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Effectiveness of Remote-Control Cars and Authentic Learning in Strengthening Creative Thinking and Problem-Solving Abilities

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ABSTRACT: Innovation in the design of curricula is widely discussed. Innovative curricula expose students to a diverse range of learning environments and prompt them to ask questions, stimulating their creativity and allowing them to develop a sense of initiative and to hone their problem-solving skills and ability to apply knowledge to practice. The introduction of new technology to the classroom has improved pedagogy and the information literacy of students. Because of these developments, this study expanded the integrative activity curriculum for second-grade elementary school students to an innovative curriculum involving a comprehensive set of activities related to remote-control cars and their use in the community. The students underwent a process of experiential learning in which they became familiar with the operation of remote-control cars. This study divided the students of two second-grade classes into an experimental group and a control group. The experimental group participated in innovative teaching activities as a part of authentic learning courses and were familiarized with the operations of remote-control cars in traffic in the community. The control group participated in innovative teaching activities as a part of the lesson plan for remote-control cars and were familiarized with the operation of the cars in traffic in the community. The creative thinking and problem-solving skills of the students in both groups significantly improved, and the students in the experimental group outperformed those in the control group. The students in both groups indicated that they were satisfied with the curriculum.

Keywords: Authentic learning, Curriculum design, Remote-control cars, Creative thinking, Problem solving

1. Introduction

Several innovative teaching methods have been introduced into schools' curricula, allowing for teachers and students to engage in various innovative learning approaches that strengthen their problem-solving and creative thinking skills (Hinkel, 2006; Williams, 2000). Authentic learning takes place in an environment in which students experience sensations through engaging situational learning (Herrington & Oliver, 2000). Learning in such an environment promotes creative thinking and higher levels of thinking in complex tasks, such as solving problems by analyzing, synthesizing, designing, manipulating, and evaluating information (Bath et al., 2004). This type of learning enables students to explore their own reactions and feelings rather than being constrained to a fixed curriculum (Maina, 2004; Zembylas, 2002). Creative thinking is an essential skill for the 21st century and its cultivation is therefore a primary pedagogical objective (Geisinger, 2016; Lee & Carpenter, 2015; Sternberg & Lubart, 1999). Critical thinking is expressed through words and ideas and applies not only to art and design but also to how we act, think, and relate to our environment (Mayer, 1989; Rhodes, 1987; Sternberg & Lubart, 1999). The most effective method for strengthening students' problem-solving skills is to let them investigate a problem by testing out various learning strategies (Goldschmidt & Smolkov, 2006) and to incorporate problem-solving techniques into educational activities (Seechaliao, 2017; Snyder & Snyder, 2008).

With the rise of cross-disciplinary education and Industry 4.0, from 2010 to 2020 in the United States, the number of mathematics teachers increased by 16%, the number of computer system analysts increased by 22%, the number of software designers increased by 32%, and the number of medical personnel increased by 36. The demand for biomedical engineers in two fields increased by 62%. These professionals must have basic cross-disciplinary skills (Vuong et al., 2019). Therefore, students should be acclimated to integrative technological thinking and logic throughout the learning process to improve their education (Roy et al., 2013). Cross-disciplinary technology education has been implemented in several curricular areas to transform experience into practice, encourage diversity and respect, and allow for students to reflect and expand on their learning experience (Levin & Nevo, 2009).

In authentic learning, students develop new ideas and approaches to solve problems. Brown et al. (2020) and Shadiev and Yang (2020) noted that educational technology, such as social networks, artificial intelligence, virtual robots, and wearable devices, can strengthen creative thinking and problem-solving skills. Authentic learning environments with a wide range of resources can stimulate students' creativity (Maina, 2004; Wu &

Wu, 2020). An authentic learning environment provides students with the space to use their imagination (Donovan et al., 1999) as well as opportunities to strengthen their creativity and problem-solving skills (Herrington & Oliver, 2000). These abilities are generally developed during later stages of education, such as the higher grades in elementary schools, high school, or university (Colbeck et al., 2000; Reinhold, 2006).

