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When Life Science Meets Educational Robotics: A Study of Students' Problem Solving Process in a Primary School

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ABSTRACT: Previous studies on the topic of "Problem solving" indicate it's one of the skills of students in the 21st century that educational robots can effectively support. Additionally, there are gender differences in the problem-solving process. Understanding the problem-solving process and using knowledge to solve problems is key to improving one's problem-solving ability. We therefore conducted a study with 69 fifth graders aimed at exploring whether educational robots can help students improve their understanding of problem-solving process in the context of life sciences. The Intervention was carried out as five learning modules on "Human systems," and each module corresponded to different stages of engineering design practice. Our data analysis investigated the changes of problem-solving process with two independent variables: different genders and robot learning basis. The results showed educational robots can help students more effectively comprehend life science knowledge and understand the problem-solving process. By contrast, there are differences in the problem-solving process between females and males, and the robot learning basis can help students better articulate the problem-solving process. Although this study provided empirical evidence that educational robots can enhance the learning and problem solving skills for primary school children, future studies need to further explore the differences in problem-solving process from multiple perspectives to improve teaching and curriculum design practices.

Keywords: Problems-solving process, Educational robots, Primary school, Life sciences, Engineering design

1. Introduction

In a general sense, problem-solving can be regarded as a kind of mechanical, systematic yet complex skillset to acquire. For instance, solving math problems, which usually have one correct answer, involves a straightforward, logical procedure. However, in daily life, the problems we experience are usually ill-structured and complex, which leads to students' inability to solve problems outside the classroom (Yu et al., 2015). NGSS (2013) proposed that K-12 students should have the opportunity to practice design methods through real experience, and apply scientific knowledge to real world problem-solving. Therefore, more and more research has begun to focus on improving students' ability to solve ill-structured problems through engineering design activities, among which the educational robot is considered to be an effective teaching tool (Jung & Won, 2018; Spolaôr & Benitti, 2017) applied to the design of these projects.

Previous studies have shown that combining engineering design with educational robots can improve students' scientific, mathematical and engineering performance (Bethke Wendell & Rogers, 2013) and develop students' problem-solving skills (Li et al., 2016). However, most research has focused on the combination of simple machines and educational robots and little attention is paid to the changes in students' problem-solving process. Starkweather (1997) argued that cognitive understanding must be included in the curriculum, teaching, and evaluation development of technical and engineering education. It is also more valuable to explore the changes in the problem-solving process of students when dealing with ill-structured problems. The purpose of this study is to develop robot courses based on life science content through the combination of robot education and engineering design. We aim to help students to learn to use engineering design methods to solve practical problems and improve their understanding of the problem-solving process, Based on the above framework of thinking, this study proposes the following research questions:

- Can students learn life science knowledge effectively and improve their understanding of the problem-solving process with robot-based engineering design tasks?
- Are there any differences in problem-solving processes of students in different genders?
- Are there any differences in problem-solving processes of students with different learning basis of robots?

2. Problem-solving process

In the study of Grubbs et al. (2018), design process models for identifying problem-solving strategies were divided into three categories: (1) General engineering design process model (GEDP) (for example, Yu et al. (2015) focused on students' cognitive activities and compared their problem-solving process with the theoretical design process); (2) Professor engineering design process (PEDP), which aims to develop students' design ability to become experts by comparing the cognitive processes of students in different courses (Mentzer et al., 2015; Sung & Kelley, 2019); (3) Cognitive science, such as the study of Wells et al. (2016), directly focuses on the reasoning process of participants. Among the three models, process factor is one of the most critical elements to consider, which is also the key to improving students' problem-solving ability by helping them understand each step involved in a solution and then connect it with real-life situations.

When exploring the problem-solving process of students, however, it was notable that many studies had used the Concurrent think-aloud (CTA) method (Kelley & Sung, 2017; Strimel, 2014; Wells et al., 2016). While this approach can accurately capture the students' short-term thinking process, the extraction of long-term memory status is still a difficulty (Lloyd et al., 1995). Meanwhile, according to Ericsson and Simon (1984), the CTA approach requires students to: (1) Describe design-related thought processes, and (2) Make use of the prior knowledge acquired in the course. As a result, young children are unable to effectively engage in the Think aloud (Think-aloud) approach, which is one of the limitations of the CTA (Van Someren et al., 1994). Some scholars believed that students can achieve short-term and long-term cognition by expressing their ideas in a graphical representation (Ullman et al., 1990), therefore this research adopts the form of chart to allow students to express the problem solving process and analyze it in the sequential pattern.

3. Method

3.1. Participants and procedure

The participants were 69 fifth graders (aged 10-11 years old) recruited from two separate classes of a primary school located in Shanghai, including 36 boys (52.2%) and 33 girls (47.8%). The experiment took place during regular school hours, meaning all participants were taught in two separate classrooms with a similar gender distribution. To ensure the consistency of teaching, the two classes were taught by one of the researchers with identical weekly learning goals as well as curriculum content. Meanwhile, in order to further observe how primary school children implemented their problem-solving strategies, all participants in both classes were randomly assigned to 12 cell groups with two to three students in each group (Figure 1).

