, $t(16)=2.13$, $p<.05$ (see Table 1). Furthermore, teachers' responses to the open-ended question "How anxious do robotics tasks make you?" revealed several insights. Some teachers reported becoming more open to independently developing models after the program (e.g., *"Before, I only allowed my students to build robots with ready-made building instructions. Today, I encourage students to be creative and implement their ideas"*). Three teachers reported very low anxiety about robotics tasks both before and after the program (e.g., *"I'm curious and not anxious by challenges..."*). Interestingly, some teachers reported increased anxiety after the program, as they became aware of the complex interdisciplinary nature of integrating robotics into STEM education (e.g., *"I feel stressed when I can't support students with programming or building ideas in real-time"*).

3.3. The Influence of the Task-Centered PD on Teachers' Attitudes Toward Integrating Robotics into STEM Education

Before and after the program, teachers reported their attitudes toward using robotics on a scale of 1="strongly disagree" to 5="strongly agree". Although teachers' attitudes improved, the difference was only marginally significant, $t(16)=2.13$, $p=0.07$. Overall, teachers' attitudes remained high, slightly increasing from $M=4.01$, $SD=1.12$ to $M=4.54$, $SD=0.52$ (see Table 1).

Table 1

Self-efficacy, anxiety, and attitudes scores pre- and post the PD

		Pre		Post		P-value
		M	SD	M	SD	
Self-efficacy	Total TK self-efficacy score	2.85	1.50	3.35	1.02	0.071
	Total TPK self-efficacy score	2.16	1.24	3.85	0.85	0.005
	Total TPACK self-efficacy score	2.17	1.18	4.02	0.84	0.001
Overall anxiety level		3.13	1.56	1.83	1.01	0.012
Total attitudes toward robotics in STEM education		4.01	1.12	4.54	0.52	0.070

4. Discussion

This study examined the potential of a Task-Centered PD for integrating robotics into STEM education. Findings show an increase in STEM teachers' self-efficacy in hardware, software, and pedagogical robotics activities, regardless of prior programming experience. These findings align with Bandura's social cognitive theory [15], which links perceived personal control in facilitating behavioral change. As teachers experienced success with robotics tasks, their self-efficacy increased [15]. The study demonstrates how the Task-Centered Instructional Strategy [5] may be used to develop self-efficacy in coding and robotics competencies in STEM teachers. This strategy, combining direct instruction with progressively complex tasks, may support novice teachers in developing robotics competencies, consistent with Merrill's framework and Rosenberg-Kima et al. [7], who showed that such structured approaches can enhance self-efficacy. In our study, teachers also reported reduced anxiety, which may increase their self-efficacy, confidence, and willingness to integrate robotics activities into teaching, as also supported by Bandura's view that low anxiety enhances the adoption of technological innovation [15]. While self-efficacy and anxiety showed significant changes, the improvement in attitude towards the integration of robotics activities was not statistically significant. One possible explanation is that many participants may have already held positive attitudes toward robotics before the program, limiting measurable change. Interestingly, some teachers, following their participation in the PD, recognized that robotics environments may be more complex and offer more features and potential than they had initially anticipated. This realization is consistent with Khanlari [14], who found that despite recognizing the educational value of robotics, teachers face challenges such as limited technical support and low confidence in their skills, that hinder effective classroom integration. Further research could explore these realizations and their implications for teaching and learning.

Future studies should address this study's limitations, including the absence of a control group, small sample size, and lack of actual competence measurement. Although most participants had no robotics experience, their STEM backgrounds may have supported their development of robotics-related competencies.

In conclusion, this research suggests an approach to prepare STEM teachers with no robotics background to incorporate robotics into their lessons. We believe this approach can be implemented to support teachers' use of educational robotics across different domains.

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Declaration on Generative AI

During the preparation of this work, the authors used Grammarly and aqauillabaot in order to: Grammar and spelling check. After using these tools, the authors reviewed and edited the content as needed and takes full responsibility for the publication's content.