Yalçın and Erden (2021) described the effect of cross-disciplinary education activities in the design-thinking model on the creativity and problem-solving skills of preschool children. The use of small groups encouraged communication and interaction, and the children were able to apply what they learned in school to their lives. Çakır et al. (2021) noted that lessons on coding robots affected preschool children's problem-solving and creative thinking skills. Kaplancali and Demirkol (2017) provided programming courses to students aged ≥5 years and integrated mathematics into the curricular activities (Skemp, 1976). These studies demonstrate that many researchers have adopted a grounded approach to programming, allowing preschool and elementary schoolchildren to learn programming and coding through the educational methods in the curriculum and to develop an understanding of engineering technology. Although the aforementioned literature has reported that many courses for first and second graders have involved programming activities, few of them introduced the authentic learning approach. After the students acquire knowledge in class, they rarely have the opportunity to apply it to practice. In this study, a curriculum was designed to combine the activities in the school's curriculum with the opportunity to gain hands-on experience. Self-propelled vehicle assembly and programming activities were incorporated into the curriculum to increase students' engagement in learning and expand their range of knowledge and cognitive processes. Many studies have demonstrated the positive benefits of programming education for children. Otherwise, few studies have explored this in the context of second-grade elementary students or applied authentic curricula. Most studies have focused on programming education and computational thinking and have rarely explored creative thinking and problem solving.

Therefore, this study designed an innovative curriculum by adding lessons on remote-control cars to the integrative activity curriculum for second-grade students and investigated the efficacy of authentic learning in strengthening creative thinking and problem-solving skills. Authentic learning was implemented to provide students with a more experiential form of learning. The instructor for the experimental group followed an authentic curriculum in which students drew maps of their neighborhoods and then drew remote-control cars traveling through the map. The activity enabled the students to understand the concept of community living. In the programming lessons, the remote-control cars from the authentic curriculum were used to introduce the concept of driverless cars. The control group learned through the integration of remote-control cars into curriculum. The students' creative thinking, problem-solving abilities, and satisfaction with the course were then analyzed.

The research questions of this study were as follows:

- How would the students' creative thinking skills be affected in the experimental and control groups?
- How would the students' problem-solving skills be affected in the experimental and control groups?
- How satisfied would the groups be with the course?

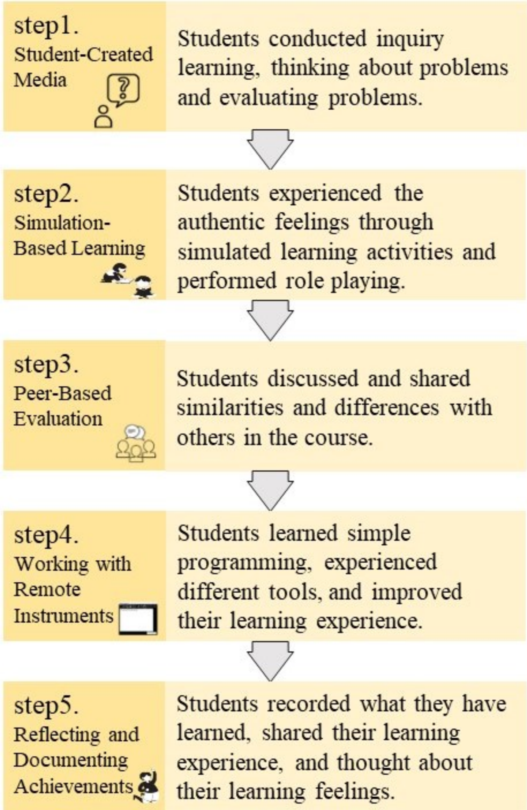
2. Learning design

2.1. Considerations

Johnson et al. (2007) compiled examples of authentic learning in the 21st century. Researchers have identified 10 design elements of authentic learning that educators can apply to any subject area. We used five of these elements in the instructional design process, namely exploratory learning, simulated learning, peer evaluation, working with remote instruments, and reflection and documentation of achievements. Figure 1 presents the instructional model, with a break down of the learning process and framework.

