Robot-Supported STEM Learning in Primary School: A Self-Determination Perspective

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Abstract

The integration of science, technology, engineering, and mathematics (STEM) into primary education is increasingly important. Robots can make abstract STEM concepts more tangible through hands-on trials. However, limited research has examined the impact of robot-supported STEM (R-STEM) learning on primary students in Cantonese-speaking contexts. To address this gap, this study employs a quasi-experimental classroom design to investigate the effects of R-STEM learning on primary students' learning participation and perceptions. The findings indicate that the experimental group shows a statistically significant improvement in motivation and engagement, whereas the control group shows a decline over time. The R-STEM group also reports positive perceptions of the workshop, particularly in task motivation, programming knowledge and skills, and awareness of empathy and ethical concerns.

CCS Concepts

• **Applied computing** → **Computer-assisted instruction**; • **Social and professional topics** → **K-12 education**; • **Human-centered computing** → *Empirical studies in HCI*.

Keywords

STEM Learning, Robot, Engagement, Programming, Cantonese

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1 Introduction

Robotics have emerged as an interdisciplinary pedagogical approach for teaching science, technology, engineering, and mathematics (STEM) concepts through hands-on learning [4]. By providing embodied and interactive learning experiences, social robots can support the development of targeted knowledge and skills toward STEM [3]. Prior work in human-agent interaction (HAI) suggests that robots can support participation, dialogue, and multimodal engagement learning experiences in an educational context [13]. In addition, recent research on human-like robots and computational thinking has shown that robot-based learning can help students understand programming and problem-solving processes through embodied interaction and collaborative tasks [24].

In addition to acquiring technical knowledge, robot-supported STEM (R-STEM) can shape learners' attitudes toward learning [22]. From a self-determination theory (SDT) perspective, such experiences may enhance competence by making programming logic understandable, autonomy by allowing students to control and test robot actions, and relatedness by embedding these tasks in collaborative group work [6]. Student engagement can be understood as multidimensional: behavioural engagement (BE) refers to students' active participation in interacting with the robot [18]; cognitive engagement (CE) involves questioning, predicting outcomes, solving problems, and reflecting on what happens when the robot executes a command as expected [17]; emotional engagement (EE) includes feelings, such as confidence, enjoyment and perseverance when facing challenges [23]. Students may experience a sense of autonomy when deciding how to solve a task [15]. They may also perceive competence when they successfully deploy and debug their programs, thereby developing a sense of mastery over the task [25]. Moreover, students may perceive relatedness through collaboration with peers during programming activities [9]. Although previous works have reported positive effects of robotics in school settings [26], there remains a need for classroom studies that compare robot-supported learning with conventional instruction in Cantonese-speaking contexts, particularly in relation to SDT and learners' perceptions. This study aimed to investigate (1) to what extent learning with human-like robots in a STEM workshop can change students' learning engagement and (2) how students perceive the R-STEM experience in multiple dimensions.

2 Method

Study design. The study employed a quasi-experimental pre-/post-test design for two groups. They completed the same pre-SDT questionnaire prior to the intervention. The control group received teacher-led instruction, while the experimental group received R-STEM instruction. The experimental group participated in a 90-min workshop, with 20 min of learning basic programming functions, 20 min of interacting with robots, 35 min of programming with robots, and 15 min of questionnaires. After the intervention, the control group completed the post-SDT questionnaire. The experiment group completed the post-SDT and STEM questionnaires.

Self-determination theory. The control and experiment groups completed the pre-/post-SDT questionnaire. This study adopted a validated questionnaire from a previous study conducted in the

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same region [8]. The pre-questionnaire comprised four SDT variables [6]: behavioural (I try my best to do well), emotional (I find much enjoyment), cognitive engagement (I understand what I am learning and why), and motivation (I feel very happy). The control group completed the same SDT-based questionnaire, whereas the experimental group completed an extended version that included three additional need-satisfaction variables [5].

STEM-related questionnaire. The experimental group completed another STEM-related questionnaire that covered seven domains: (1) task motivation [7], (2) knowledge and skills [19], (3) knowledge construction and expression [12], (4) creative problem solving [1], (5) programming knowledge and skills [14], (6) empathy and ethical concerns [21], and (7) community inclusion [20].

Measurement. Each variable was measured using a five-point Likert scale, with responses ranging from 1 (totally disagree) to 5 (totally agree). Each questionnaire item was assigned equal weight. The control group completed a 12-item SDT questionnaire in both the pre- and post-test. The experimental group completed a 12-item SDT questionnaire in the pre-test, a 21-item SDT questionnaire in the post-test, and a 34-item STEM-related questionnaire.

