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Can Educational Robots Improve Student Creativity: A Meta-analysis based on 48 Experimental and Quasi-experimental Studies

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Cultivating innovative talents has become a critical strategy for building China into a strong country in science and technology. Catering to the trend of educational reform in the intelligent era, the use of robotics in developing student creativity proves to be of greater practical value. The findings of this study are that: first, the overall effect of educational robotics on student creativity reaches above-moderate level; second, educational robotics has more significant effects on creativity of primary and junior secondary students; third, in terms of subjects, robotics courses can most effectively promote student creativity; fourth, among various teaching topics, prototype creation has the most substantial impact on student creativity; fifth, in terms of instruction methods, inquiry-driven teaching can best stimulate student creativity; sixth, compared with ordinary classrooms, the laboratory environment is more favorable for the development of student creativity. The paper also offers recommendations for popularizing robotics curriculum at different education levels.

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This paper uses meta-analysis to code and analyze experimental research on robotics education in China and other countries and combines field research to investigate the effect of robotics education on student creativity, aiming to provide useful references for the implementation of robotics curriculum in schools. In this study, three teaching methods are discussed to utilize educational robots to develop student creativity: the robotics-based inquiry-driven method; the robot design-based teaching method; the robotic application project-based teaching method.

Research Design

Methods and Instruments

The present study uses meta-analysis to examine the sample data in existing research to systematically evaluate the results of numerous studies by quantitative synthesis. Samples and parameters such as the mean values and standard deviations of the experimental and control groups are extracted from the experimental studies to calculate standardized mean differences (SMD) which are treated as effect sizes. Hedges' g value is one of the estimated values of SMD, a computation result combining the SMD with the mixed variance of the control group and the experimental group. Compared with Cohen's d and Glass' values, it is more suitable for the meta-analysis of effect sizes based on relatively small sample sizes and limited number of studies. Hence, Hedges's g value is used as the final effect size to demonstrate the effect of robotics education on student creativity.

Data Selection and Coding

The present study searched Chinese and foreign literature databases for journal articles, dissertations, academic conference papers, etc. to acquire as many samples as possible. A total of 852 pieces of literature addressing the relationship between educational robots and student creativity and published between 2001 and 2020 were obtained. All of them adopt randomized experimental or quasi-experimental methods and encompass experimental and control groups, sample sizes in statistical results, means, standard deviations, experimental periods, and other data. The following criteria were used to decide whether to include the study in the analysis: i) applying robotics in educational and teaching activities, including the cases wherein the experimental group employs robots in teaching while the control group adopts conventional teaching methods; ii) treating student creativity as the dependent variable in both the experimental and the control group; iii) providing sufficient data for the computation of the average effect size (the data resulting from the experimental and control group analysis must include sample sizes, means, standard deviations, etc.). After several rounds of screening, 48 papers were selected, and 6,057 samples extracted for this meta-analysis. The included literature covers all the education levels ranging from kindergarten to university; subjects such as mathematics, geography, science, and robotics; teaching programs like prototype creation, engineering production, scientific inquiry, and result verification; teaching methods including inquiry-driven, design-based, and project-based instruction; teaching locations including experiment rooms and classrooms. This paper classifies student creativity into three categories: A-creative thinking (critical thinking, logical thinking, divergent thinking, imagination, spatial thinking ability, etc.), B-practical innovation ability (practical operation, problem solving, engineering, scientific inquiry, etc.), and C-creative personality and psychology (personality traits, perseverance, teamwork, interest in learning, etc.)

Results

The Test of Overall Effect

The test results demonstrate that Hedges' s g-values of both the fixed effects model and the random effects model are greater than 0, and the P-value in the two-tailed test is less than 0.001, indicating that robotics education has a significant positive impact on student creativity. Compared with fixed-effects models, random-effects models are more useful in addressing the measurement discrepancy between various study results and the overall effect size. According to the theory of SMD statistics, when $0.51 \leqslant \text{SMD} \leqslant 1$, it is considered an effect size of above-moderate level. Thus, the analysis results of summary effect size (SMD = 0.576) in this study demonstrate that robotics education exerts an above-moderate positive impact on student creativity.