The students engaged in exploratory learning, simulated learning, and peer evaluation. The students shared their experiences with their groups and the class throughout the course. In the first stage, the students participated in inquiry learning, asked questions, and reflected on problems to solve them through discussion with others using the knowledge they had gained. In the second stage, the students participated in simulated learning activities and engaged in role-play activities. Active participation in the course helped "develop valuable communication, collaboration, and leadership skills that help students succeed as professionals in their field of study" (Lombardi, 2008). In the third stage, the students identified similarities and differences. The students also participated in peer evaluation. Because each student has a unique perception of what is being taught, they can gain a deeper understanding of a subject through student–student discussion. In the fourth stage, the students learned simple programming and used various technological tools (Lombardi, 2008). In the fifth stage, the students recorded what they had learned, shared their experiences, and reflected on their feelings during the process. The students also kept a record of their observations. The authentic learning tasks allowed for the students to reflect on how they learned (Blumenfeld et al., 1991; Lombardi, 2007; Newmann et al., 1996).

Figure 1. The steps of learning station rotation model



3. Research design

3.1. Curriculum design

This study explored the second-grade integrative activity curriculum of an elementary school in Taiwan. The integrative activity curriculum is intended to achieve the following: students learn topics related to self-knowledge, life management, social engagement, and environmentalism. The integrative activity curriculum consists of integrative classes on life, languages, health education, and arts and humanities. Students learn to respect life and multiculturalism, use and develop resources, and protect the environment. This experiment was conducted in two modules of the second-grade integrative activity course, namely “A Small Community in a Big World” and “Living Sphere in the Community.” This curriculum consists of lessons on the community, living spheres in the community, and the connections between modes of transportation in that community. Remote-control cars were added to the original curriculum. The innovative curriculum was designed to enable students to familiarize themselves with remote-control cars and programming over the course of their education.

The experimental process was designed to enable the students to connect what they had learned to their daily lives. The experimental group received both modules of the integrative activity curriculum as well as some elements of authentic learning. The students drew a map of their community and then provided feedback. The map was later used for a simulated test drive of the remote-control car to deepen the students’ understanding of the methods and logic of programming as applied to remote-control cars; the intention was that they would learn about how driverless cars detect objects, respond to verbal commands, and follow directions. The difference between the experimental group and the control group was that the students in the experimental group created an authentic link between the lesson and their own community. The concept of driverless cars was then introduced. A detailed description of the difference between the experimental and control groups is provided in Appendix 1.

3.2. Experimental process

3.2.1. Experimental group: Using driverless cars to integrate authentic learning

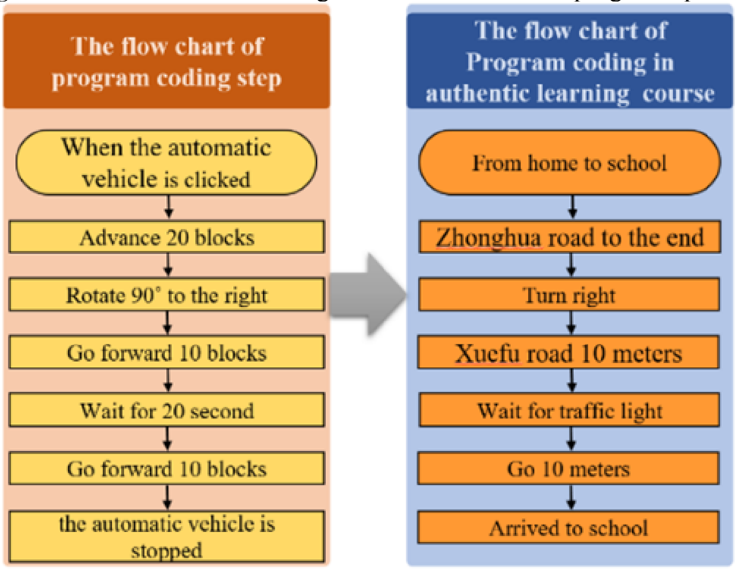
The experimental group completed a pretest for creative thinking and problem solving in the first week. The students were sorted into heterogeneous groups of four on the basis of their final exam scores the previous semester (24 students in six groups) for group discussion and sharing.