Figure 1. Curriculum instruction

Considering the cognitive development of fifth graders, we chose the theme of helping autistic children design robot friends. The course was divided into 5 modules (Table 1). Each module corresponded to different content of life science about human systems and body's sensory. Students were required to participate in didactical activities according to the process of engineering design. The course lasted for 4 consecutive weeks and was 90 minutes in length each week.

Table 1. Course content

Module	Engineering design	Time	Students' challenge
1. I have a robot friend	(1) Identify need or problem	90min	1. Understand the knowledge of autism, help children to establish a healthy psychological concept; 2. Understand the engineering design process; 3. Learning about the composition of human systems and the hierarchy of human structures; 4. Define problems and set goals.
2. Three days to see	(2) Research need or problem (3) Develop possible solution (4) Select the best possible solution	90min	5. Understand the working principle of the ultrasonic sensor; 6. Learning about the body's sensory organs and ways to protect them (eyes, ears, brain); 7. learning to use ultrasonic sensors; 8. Learn the method of sketch design, brainstorm, design the solution, and select the best solution.
3. My emotions	(5) Construct a prototype (6) Test and evaluate the solution (7) Communicate the solution	90min	9. Understand how touch sensors work; 10. Learning how the body feels; Learn simple programming; 11. Build the model according to the solution, test and evaluate; 12. Communication in the group.
4. I need to upgrade	(8) Redesign	45min	13. Improve sketch plan and model design
5. Make more friends	(9) Completion	45min	14. Group communication display, the introduction of works; 15. the completion of robot friends.

3.2. Design

A single group (n = 69) of pre-and post-test quasi-experimental study was adopted in this study. We first compared the participant's overall mastery of subject knowledge through paper-based drawings and written tests before and after the instructional intervention. Later, investigations on each participant's perceived problem-solving process were conducted to analyze the perceived number of steps and paths regarding problem-solving task. To further clarify the effect of intervention on one's problem-solving process, we included "gender" and "robot learning basis" as two independent variables. Robot learning basis referred to whether participants had previous learning experiences with robotics and a questionnaire was designed to identify any differences in robotic knowledge. Aside from quantitative analysis, semi-structured interviews were carried out to supplement the experimental findings.

3.3. Data collection

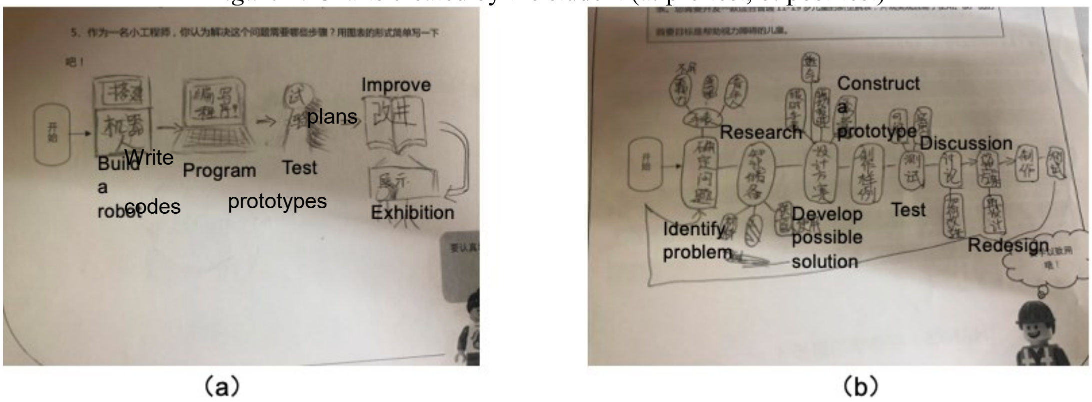
This study mainly collected three forms of data to compare and evaluate the teaching effect and students' cognition of the problem-solving process.

(1) Chart To understand the problem-solving process, participants were required to draw a chart of the problem-solving process as an engineer based on an assigned, specific problem situation before and after the course. In Figure 2, for instance, students outlined their problem-solving process as a straightforward, four-step framework in the pre-test while a more contemplated and sophisticated process is outlined in the post-test.

(2) Subject paper To evaluate the teaching effect of the course, the researchers developed the subject paper, which was composed of background information, life science questions and engineering questions. The background information was to investigate the participant's demographics and robotics learning basis (i.e., whether the student has taken a robotics course prior to the study). The questions were in the form of multiple-choice questions and fill-in-the-blank questions. Life science content accounts for 80% and engineering content accounts for 20%. There are some changes in the sequence of questions and options in the pre-and post-test, but the difficulty and content of the test remained the same. All participants were given ample time to fill in the questions before and after the course.

(3) Interview outline To further analyze the teaching effect of the course, 12 students from the two classes were randomly selected to conduct semi-structured interviews after the course.

