Teaching STEM with Educational Robotics: Competencies and Professional Development (Short Paper)

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הוראת STEM עם רובוטיקה חינוכית: כישורים ופיתוח מקצועי (מאמר קצר)

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Abstract

This study identifies the competencies essential for integrating robotics activities into STEM education, focusing on Technological, Pedagogical, and Content Knowledge as well as 21st-century skills. Additionally, it introduces a professional development program for middle school teachers aimed at fostering these competencies. It also investigates teachers' and students' interest and perceived utility of robotics activities and identifies factors influencing robotics integration. A 30-hour Task-Centered professional development included direct instruction in the context of three tasks was design. Results revealed a significant increase in teachers' self-efficacy regarding robotics competencies and a significant decrease in anxiety, with attitudes also improving, though not significantly. This study supports the potential of the Task-Centered program in training teachers with no prior technological knowledge to incorporate robotics activities into their STEM classrooms.

Keywords: Robotics Activities, STEM Education, Professional Development.

Introduction

Educational robotics has proven to be a powerful tool in classrooms, allowing teachers to create interactive and engaging lessons through hands-on, interdisciplinary learning. By linking STEM concepts to real-world applications, robotics encourages active student participation and engagement. Studies show that students who participate in robotics activities gain a deeper understanding of scientific concepts, develop a greater interest in STEM subjects, and develop essential 21st century skills that are critical for future success in STEM subjects (Addido, Borowczak, and Walwema 2023; Cuperman and Verner 2019).

Teachers play a central role in the successful introduction of robotics into the classroom, as their beliefs and attitudes towards technology significantly influence their integration. While some teachers see robotics as a valuable tool for facilitating learning and developing basic skills, others see it as resource-intensive and difficult to implement. These differences in attitudes are not necessarily age- or gender-specific but are often due to perceived skill gaps and practical challenges in integrating robotics into existing classroom practices (Khanlari 2016; Rahman, Krishnan, and Kapila 2017).

Targeted Professional Development (PD) is essential to address these challenges. Such programs should provide teachers with both technical and pedagogical skills, boosting their confidence, increasing self-efficacy, and reducing anxiety about integrating robotics. This can lead to more effective and sustainable use of robotics in STEM education.

This study investigates the competencies required for teaching robotics in STEM education and assesses how a Task-Centered (Merrill 2007) PD, which emphasizes complex learning through direct instruction within the framework of real-world task progression, influences teachers' abilities and attitudes.

Methodology

Participants

Five Israeli male experts and five experienced teachers (one female, four males) were interviewed in 2021 about the competencies needed to teach robotics. Additionally, 55 teachers (22 females, 33 males), with 35 (~64%) having prior robotics experience, completed a questionnaire on competencies for teaching STEM with robotics.

Next, sixteen Israeli Arab middle school teachers (mean age = 39, SD = 6.5; 10 females, 6 males, average seniority = 15 years, SD = 6.5) participated in a 30-hour PD during 2021 - 2022. Six taught computer science and mathematics, while ten taught science. Eleven (~69%) had no prior robotics experience.

The participants signed a consent form approved by the Institutional Ethical Committee.

Research Tools

The study employed a mixed-methods participatory approach (Creswell 2003), combining quantitative and qualitative research methods:

Interviews. Semi-structured interviews were conducted with experts and experienced teachers to validate the competencies needed to teach robotics.

Questionnaires. Teachers completed pre- and post-program questionnaires that measured self-efficacy (Saad, Verner, and Rosenberg-Kima 2023), anxiety levels (Mallik, Rajguru, and Kapila 2018), and attitudes toward robotics integration (Franklin 2016; Khanlari 2016; Musić et al. 2020; Saad et al. 2023).