In the second week, the students began Modules 1 and 2 of the integrative activity curriculum, namely “A Small Community in a Big World” and “Living Sphere in the Community.” The first module was intended to teach the students to understand their community and its connections other external communities. The second module was intended to teach the students to recognize the transportation tools used in their community; exploratory learning was encouraged through textbook activities. The students were asked to discuss the convenience of community life by exploring its connections with transportation and related problems. Then, the remote-control cars were introduced and integrated into the transportation and life activity.

During simulation learning in the third week, the experimental group engaged in simulation and role play by drawing community maps in authentic lessons. Simulation and role play allowed the students to actively participate in the curriculum games, learn how to operate the remote-control cars, and use examples from real life. Actual dialogues between drivers and passengers were integrated into the learning process. The teacher provided worksheets and textbook-based instruction. The worksheets were related to the lessons and questions from the textbook, and the students discussed and answered the questions together. During the sharing segments, the students were asked to write down their thoughts and feedback and share their feelings with their classmates. The students developed new perspectives by discussing their ideas with their classmates.

Weeks 4 and 5 involved peer evaluation and the remote-control car lesson. During the activities, the students worked with remote-control cars and were taught to operate the programs using standard programming procedures that incorporated real-life scenarios. Examples of these scenarios include “advance 20 blocks and turn left” and “continue to the traffic light, then turn left” (Figure 2). Students were encouraged to discuss problems and their strategies to operate the remote-control cars with each other. These authentic lessons enabled the students to perceive the innovativeness and convenience of driverless cars. The discussions allowed for the students to understand different viewpoints on topics and develop a deeper understanding of them.

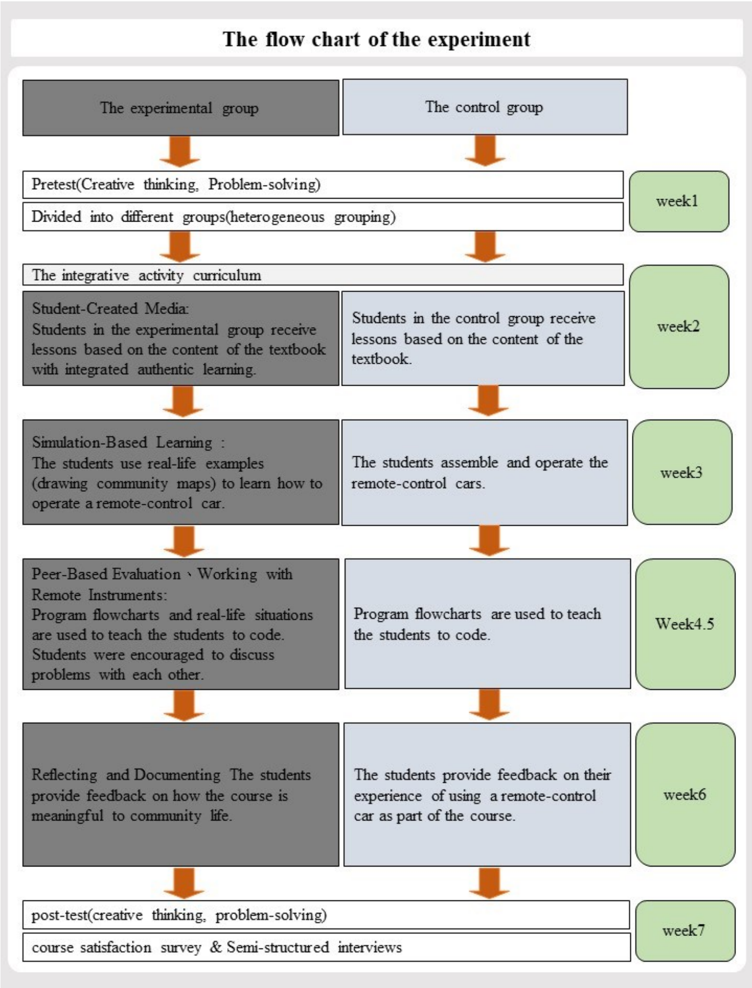
Figure 2. Real-life situation integrated into the standard program operation