Figure 2. Charts created by the student (a: pre-test, b: post-test)



3.4. Data coding and analysis

The engineering design model proposed by Hynes et al. (2011) is used as the coding scheme in this study to encode the charts drawn by students and identify their problem-solving process. The coding scheme divides the problem solving process into 9 steps, including: (1) Identify need or problem, (2) Research need or problem, (3) Develop possible solution, (4) Select the best possible solution, (5) Construct a prototype, (6) Test and evaluate the solution, (7) Communicate the solution, (8) Redesign, and (9) Completion. We used P1-- P9 to represent the different engineering design steps. To ensure the reliability of coding, charts of 30 students are randomly selected by another researcher for coding (Kappa = .816), showing high consistency. In this study, GSEQ5.1 software is used for sequence analysis of coded data, which is developed by Bakeman and Quera (2015).

Sequence analysis can help researchers effectively identify problem-solving patterns of students (Jung & Won, 2018). In sequence analysis, “Given” represents the current event and “Target” represents the target event, namely the second of two consecutive events. The degree of correlation between the current event and the target event is expressed by adjusted Z-score. Bakeman and Gottman (1997) proposed the formula for adjusted Z-score:

$$\text{Adjusted residual (Z-score)}=\frac{x_{rc}-e_{rc}}{\sqrt{e_{rc}\left(1-\frac{f(c)}{N}\right)\left(1-\frac{f(r)}{N}\right)}}\quad\text{(Bakeman \& Gottman, 1997)}$$

Where X_{re} represents the frequency of the two observed events, e_{rc} represents the expected frequency, f (c) is the total number of events in column c, f (r) is the total number of events in column r, and N is the total number of events. According to the formula, the larger X_{re} is, the larger the Z-score is, indicating a stronger correlation between the two behaviors. For the data collected from the questionnaire, SPSS 21 is used for descriptive statistics in this study.

4. Result

4.1. Academic results and cognition of the problem-solving process

4.1.1. Academic results

Paired *t*-test was adopted in this research to explore students’ mastery of subject knowledge before and after the implementation of the course (Table 2). The results showed that there was a significant difference in the subject scores of students ($p < .01$), meaning the post-test scores of students significantly improved as compared with the pre-test scores.

Table 2. Pre-and Post-test of academic results

	N	*M*	*SD*	*t*	Sig. (2-tailed)
Pre-test	69	8.64	1.697	-8.015	.000**
Post-test	69	11.30	2.103		

Note. $^{**}p < .01$.

4.1.2. Cognition of problem-solving process

The number of steps in the problem-solving process of students was shown in Figure 3. In the pre-test, students' problem-solving steps mainly focused on 3 to 4 steps while only a few students can write the complete steps. In the post-test, students can generate more steps, mainly focusing on 6 steps. And the number of students who wrote 8 steps also increased. At the same time, this study paired the students' problem-solving steps pre- and post-test with the *t*-test (Table 3), and the results showed that a significant difference in the number of problem-solving steps before and after the implementation of the curriculum ($p < .01$).

Figure 3. Problem-solving steps of students

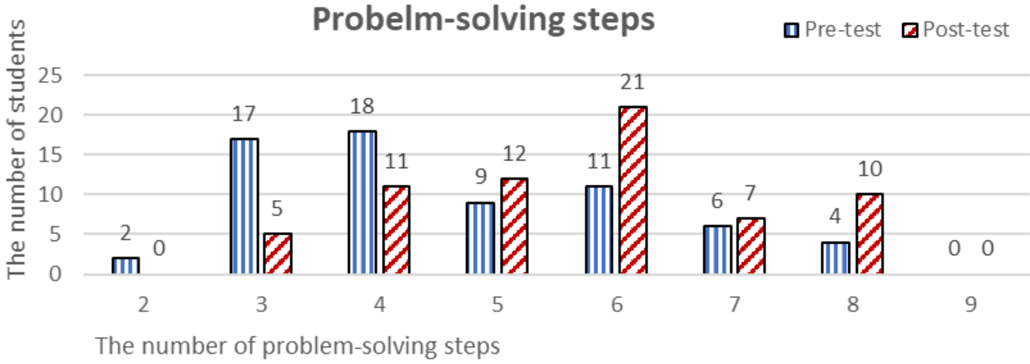


Table 3. Pre-test and Post-test of problem-solving steps

	M	*N*	*SD*	*t*	Sig. (2-tailed)
Pre-test	4.64	67	1.595	-4.097	.000**
Post-test	5.59	66	1.478		

Note. $^{**}p < .01$.

To further explore the changes in students' cognition of problem-solving process before and after the curriculum, the initial steps of students' problem-solving process during pre-test and post-test were counted in this study (Table 4). The results indicated that students took a step from P1 (Identify need or problem), P2 (Research need or problem), P3 (Develop possible solution), and P5 (Construct a prototype) as the first step of problem-solving in both pre-test and post-test. In the pre-test, 37% of the students believed that the first step of problem-solving is to "construct a prototype," while only 28% of the students believed that **the first step** of problem-solving is to "Identify need or problem." In the post-test, the proportion of students taking "Identify need or problem" as the starting step was significantly increased (58%), while the proportion of students taking "construct a prototype" as the starting step was significantly reduced (only 1%).