The Test of Effects on Different Categories of Student Creativity

Robotics education has significant effects on student creativity in different categories and in various combinations of these categories. Specifically, student practical innovation ability (B category) is most significantly enhanced (SMD = 0.453, $P < 0.001$) by robotics education, followed by student creative thinking (A category) (SMD = 0.386, $P < 0.001$), while student creative personality and psychology (C category) is moderately improved (SMD = 0.283, $P < 0.001$, $0.21 \leq \text{SMD} \leq 0.50$). In terms of student creativity in different category combinations, the configuration of A and B categories is most substantially and positively affected by educational robotics (SMD = 0.757, $P < 0.001$), indicating that the robotics curriculum significantly bolsters student creative thinking and practical innovation ability.

Tests of Various Mediating Effects

i. Robotics education engenders differential effects on student creativity at different education levels. Due to the limited sample size of kindergartens and universities, the comparison is focused on the different effects on the creativity of primary, junior secondary, and senior secondary students. The creativity of junior secondary students is most significantly boosted by robotics education (SMD = 0.607, $P < 0.001$), followed by that of primary students (SMD = 0.435, $P < 0.001$), but it has no significant effect on the creativity of senior secondary students.

ii. There are subject differences in the effects of robotics curriculum on student creativity. In the robotics course, the boosting effect on student creativity is the most remarkable, reaching the above-moderate level (SMD= 0.606, P< 0.001), followed by the mathematics course (SMD = 0.466, P < 0.001). The sample sizes of geography and science courses are too small to represent significant effect.

iii. Mediating effects diverge among various teaching programs in robotics curriculum, while all of them can significantly promote student creativity. Programs such as hands-on creation, experimental verification, process participation are exceptionally effective in enhancing student innovation ability.

iv. In terms of the mediation of different teaching methods, the influence of inquiry-driven teaching on student creativity is extremely significant (SMD = 0.927, P < 0.001), followed by that of design-based teaching (SMD = 0.598, P < 0.001) and project-based teaching (SMD = 0.529, P < 0.001), which implies that robotics curriculum can maximize its effect on the cultivation of student creativity through project exploration, high student participation, hands-on learning and other methods.

v. Robotics education at various teaching locations can all contribute to the development of student creativity. In the ordinary classroom, robotics teaching yields a significant effect on the advancement of student creativity (SMD = 0.485, P < 0.001). In the laboratory environment, the creation of learning situations and interaction with educational robots significantly improve the effect of robotics education on student creativity (SMD = 0.578, P < 0.001), highlighting the relevance of strengthening laboratory environment construction.

Conclusions and Discussion

Popularizing the Robotics Education Curriculum

The positive effect of robotics curriculum on student creativity reflects the substantial benefits of intelligent education for student creativity development. Therefore, it is of vital importance to incorporate the education of intelligent robots into the school curriculum to improve students' literacy in programming control, human-computer interaction, algorithm programs, neural networks, and intelligent ethics.

Emphasizing the Cultivation of Student Creativity at Basic Education Levels

It is recommended to invest more in promoting student creativity by robotics education at the primary and secondary stages. The secondary school level is particularly critical to the comprehensive development of student innovation ability.

Constructing a Robot Maker Teaching Model Suitable for Student Innovation Capability

The effects of various teaching programs and methods on student creativity in robotics education suggest that teaching modes that assist in prototype creation and inquiry-driven learning is most beneficial to enhancing student creativity.

Strengthening the Construction of the Laboratory's Tangible and Soft Conditions

Tangible conditions cover the following facilities that enable students to experience robotic learning: equipment for conception, such as multimedia devices, drawing tools, and electronic whiteboards; designing equipment, including modeling software, robot making software, online robot simulation platform, etc.; operation facilities, such as LEGO robots, Arduino robots, and assembly welding equipment; presentation facilities, providing students with display platforms to test the performance of their robots. Soft conditions involve teaching program making, case demonstration, information resources, cognitive tools, dialogue and collaboration instruments, and social network support. The effective integration of tangible and soft conditions creates an environment facilitating robotic experimental teaching and promoting student innovation thinking, hands-on creation, and teamwork skills.

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