In Week 6, the students provided feedback about the course after learning to control the remote-control cars remotely. The experimental group was asked to provide feedback on the lessons on community life, particularly in regards to the points they thought were meaningful and any connections they made. This gave the students an opportunity to reflect on their learning and to discuss their feelings about how the remote-control cars were incorporated into their lessons. The students also showed each other their worksheets and the remote-control cars they designed; this allowed the students to collectively reflect on their learning.

In Week 7, a post-test for creative thinking and problem solving was conducted, and a survey about the students' satisfaction with the course was distributed. The survey involved semi-structured interviews in which the students provided feedback on the community life lessons. Figure 3 presents a flowchart of the procedure, and the content of the semi-structured interviews is detailed in Appendix 2.

Figure 3. Experimental procedure



3.2.2. Control group: Using driverless cars to learn

The control group learned using the same curriculum as did the experimental group during Weeks 1, but the curriculum differed for Weeks 2–6. In Week 2, the control group began following Modules 1 and 2 of the integrative activity curriculum. Then, the remote-control car lessons were introduced.

In Week 3, the students assembled and operated the remote-control cars. The teacher provided textbook instruction and worksheets for the students to complete during class. The worksheets were related to the lessons and questions from the textbook, and the students discussed the answers with each other. During the student sharing segments, students were asked to write down their thoughts and feedback and to share their feelings with their classmates.

In Weeks 4 and 5, the lessons on the coding of the remote-control devices began. The classes in which the students learned how to operate the remote-control cars were taught using standard programming procedures. Students were able to discuss and express problems operating the remote-control cars while learning simple coding. The discussions helped the students to understand different viewpoints on the lesson and develop a deeper understanding of the topic. During the peer evaluation section and the teleoperation task, the students in the control group shared their experience and worked together to solve each other's problems.

In Week 6, the students provided feedback on their experience of using remote-control cars as part of this course. Week 7 was similar for the control and experimental groups, with the students completing a posttest for creative thinking and problem solving; a survey measuring the students' satisfaction with the course was also distributed.

3.3. Participants

Of the 48 participants (7–8 years old), 25 were boys and 23 were girls; the control and experimental groups each had 24 students. The experiment was approved by the school and the parents of the participants. All students who participated in this study were less than 18 years old. Thus, in accordance with ethical procedures, written consent was obtained from their parents, and all students expressed their willingness to participate. Appendix 3 presents the parental consent form.

Figure 4. Students completing the pretest and post-test

Figure 5. Students constructing the remote-control cars and completing the worksheets

Figure 6. Experimental group drawing maps of their neighborhood and sharing their ideas with classmates

The students had not previously participated in a similar course. The experimental group followed the innovative and authentic learning curricula, and the control group followed the innovative curriculum. Figure 4 depicts the students completing the pretest and posttest, and Figure 5 shows the students assembling the remote-control cars and filling out the worksheets. Figure 6 depicts those in the experimental group drawing maps of their neighborhood and working together during the integrative activity.

3.4. Devices used

Figure 7 displays the parts, remote control, and motor of the remote-control car. Figure 8 displays the Arduino Uno board, infrared transmitter, and operational interface of the programs to control the remote-control car. The building block car and its accessories were tools to help the students think logically, hone their creativity, develop motor skills, and cultivate habits of concentration. Once assembled, the block cars could be controlled remotely. To use the remote control, the students were required to use the control mode, which trains logical and mathematical thinking.