Table 4. The starting step of the problem-solving process

	Pre-test		Post-test	
	N	%	*N*	%
P1	19	28%	38	58%
P2	9	14%	11	17%
P3	14	21%	16	24%
P5	25	37%	1	1%
Total	67	100%	66	100%

To explore the changes of the problem-solving path of most students before and after the curriculum, in this study, the problem-solving process codes of 37% of the students in the pre-test and 58% of the students in the post-test who started with the "Construct a prototype" and "Identify need or problem" were respectively input into GSEQ5.1 to calculate and generate adjusted Z-scores.

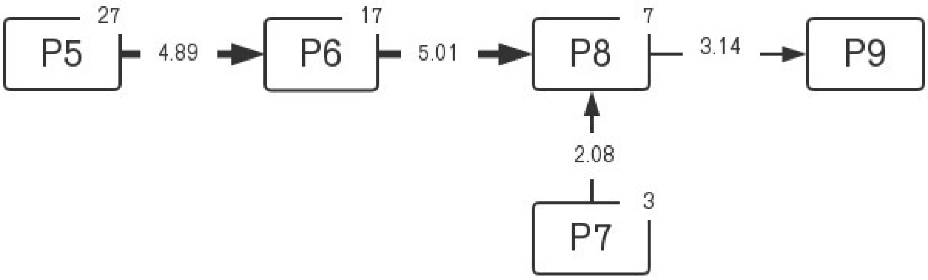
Table 5 is the adjusted Z-score residual table of students' problem-solving process in the pre-test, and Z-score >1.96, meaning there was a significant correlation between their engineering design behaviors. As shown in Table 5, in the pre-test, the steps with significant correlation in students' problem-solving include the following conditions: P5-P6, P6-P8, P7-P8, P8-P9. According to the adjusted Z-score residuals table, most students in this study generated the problem-solving path diagram exhibited by Fig. 4, before the implementation of the course. The nodes in the figure represent different user behaviors. The number in the upper left corner of the node represents the number of people from the current behavior to the target behavior. The connection between behaviors was significant. The arrow represented the direction of the behavior transition. The thickness of the line indicated the degree of correlation of the behavioral connection, while the data on the line was the adjusted Z-score. As shown in Figure 4, in the pre-test, most students chose to start with the "Construct a prototype," focusing on the construction and testing of the model, and make improvements through group discussions to finally complete the design work.

Table 5. Adjusted Z-score residual table for pre-test

	Target								
Given	P1	P2	P3	P4	P5	P6	P7	P8	P9
P1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P2	0.00	-0.20	0.00	0.00	0.82	0.64	-0.35	-0.76	-0.62
P3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P5	0.00	1.48	0.00	0.00	0.00	**4.89****	1.77	-3.50	-3.80
P6	0.00	-0.93	0.00	0.00	-0.97	-4.38	-0.72	**5.01****	1.71
P7	0.00	-0.31	0.00	0.00	-0.26	-1.49	-0.56	**2.08****	0.27
P8	0.00	-0.62	0.00	0.00	1.07	-0.60	-1.09	-2.40	**3.14****
P9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Note. $^{**}p < .01$.

Figure 4. Most students' problem-solving process (Pre-test)



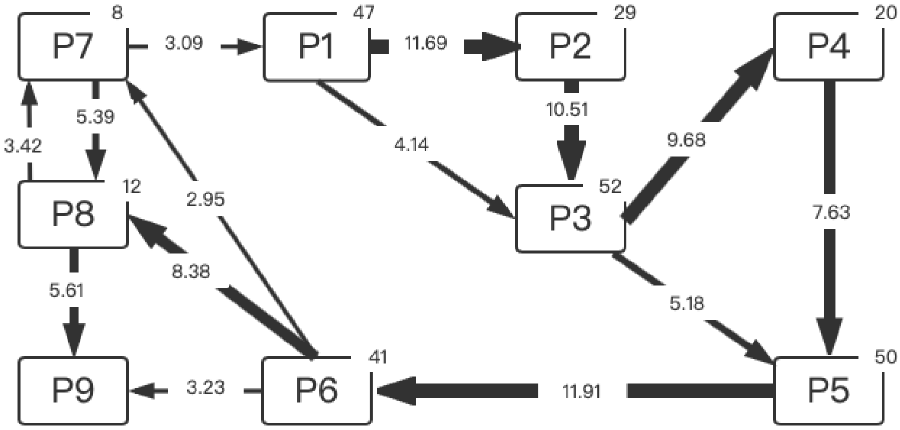
Similarly, Table 6 is the adjusted Z-score residuals table for the problem-solving process of most students in the post-test. As shown in Table 6, in the post-test, the steps with significant correlation in students' problem-solving include the following conditions: P1-P2, P1-P3, P2-P4, P3-P4, P3-P5, P4-P5, P5-p6, P6-P1, P6-P7, P6-P8, P6-P9, P7-P1, P7-P8, P8-P7, P8-P9. According to the adjusted Z-score, most students in this study generated the problem-solving path chart exhibited by Fig. 5, after the course. As shown in Figure 5, in the post-test, the problem-solving process of students started from "Identify need or problem." As shown by the strength of the correlation of students' behaviors, students usually carried out "Research need or problem," "Develop possible solution," "Select the best possible solution," "Construct a prototype," "Test and evaluate the solution" according to the logical order. After the test was completed, most students thought that improvement should be carried out directly according to the test results. Some students also thought that they should discuss and rethink the applicability of problems and requirements, and then continue to iterate between improvement and discussion until the problems are solved.