Regulation. This study obtained informed consent from guardians and students prior to the experiment. The experimental protocol was also approved by the University's Institutional Review Board (IRB). The inclusion criteria for participants were: enrolled in Grade 3; able to understand Traditional Chinese (Cantonese); and no medical, cognitive, or physical disabilities that could affect their interaction with robots or their programming ability.

Participants. Both groups were from the same school, grade level and taught by the same teacher. To ensure a fair comparison, school teachers organised two groups. The **control group** consisted of 22 students (M=8.85, SD=.42) with 13 females and 9 males. They participated in conventional instruction led by the teacher without interaction with the robot. This condition served as the baseline instructional comparison and reflected regular classroom practice. The **experiment group** comprised 23 students (M=8.86, SD=.41) with 13 females and 10 males. They participated in a R-STEM workshop using human-like robots.

Teaching and learning workshop. Students were randomly assigned to groups of four. Students learned fundamental computational skills, such as starting, simultaneous execution, and control of limbs with angles. Second, they experienced the functions and interacted with the robot. Third, students programmed by themselves through an online portal, "Code lab" and configured it into the robot. The intervention integrated robotics and multimedia interaction, allowing students to immediately deploy programmed behaviours with visible results.

3 Data analysis

RQ1: To what extent does robot-supported STEM learning impact primary students' learning motivation and engagement? We conducted a single-factor ANOVA on questionnaire data for both groups and examined correlations for each variable in the experimental group. **Control group.** BE decreased by 6.11% (Pre: M=79.39, SD=19.29; Post: M=74.55, SD=16.79; p>.05; f=.79). EE decreased by 10.71 % (Pre: M=76.36, SD=24.75; Post: M=68.18, SD=23.81; p>.05; f=.27). CE decreased by 1.28% (Pre: M=71.21, SD=21.71; Post: M=70.30, SD=21.15; p>.05; f=.02). Motivation decreased by 14.96% (Pre: M=76.97, SD=23.16; Post: M=65.45, SD=20.74; p>.05; f=3.02). **Experimental group.** BE demonstrated statistically significant improvement by 13.79% (Pre: M=75.65, SD=17.25; Post: M=86.09, SD=14.34; p<.05; f=4.98). EEt exhibited statistically significant improvement by 27.08% (Pre: M=69.57, SD=24.19; Post: M=88.41, SD=14.80; p<.01; f=10.15). CE showed statistically significant improvement by 21.86% (Pre: M=71.59, SD=21.58; Post: M=87.25, SD=15.03; p<.01; f=8.15). Motivation manifested statistically significant improvement by 30.30% (Pre: M=66.96, SD=21.51; Post: M=87.25, SD=14.20; p<.001; f=14.26).

Correlation analysis indicated positive associations among all variables in the experimental group. The strongest three relationships were found in relatedness - competence (r=.91, p<.01), BE - autonomy (r=.86, p<.01), and EE - CE (r=.85, p<.01), while the weakest was in Motivation - competence (r=.20), Motivation - relatedness (r=.31), and Motivation - autonomy (r=.32).

RQ2: How do students perceive the robot-supported STEM learning in a socio-ethical perspective? All factors showed strong to very strong positive relationships (r>.7, p< .01). Community inclusion recorded the highest mean score (M=88.04, σ=14.36), followed by empathy and ethical concerns (M=86.96, σ=13.71). The strongest correlation was observed between task motivation and knowledge construction and expression (r=.95, p<.01), followed by empathy and ethical concerns with community inclusion (r=.95, p<.01). The results suggested that students' motivation and knowledge-building, ethical awareness, and sense of inclusion were closely interconnected in the R-STEM learning.

4 Discussion

Need satisfaction The strong correlation results suggested that students in the R-STEM workshop experienced a sense of capability [11]. This pattern is consistent with SDT, suggesting that basic psychological need satisfaction can support more internalized forms of motivation [16]. In the workshop, students used an accessible interface on the portal to program robot limbs and wheel-based movement, and then instantly tested and revised these behaviours through simulation. The immediate-feedback design can strengthen students' sense of competence by helping them connect abstract programming instructions with observable robot behaviour [2].

Motivation and Socio-Ethics Two socio-ethical relationships were strong. Students were more likely to perceive themselves as able to explain and express what they learned. This condition supports constructivist views that motivation underpins active knowledge construction in R-STEM. Students not only drag and drop the coding blocks (abstract), but also visualise their ideas in real-time (concrete). This process likely strengthens the connection between motivation and knowledge construction [10].

5 Conclusion

This study examined the implementation of R-STEM learning in a primary school Cantonese-speaking context. The results indicated that students who participated in R-STEM instruction showed a high level of engagement and motivation. But this work is limited by its sample size, target group, and educational scope. Future studies will investigate this approach with broader populations.

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