Figure 7. DIY Building Block (Remote-control) Car

Figure 8. Arduino Uno board, infrared Linker, and operational interface

4. Data collection and analysis

4.1. Torrance Tests of Creative Thinking

To evaluate creativity in the pretest and post-test, the study used the figural exercises of the Torrance Tests of Creative Thinking (TTCT), which comprises two tests. The pretest and post-test scores were divided into three domains: fluency, flexibility, and originality (Davis & Fichtenholtz, 2019). Fluency represents the ability to propose ideas in response to open-ended, oral, or nonverbal questions; flexibility represents the ability to adopt different methods in response to a problem, to consider different types of ideas, or to look at a situation from different angles; and originality represents statistical rarity or uniqueness and nonconformity. This study utilized Williams' Creativity Assessment Packet, with the creative-thinking activity used to establish criterion-related validity. The parameters were between .574 and .877. The internal correlation of the scores in Type A and Type B were between .597 and .812, all reaching a statistically significant level. Thus, the revised TTCT had favorable reliability and validity.

4.2. Problem-solving ability

Problem-solving ability was assessed through a revised version of a problem-solving test proposed in Bransford et al. (1986). The questions were related to five short stories and covered three domains: solutions, problem reasoning, and problem prevention. The participants answered the questions, and the reviewer analyzed the results for the three domains. The Cronbach's α for the test was 0.823. Solutions assessed participants' thinking ability in relation to proposing diverse and effective problem-solving concepts. Problem reasoning reflected participants' thinking ability from various perspectives in their search for potential reasons for the problem. Problem prevention assessed participants' metacognitive abilities toward absorbing problem-solving experiences and formulating various methods to prevent problem occurrence.

4.3. Course satisfaction

Course satisfaction was measured through the questionnaire proposed by Alperin (1998) and Biner et al. (1997). The questions were scored on a 5-point Likert scale (*strongly agree* to *strongly disagree*). The questionnaire consisted of three parts, namely course content (four questions), self-identification (three questions), and teaching (three questions). The Cronbach's α for the questionnaire was 0.955, indicating considerably high internal consistency; thus, the questionnaire was reliable.

5. Research results

5.1. TTCT

Table 1 presents the two groups' independent-samples t-test scores for the creative thinking skills pretest. In the fluency domain, the mean score of the experimental group was 82.13 (standard deviation [SD] = 7.08), whereas that of the control group was 79.29 (SD = 9.47). The mean flexibility score was 81.17 (SD = 7.09) for the experimental group and 81.00 (SD = 6.91) for the control group. The mean originality score was 82.13 (SD = 7.81) for the experimental group and 81.33 (SD = 7.01) for the control group. The mean total score was 81.81 (SD = 6.83) for the experimental group and 80.50 (SD = 7.53) for the control group. For each item, $p > .05$ indicated no difference in creative thinking between the groups and that, therefore, the groups were homogenous.

Table 1. Independent samples t-test results for creative thinking pretest

Item	Group	Numbers	M	SD	t
Fluency	Experimental group	24	82.13	7.08	1.174
	Control group	24	79.29	9.47	
Flexibility	Experimental group	24	81.17	7.09	.082
	Control group	24	81.00	6.91	
Originality	Experimental group	24	82.13	7.81	.369
	Control group	24	81.33	7.01	
Total score	Experimental group	24	81.81	6.83	.629
	Control group	24	80.50	7.53	

According to the post-test independent-samples t-test results (Table 2), the mean fluency, flexibility, and originality scores of the experimental group were 86.41 (SD = 6.37), 86.08 (SD = 7.87), and 87.08 (SD = 7.67), respectively; their mean total score was 86.53 (SD = 7.09). The mean fluency, flexibility, and originality scores for the control group were 85.91 (SD = 8.53), 85.48 (SD = 8.81), and 86.54 (SD = 10.60), respectively; their mean total score was 85.98 (SD = 8.07). For each item, $p > .05$. A comparison of the results revealed no significant differences between groups; however, the mean score of the experimental group was higher than that of the control group.