Table 6. Adjusted Z-score residual table for post-test

Given	Target								
	P1	P2	P3	P4	P5	P6	P7	P8	P9
P1	0.00	11.69**	4.14**	-2.15	-3.52	-3.88	-1.42	-2.69	-1.87
P2	-1.14	0.00	10.51**	-1.70	-2.63	-3.06	-1.12	-2.12	-1.48
P3	-1.68	-2.93	0.00	9.68**	5.18**	-4.50	-0.88	-3.12	-2.17
P4	-0.97	-1.70	-2.50	0.00	7.63**	-1.07	-0.96	-1.81	-1.26
P5	-1.71	-2.99	-4.40	-2.55	0.00	11.91**	-1.69	-2.32	-1.04
P6	3.59**	-2.46	-3.95	-2.49	-3.84	0.00	2.95**	8.38**	3.23**
P7	3.09**	-1.02	-1.49	-0.87	-1.57	-0.74	0.00	5.39**	-0.75
P8	0.05	-0.47	-1.17	-1.55	-0.87	-1.33	3.42**	0.00	5.61**
P9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Note. $^{**}p < .01$.

Figure 5. Most students' problem-solving process (Post-test)



4.2. Problem-solving process of students in different genders

To answer this question, the number of problem-solving steps of boys and girls in pre-and post-test is paired to a *t*-test. As shown in Table 7, there was a significant difference in the number of problem-solving steps for boys before and after the course ($p < .01$), while there is no significant difference found for girls. However, on the whole, the number of problem-solving steps before and after the implementation of the curriculum was higher for girls than that for boys. In the pre-test, there is a huge difference in the number of problem-solving steps between girls and boys. After the course, however, the number difference of problem-solving steps between the two genders was relatively smaller in the post-test.

Figure 6. Problem-solving process of students in different genders (a: female, b: male)

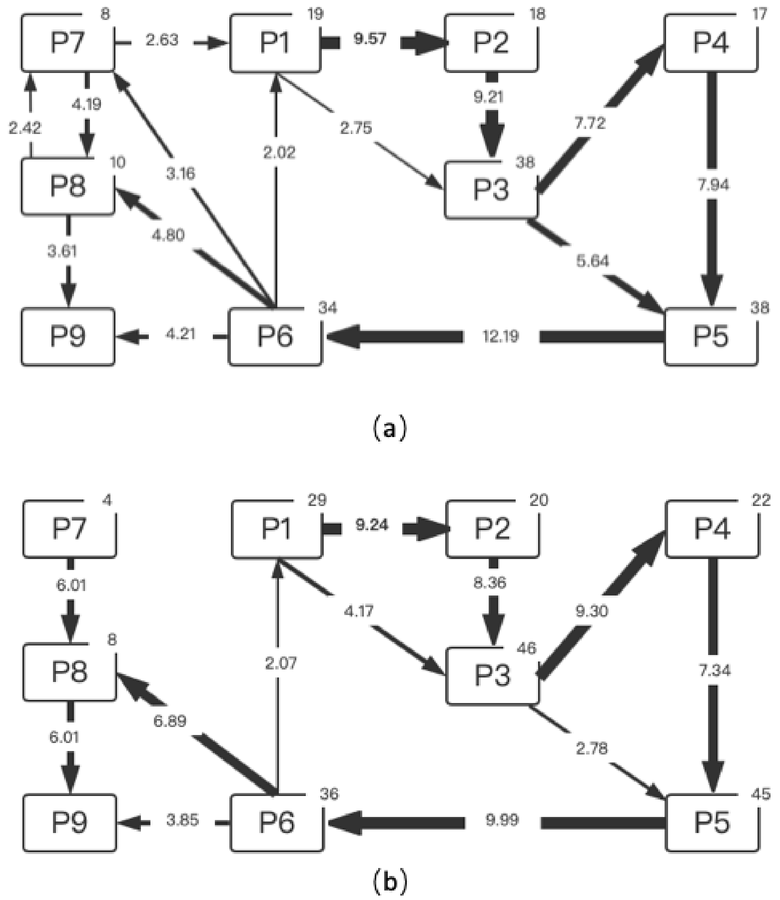


Table 7. Problem-solving steps of students in different genders

		M	*N*	*SD*	*t*	Sig. (2-tailed)
Male	Pre-test	4.17	35	1.272	-4.460	.000**
	Post-test	5.51	35	1.442		
Female	Pre-test	5.16	31	1.772	-1.476	.150
	Post-test	5.68	31	1.536		

Note. $^{**}p < .01$.