References

[1] J. Addido, A. C. Borowczak, and G. B. Walwema, "Teaching Newtonian physics with LEGO EV3 robots: An integrated STEM approach," *EURASIA J Math Sci Tech Ed*, vol. 19, no. 6, p. em2280, Jun. 2023, doi: 10.29333/ejmste/13232.

[2] D. Cuperman and I. M. Verner, "Fostering analogical reasoning through creating robotic models of biological systems," *Journal of Science Education and Technology*, vol. 28, pp. 90–103, 2019.

[3] T. Anisimova, F. Sabirova, and O. Shatunova, "Formation of design and research competencies in future teachers in the framework of STEAM education," *International Journal of Emerging Technologies in Learning (iJET)*, vol. 15, no. 2, pp. 204–217, 2020.

[4] H. S. You, S. M. Chacko, and V. Kapila, "Examining the Effectiveness of a Professional Development Program: Integration of Educational Robotics into Science and Mathematics Curricula," *Journal of Science Education and Technology*, pp. 1–15, 2021.

[5] M. D. Merrill, "A task-centered instructional strategy," *Journal of research on Technology in Education*, vol. 40, no. 1, pp. 5–22, 2007.

[6] M. Rollins, *Beginning Lego Mindstorms Ev3*. Apress, 2014. Accessed: Apr. 17, 2025. [Online]. Available: https://books.google.com/books?hl=iw&lr=&id=oenaAgAAQBAJ&oi=fnd&pg=PR18&dq=Rollins,+M.+(2014).+Beginning+Lego+Mindstorms+Ev3.+Apress.&ots=bcKMgPAFv7&sig=KvsFxSmosMFO7E1rSnFPAeEbgDs

[7] R. B. Rosenberg-Kima, M. D. Merrill, A. L. Baylor, and T. E. Johnson, "Explicit instruction in the context of whole-tasks: the effectiveness of the task-centered instructional strategy in computer science education," *Education Tech Research Dev*, Jul. 2022, doi: 10.1007/s11423-022-10143-7.

[8] P. Mishra and M. Koehler, "J.(2006). Technological pedagogical content knowledge: A framework for teacher knowledge," *Teachers college record*, vol. 108, no. 6, pp. 1017–1054, 2006.

[9] W. J. Creswell, "Research Design: Qualitative, Quantitative and Mixed Methods," 2003.

[10] M. Bassey, *Case study research in educational settings*. McGraw-Hill Education (UK), 1999.

[11] V. Braun and V. Clarke, "Using thematic analysis in psychology," *Qualitative Research in Psychology*, vol. 3, no. 2, pp. 77–101, Jan. 2006, doi: 10.1191/1478088706qp063oa.

[12] D. Saad, I. Verner, and R. B. Rosenberg-Kima, "Task-Centered Approach to Nurture Science Teachers' Self-Efficacy and Attitudes Toward Applying Robotics," in *INTED2023 Proceedings*, IATED, 2023, pp. 4401–4406. Accessed: Dec. 29, 2023. [Online]. Available: https://library.iated.org/view/SAAD2023TAS

[13] A. Mallik, S. B. Rajguru, and V. Kapila, "Fundamental: Analyzing the Effects of a Robotics Training Workshop on the Self-efficacy of High School Teachers," in *American Society for Engineering Education Annual Conference & Exposition", June*, 2018, pp. 24–27.
[14] A. Khanlari, "Teachers' perceptions of the benefits and the challenges of integrating educational robots into primary/elementary curricula," *European Journal of Engineering Education*, vol. 41, no. 3, pp. 320–330, May 2016, doi: 10.1080/03043797.2015.1056106.
[15] A. Bandura, "Social Cognitive Theory: An Agentic Perspective," *Asian Journal of Social Psychology*, vol. 2, no. 1, pp. 21–41, 1999, doi: https://doi.org/10.1111/1467-839X.00024.