Table 2. Independent samples t-test results for creative thinking post-test

Item	Group	Numbers	M	SD	t
Fluency	Experimental group	24	86.41	6.37	.970
	Control group	24	85.91	8.53	
Flexibility	Experimental group	24	86.08	7.87	.973
	Control group	24	85.48	8.81	
Originality	Experimental group	24	87.08	7.67	.901
	Control group	24	86.54	10.60	
Total score	Experimental group	24	86.53	7.09	.805
	Control group	24	85.98	8.07	

The results of a paired-samples t test indicated that the creative thinking ability of the experimental group significantly differed ($p < .001$) between the pretest and the post-test (Table 3). The t-test results for each part of the TTCT were as follows: fluency, −4.737 (p = .001); flexibility, −7.085 (p = .001); and originality, −7.536 (p = .001). The total TTCT score was −9.316 (p = .000).

Similarly, a paired-samples t test indicated that the creative thinking ability of the control group significantly differed ($p < .05$) in the pretest and post-test (Table 4). The t-test results were as follows: fluency, $t = -7.351$ ($p = .001$); flexibility, $t = -4.195$ ($p = .001$); originality, $t = -3.928$ ($p = .001$); and total TTCT score, $t = -6.374$ ($p = .001$).

Table 3. Paired samples t-test scores for creative thinking ability of experimental group

Item	Numbers	*M*	*SD*	*t*	*df*	*p*
Fluency	Pre-test(24)	82.13	3.71	-4.737	23	$.001^{***}$
	Post-test(24)	86.42				
Flexibility	Pre-test(24)	81.17	3.40	-7.085	23	$.001^{***}$
	Post-test(24)	86.08				
Originality	Pre-test(24)	82.13	3.22	-7.536	23	$.001^{***}$
	Post-test(24)	87.08				
Total Score	Pre-test(24)	81.81	2.36	-9.316	23	$.001^{***}$
	Post-test(24)	86.53				

Note. $^{***}p < .001$.

Table 4. Paired samples t-test scores for creative thinking ability of control group

Item	Numbers	*M*	*SD*	*t*	*df*	*p*
Fluency	Pre-test(24)	79.29	4.89	-7.351	23	$.001^{***}$
	Post-test(24)	85.91				
Flexibility	Pre-test(24)	81.00	6.03	-4.195	23	$.001^{***}$
	Post-test(24)	85.48				
Originality	Pre-test(24)	81.33	7.59	-3.928	23	$.001^{***}$
	Post-test(24)	86.54				
Total score	Pre-test(24)	80.50	4.21	-6.374	23	$.001^{***}$
	Post-test(24)	85.98				

Note. $^{***}p < .001$.

Although the two groups did not exhibit any significant differences in their post-test scores after the lessons with the remote-control cars, a comparison of the creative thinking pretest and post-test scores indicated significant differences in the three domains and in the total scores.

5.2. Problem-solving ability

Table 5 presents the pretest independent-samples t-test results for the problem-solving ability of the experimental and control groups. For solutions, the mean score was 23.50 ($SD = 4.20$) for the experimental group and 23.04 ($SD = 4.54$) for the control group. The mean problem reasoning score was 28.92 ($SD = 5.90$) for the experimental group and 28.96 ($SD = 5.59$) for the control group. The mean problem prevention score was 20.83 ($SD = 3.52$) for the experimental group and 21.08 ($SD = 3.61$) for the control group. The mean total score was 73.25 ($SD = 12.73$) for the experimental group and 73.08 ($SD = 13.07$) for the control group. For each item, $p > .05$ indicated that no significant differences were observed and therefore no heterogeneity was evident between the two groups.

Table 5. Independent samples t-test results for problem solving pretest

Item	Group	Numbers	*M*	*SD*	*t*
Solutions	Experimental group	24	23.50	4.20	.363
	Control group	24	23.04	4.54	
Problem reasoning	Experimental group	24	28.92	5.90	-.567
	Control group	24	28.96	5.59	
Problem prevention	Experimental group	24	20.83	3.52	.902
	Control group	24	21.08	3.61	
Total score	Experimental group	24	73.25	12.73	.964
	Control group	24	73.08	13.07	

Table 6 presents the post-test independent-samples t-test results for problem solving. The mean scores of the experimental group were 25.83 ($SD = 3.81$) for solutions, 31.96 ($SD = 4.98$) for problem reasoning, and 22.75 ($SD = 3.07$) for problem prevention. The mean scores of the control group were 24.25 ($SD = 4.19$) for solutions, 30.58 ($SD = 5.72$) for problem reasoning, and 22.75 (SD = 3.07) for problem prevention. The total mean score of the experimental group was 80.54 ($SD = 10.89$), and that of the control group was 76.79 ($SD = 12.90$). For each item, $p > .05$ indicated no significant differences.