In this study, the number of problem-solving steps of boys and girls was carried out with an independent sample *t*-test to explore whether gender is the key factor affecting problem-solving. The results of Levene's variance test showed that (Sig = .719), the variance was homogeneous, and there was no significant difference in the number of problem-solving steps between the two genders (Sig = .658), indicating that gender was not statistically significant in affecting the number of steps they took in problem-solving process. Additionally, we have compared the problem-solving process of boys and girls in this study. As shown in Figure 6 (a) and (b), boys and girls show a strong correlation between the first 6 steps of problem-solving (P1-P2, P2-P3, P4-P5, P5-P6) after taking part in the course. The difference was that compared with boys, girls still have a strong correlation between P3 (Develop possible solution) and P5 (Construct a prototype). Some girls did not distinguish very well between P4 (Select the best possible solution) and P3. For the last three stages of problem-solving (P7, P8, P9), boys and girls produced different results. Girls were more aware of the importance of P7 (Communicate the solution) and thought about the applicability of solutions than boys. P7-P1, P8-P7, and P6-P7 were correlated to some extent.

4.3. Problem-solving steps of students with different robot learning basis

This study takes whether students have the robot learning basis as an independent variable to explore the influences of different experiences on the understanding of the problem-solving process. In this study, the number of problem-solving steps of students who have the robotics learning basis and students who do not have the robotics learning basis are paired with a *t*-test. As shown in Table 8, there was a significant difference in the number of problem-solving steps for students who have learned robotics courses before and after the implementation of the course ($p < .01$), while there was no significant difference in the number of problem-solving steps for students who don't have robotics learning basis. On the whole, regardless of previous learning experiences, the number of problem-solving steps among students was very close in the pre-test. After the intervention, however, the number of problem-solving steps for the students with robotics learning basis was higher than that for the students without robotics learning basis.

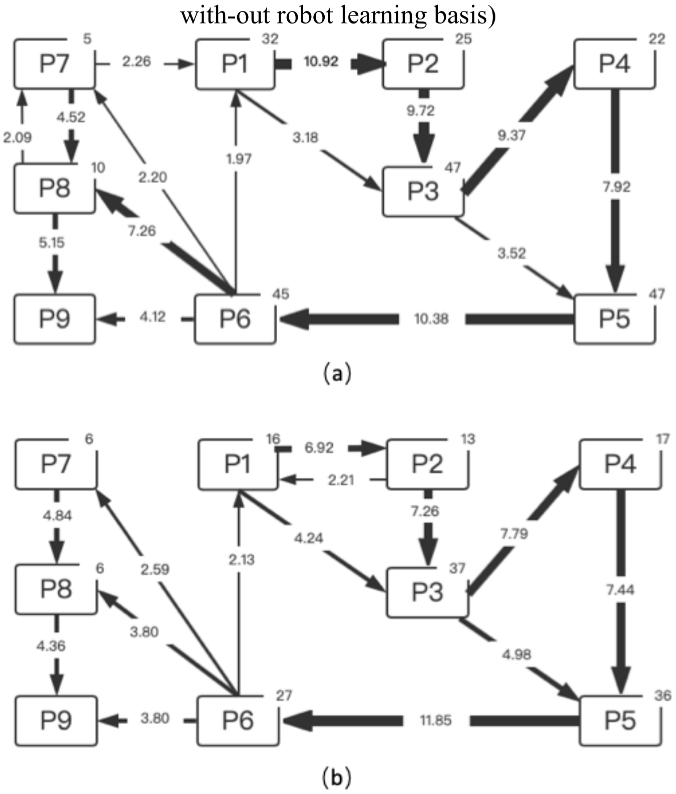
Table 8. Problem-solving steps of students in different robot learning basis

		M	*N*	*SD*	*t*	Sig. (2-tailed)
Without robot learning basis	Pre-test	4.68	28	1.786	-1.565	.129
	Post-test	5.36	28	1.660		
With robotics learning basis	Pre-test	4.66	38	1.419	-3.698	.001**
	Post-test	5.76	38	1.324		

Note. $^{**}p < .01$.

An independent sample *t*-test was also conducted on the number of problem-solving steps between students with and without robotics learning basis. The results of the Levene's variance test (Sig = .102) showed homogeneity of variance. There was no significant difference in the number of problem-solving steps between different robotics learning basis (Sig = .273). Therefore, whether students have robot learning experiences does not statistically significantly in affect the number of steps they took in problem-solving process. When analyzing the actual problem-solving process, as shown in Figure 7 (a) and (b), students under both experience conditions have a strong correlation between the first six steps of problem-solving (P1-P2, P2-P3, P3-P4, P4-P5, P5-P6). Moreover, students who had learned robotics courses have a clearer logical relationship with these steps, and the correlation between these steps was higher than those without robotics learning basis. As for the last three stages of problem-solving (P7, P8, and P9), students who had a robotics learning basis pay more attention to the stage of P7 and P1, and there is a certain correlation between P7-P1 and P8-P7.

Figure 7. Problem-solving process of students with different robot learning basis (a: with robot learning basis, b: with-out robot learning basis)



4.4. Interviews

This study conducted semi-structured interviews with students from two aspects of problem-solving and course content. The results were as follows:

4.4.1. Course content

It can be inferred that participants generally think it is difficult to design and build solutions by themselves. Besides this, students think using robots to learn life science knowledge is very interesting. Most of the students said they learned a lot about building and programming robots, as well as about human systems and organs, and some said they learned how to carry out a project to design and solve problems.

Researcher： Do you think the course content is difficult? If so, which parts do you find difficult?