A Task-Centered PD

A Task-Centered PD "STEM Education with Robotics Activities" was designed to foster STEM teachers' needed competencies to develop and implement robotics activities in their classrooms. The program consisted of ten 3-hour sessions (30 hours total) and followed the Task-Centered Instructional Strategy (Merrill 2007). The program included three tasks, all of which involved technological, pedagogical, and scientific knowledge (Mishra and Koehler 2006; You, Chacko, and Kapila 2021) (see Figure 1):

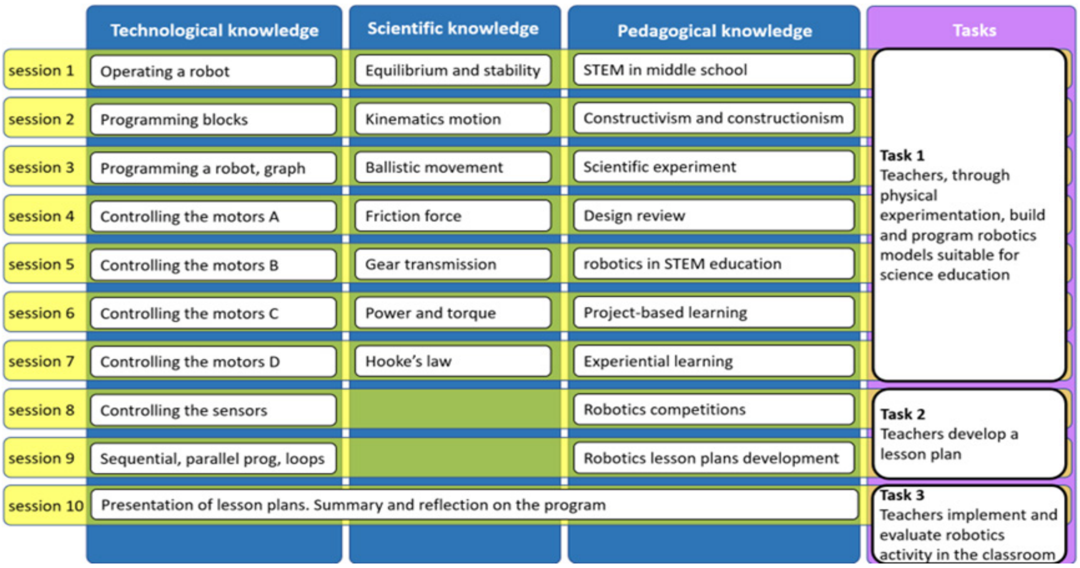

Figure 1. Outline of the program.

Findings

This study provided insights into the competencies necessary for robotics integration in STEM education and the impact of the Task-Centered PD on teachers' self-efficacy, anxiety, and attitudes.

Competencies for Robotics Integration

The first phase of this study identified 23 key competencies required for integrating robotics into STEM education. These competencies were derived from a literature review, expert validation, and teacher questionnaires. Factor analysis revealed three core competency areas: (1) 21st-century skills, (2) scientific-technological content knowledge, which includes both technological-pedagogical content knowledge and technological content knowledge, and (3) non-scientific technological knowledge, which encompasses both technological-pedagogical knowledge and technological-pedagogical content knowledge (see Table 1).

Table 1. Factor Analysis results for competencies for integrating robotics into STEM lessons questionnaire (N=55)