Student： A little bit, the design and construction of our own hands, no drawings, a little hectic. (Student 1). One thing is, it's too hard for me to design my solution and make it workable. (Student 6)

Researcher: Do you think the course content is interesting? What have you learned?
Student: Interesting, I learned how to carry out a project, design, production. (Student 3) Interesting, I know the steps to solve the problem, human organs and robot organs. (Student 1)

4.4.2. Problem-solving process

In terms of problem-solving, most students have a clear process in-mind and can describe the complete steps in their solution plans. Students think that the way to solve problems learned in the course is applicable to other situations in everyday life.

Researcher： Through this course， what steps do you think should be taken to solve the problem?

Student：Identify problems, build knowledge, develop possible solutions, build models, discuss, redesign, and work until you find the best solution. (Student 1). Identify questions, think about what materials you have, interview, produce, test. (Student 4)

Researcher: Do you think the knowledge gained in this training course helps you to solve problems in your everyday life?

Student: There is a certain help when solving math problems, I used to do it directly, now I know that I can first look at the problem type, and then think about which solution to implement, and then choose the best one (Student 6). Yes. Now if I have some problems, I know where to start with. (Student 4)

5. Discussion

5.1. Academic results and cognition of the problem-solving process

5.1.1. Academic results

Statistics of this study show that educational robots can help students learn life science knowledge, and students' test scores have been significantly improved in the post-test. From the interview results, we can see that students are very interested in attending robot design courses, which also improves their motivation for learning courses and classroom participation. Also, this teaching adopts student-centered inquiry and "learning by doing" to help students better understand life sciences content. This is consistent with previous research findings, which show that robotics courses can encourage students to think and discuss, and at the same time, improve students' learning motivation and promote classroom learning (Cukurbasi & Kiyici, 2018) to improve learning efficiency (Bethke Wendell & Rogers, 2013). However, the research found that some students still fail to understand the content of this part in the post-test, resulting in low scores. Additionally, the interview results show that some students might have difficulty memorizing the details of course content, which is the main reason why they failed to score effectively. In terms of course design, some course content is relatively abstract and not closely related to robot tools. Moreover, course content itself is difficult, which leads to students' inability to master course contents.

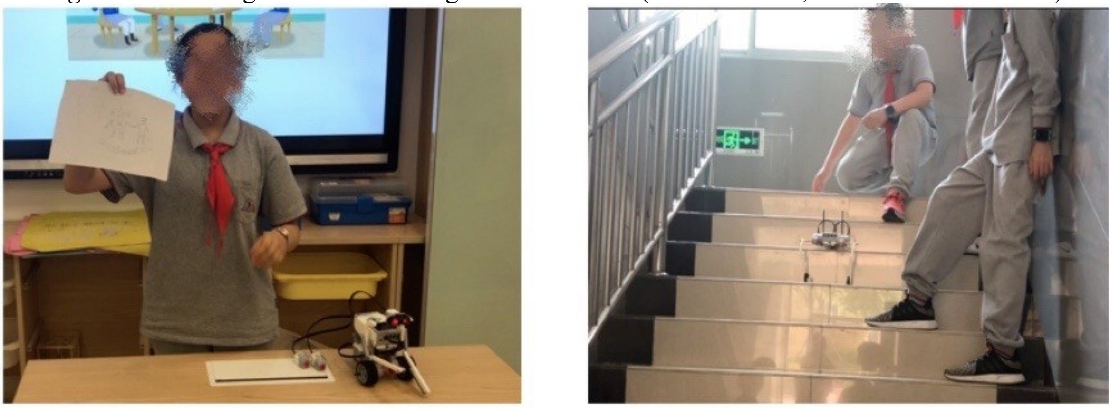
5.1.2. Cognition of problem-solving process

It is evident that students can generate more steps for problem-solving after the course. From the results of specific charts, in the post-test, students' steps of problem-solving become more systematic and logical, and the process of work design is more in line with the process of engineering design. Previous studies have shown that robot education can improve students' problem-solving ability (Ilori & Watchorn, 2016; Li et al., 2016). From the perspective of the change of the problem-solving process, this study proves the improvement of students' problem-solving ability.

Sung and Kelley (2019) believed that sequence analysis can successfully describe the problem-solving process of young learners. According to the results of sequence analysis, in the pre-test, most students start with the construction of the prototype and focus on the design and improvement of the model. However, little attention has been paid to other steps of problem-solving. According to the research of Mentzer et al. (2015), compared with experts, novice problem solvers usually spend less time on problem definition and developing possible solutions. Meanwhile, it is also found that students tend to ignore the test (P6) stage in the design process (Kelley et al., 2015), which is consistent with the results of this study. But after teaching, students' problem-solving process is improved. The process is more logical and systematic in the post-test, and students pay attention to the importance of steps such as P1 (Identify need or problem), P2 (Research the problem) and P3 (Develop possible solution), they begin to design iteratively around problems and requirements. The results of the interview show that most students can understand the process of problem-solving, describe the steps of problem-solving, and use this process as a framework of thinking to solve similar problems encountered.