		Factors			Ratings	
	Competencies	**TK & TPK**	**21st skills**	**TCK & TPACK**	**M**	**SD**
1	Basic ability to solve faults in robot operation (TK)	0.79			4.00	1.09
2	Basic ability to program an educational robot (TK)	0.76			3.96	1.15
3	Ability to teach students to build a robot (TPK)	0.75			3.89	1.18
4	Ability to guide students to a robotics project (TPK)	0.72			4.04	1.12
5	Ability to teach students to program a robot (TPK)	0.70			3.96	1.23
6	Basic ability to build an educational robot (TK)	0.67			4.07	1.05
7	Ability and motivation to learn to operate educational robots (TK)	0.67			4.16	0.96
8	Ability to use robotics activities in class to increase educational motivation (TPK)	0.62			4.35	0.82
9	Ability to develop and manage educational environments to experiment with robotics (TPK)	0.63			4.00	0.96
10	Ability to improve study results in robotics classes based on evaluation of previous experience (TPK)	0.61			4.09	0.95
11	Ability to cooperate (21st-century skill)		0.82		4.27	0.95
12	Ability to solve problems (21st-century skill)		0.82		4.44	0.94
13	Teamwork ability (21st-century skill)		0.79		4.25	1.00
14	Creativity (21st-century skill)		0.77		4.33	0.94
15	Ability to think critically (21st-century skill)		0.74		4.20	0.95
16	Self-regulated ability (21st-century skill)		0.74		4.35	1.04
17	Communication ability (21st-century skill)		0.73		4.07	1.05
18	Ability to make decisions (21st-century skill)		0.71		4.25	1.02
19	Ability to plan and perform an experiment with a robot to expand the scientific content (TPACK)			0.70	4.07	0.92
20	Ability to direct robotics activities in class to develop higher order thinking skills (TPACK)			0.67	4.15	1.03
21	Ability to enrich an explanation of a scientific concept to deepen its understanding and illustrate it using a robot (TPACK)			0.65	4.11	0.99
22	Ability to define an applied problem in robotics and solve it based on mathematical and scientific methods (TCK)			0.60	3.60	1.13
23	Ability to model natural phenomena with the help of a robotic system (TCK)			0.60	3.80	1.01
F1	**The overall perceived necessity of TK &TPK**				**4.05**	**1.05**
F2	**The overall perceived necessity of 21st-century skills**				**4.27**	**0.98**
F3	**The overall perceived necessity of TCK &TPACK**				**3.95**	**1.01**

Impact of the PD Program

Before and after the program, teachers reported their self-efficacy, anxiety, and attitudes toward using robotics (see Table 2).

Teachers rated their perceived TK, TPK, and TPACK self-efficacy toward robotics activities on a scale of 1= "very low level" to 5= "very high level". Teachers' TPK self-efficacy significantly increased. Likewise, teachers' TPACK self-efficacy significantly increased. Although teachers' TK self-efficacy improved, the difference was only marginally significant. There was a significant increase in both TPK and TPACK self-efficacy, while the improvement in TK self-efficacy was marginally significant.

Teachers rated their anxiety levels when performing robotics tasks on a scale from 1= "very low" to 5= "very high". By the end of the program, anxiety levels significantly decreased. Nevertheless, while most of the teachers became more confident in encouraging student creativity, a few reported increased anxieties due to the interdisciplinary complexity of robotics integration.

Teachers reported their attitudes toward using robotics on a scale of 1= "strongly disagree" to 5= "strongly agree". Teachers' attitudes toward using robotics remained positive throughout the program, with a slight but marginally significant improvement by the end**.**

Table 2. 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

Conclusions

This study identified 23 essential competencies for teaching STEM in middle school using robotics, categorized into three factors: (1) 21st-century skills, (2) scientific-technological content knowledge (including both the TPACK and TCK), and (3) non-scientific technological knowledge (including both TPK and TPACK). Interestingly, in an exploratory factor analysis the distinction between scientific (TCK & TPACK) and non-scientific knowledge (TK & TPK) was more influential than the distinction between pedagogical (TPACK & TPK) and non-pedagogical knowledge (TCK & TK). This suggests that teachers' understanding of content knowledge plays a distinct role in their ability to integrate robotics into STEM education.

Next, we implemented a Task-Centered PD, which included three tasks involving TPACK aspects and 21st-century skills. Findings show that this strategy positively impacts STEM teachers' ability to engage in robotics activities, even without prior programming experience. The study demonstrates how this strategy supports the development of robotics competencies in STEM teachers. Moreover, findings indicated that this approach reduced teachers' anxiety and improved self-efficacy regarding robotics, aligning with Bandura's Social Cognitive Theory (1999), by emphasizing personal control in behavioral change.

Future studies should address this study's limitations, including comparing a control group, using a larger sample, and assessing actual competence gains.

In conclusion, this research identifies essential competencies for the integration of robotics in classrooms and suggests an approach to prepare STEM teachers to incorporate robots into their lessons. We believe this approach can be implemented to support teachers' use of educational robotics across different domains.

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