In this study, robot education is carried out to help students understand the process of problem-solving. However, this study found that in the post-test, there are still some students' problem-solving methods centered on "Develop possible solution" (24%) and "Construct a prototype" (1%). This study compared these students (25%) with the most students (58%). In Figure 8 (a), students designed a "robot friend" equipped with sensors that could interact with autistic children. And in Figure 8 (b) students designed a robot that can descend stairs. The design of the second group is more creative because they are constantly modifying and building the robot. However, they cannot solve problems well, which is also the reason why they ignore "identifying problems and requirements." On the contrary, the design of first group can solve problems better.

Figure 8. The design of different categories of students (a: robot friend, b: descend stairs robot)



(a) (b)

5.2. Differences in problem-solving process among students of different genders

Both boys and girls showed positive results in the problem-solving process after learning the course. Through the comparison of the results of the sequence analysis of the problem-solving process between male and female students, this study finds that there are still some differences in the way boys and girls approach problems. Strimel (2014) found in his study that girls spend more time communicating and designing solutions than boys, and believed that effective communication can enhance the ability to solve problems. That is why girls can write more steps of the problem-solving process than boys in the pre-test. The focus is on the two steps of "Develop possible solution" and "Communicate the solution." This is consistent with the results of this study. In the post-test, girls prefer to improve the design of work through continuous communication and discussion in the process of redesign and test evaluation, while boys pay less attention to the importance and iteration of communication and discussion in test evaluation and redesign. Besides, this study finds that compared with boys, girls pay more attention to the importance of "Identify need or problem" and think about whether the solution or the design of the work meets the needs of the problem. However, this study suggests that too much emphasis on design solutions may lead to girls' unclear distinction between "Develop possible solution" (P3) and "Select the best possible solution" (P4).

5.3. Differences in problem-solving processes of students with different learning basis of robots

The research results show that students of both learning basis categories can achieve positive changes. However, students with the basis of robot learning have made greater progress after intervention, which is manifested in that they can write more problem-solving steps, and their problem-solving process is more logical and systematic. This study found that the basis of robot learning can help students better understand the process of problem-solving and express the steps of problem-solving. This study tries to find valid evidence to support the following viewpoints from relevant studies in terms of knowledge and skills. (1) Students without the basis of robot learning lack prior knowledge related to robots. When students are required to think about how to carry out projects, they are often unable to describe the process (Barak & Zadok, 2009). On the contrary, the more conceptual knowledge students have, the better their project performance will become to effectively solve problems (Fan et al., 2018). (2) Teamwork, communication, and problem-solving are the most common skills of students trained by robots (Spolaôr & Benitti, 2017). The learning experience basis of robots helps students have a good knowledge and skill base, and therefore, helps students better comprehend the problem-solving process.

The results of sequence analysis show that students with the basis of robot learning have a clearer problem-solving process than students without the basis of robot learning, strong correlations are formed between P1-P2, P2-P3, P3-P4, and P4-P5, and attention is paid to the important role of "Communicate the solution" in the process of "Redesign," and the applicability of works or solutions to problems and requirements is considered. Strimel (2014) believed that the problem-solving steps of non-sequent participants were often chaotic and did not plan to solve the problem before constructing the prototype. By comparing the problem-solving paths of students of different categories, this study found that students of the two categories showed different degrees of "non-sequent participants." However, after the course training, the problem-solving processes of students in both categories begin to shift to the direction of "sequential participants" that they can solve problems in a logical order.

6. Conclusion

Based on the life science content and engineering design practice, this study designed a set of robot courses and explored their influence on students' problem-solving process. The study found that "when life science meets robot education," the presence of a tangible robot in teaching can help students learn life science knowledge and understand the process of problem-solving. However, there are some differences in the problem-solving process of different categories of students. For instance, male students tend to ignore communication and thinking about the applicability of solutions, while female students can hardly distinguish between designing solutions and choosing the best one. Ultimately, the foundation of robot learning can help students better understand the process of problem-solving and generate more systematic and logical problem-solving methods. Therefore, how to pay attention to the differences between students of different genders and help students with weak robot learning foundation to improve their understanding of the problem-solving process is the focus of future research, and also the part that should be improved in the robotics course of this study.

It is useful to teach students the basic knowledge of relevant scientific concepts and related concepts of problem-solving (Barak & Zadok, 2009), but it should be done in a flexible method rather than strict teaching. For instance, we found robotics offers children decent opportunities to apply mechanical design and engineering knowledge to further developing their skills in problem-solving. In other words, the learning and reflection of problem-solving practices could be effectively carried out through hands-on design experiences with robots. Future research might expand the scope of curriculum content to other subjects to engage children in developing problem-solving skills through designing and building up a tangible robot.

There are still some limitations in the implementation of this study. Firstly, the duration time of the course might be insufficient, which leads to an insignificant effect on the change of problem-solving process. Secondly, this study does not investigate the results of students' problem-solving from multiple perspectives, such as work analysis, sketch design and thinking, etc. Finally, in this study, the researcher is both teacher and interviewer. The researchers' multiple identities inevitably lead to subjective bias on the results of student interviews and questionnaires that researchers will unconsciously guide students to answer or fill in the blanks in a positive direction. Future research should involve different researchers in teaching and student interviews.

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