Table 6. Independent samples *t*-test results for problem solving post-test

Item	Group	Numbers	*M*	*SD*	*t*
Solutions	Experimental group	24	25.83	3.81	.178
	Control group	24	24.25	4.19	
Problem reasoning	Experimental group	24	31.96	4.98	.379
	Control group	24	30.58	5.72	
Problem prevention	Experimental group	24	22.75	3.07	.416
	Control group	24	21.96	3.59	
Total score	Experimental group	24	80.54	10.89	.282
	Control group	24	76.79	12.90	

A paired-samples *t* test indicated a significant improvement ($p < .001$) in the problem-solving ability of the experimental group (Table 7). The results (t) for problem solving were as follows: solutions, −5.02 ($p = .001$); problem reasoning, −6.50 ($p = .001$); and problem prevention, −4.86 ($p = .001$); the total score for problem solving was −6.84 ($p = .001$).

Table 7. Paired samples *t*-test results for problem-solving ability of experimental group

Item	Numbers	*M*	*SD*	*t*	*df*	*p*
Solutions	Pre-test(24)	23.50	2.277	-5.02	23	$.001^{***}$
	Post-test(24)	25.83				
Problem reasoning	Pre-test(24)	28.92	2.293	-6.50	23	$.001^{***}$
	Post-test(24)	31.96				
Problem prevention	Pre-test(24)	20.83	1.932	-4.86	23	$.001^{***}$
	Post-test(24)	22.75				
Total problem-solving	Pre-test(24)	73.25	5.221	-6.84	23	$.001^{***}$
score	Post-test(24)	80.54				

Note. $^{***}p < .001$.

A paired-samples *t* test indicated a significant improvement ($p < .001$) in the problem-solving ability of the control group (Table 8) as well. The results (t) were as follows: problem solving, −6.06 ($p = .001$); problem reasoning, −4.23 ($p = .001$); and problem prevention, −3.84 ($p = .001$); the total score for problem solving was −5.50 ($p = .001$).

Table 8. Paired samples *t*-test results for problem-solving ability of control group

Item	Numbers	*M*	*SD*	*t*	*df*	*p*
Solutions	Pre-test(24)	23.04	0.977	-6.06	23	$.001^{***}$
	Post-test(24)	24.25				
Problem reasoning	Pre-test(24)	28.96	1.884	-4.23	23	$.001^{***}$
	Post-test(24)	30.58				
Problem prevention	Pre-test(24)	21.08	1.116	-3.84	23	$.001^{***}$
	Post-test(24)	21.96				
Total problem-solving	Pre-test(24)	73.08	3.303	-5.50	23	$.001^{***}$
score	Post-test(24)	76.79				

Note. $^{***}p < .001$.

After the integrative activity modules, both the experimental group and the control group had significant improvements in problem-solving abilities.

5.3. Course satisfaction

Table 9 presents the independent-samples *t*-test results for course satisfaction of the experimental and control groups. The experimental group had a mean value of 4.24, whereas the control group had a mean value of 4.13. Under equal variance, the *t* value was nonsignificant ($t = 0.745$, $p = .461$), and p was greater than .05, indicating that the groups did not have significant differences in course satisfaction. The means in each area of satisfaction were higher than 4.

Table 9. Independent-samples *t*-test results for course satisfaction

Dimension	Group	N	*M*	*SD*	*t*	*p*
Course content	Experimental group	24	4.34	.619	1.889	.065
	Control group	24	3.98	.710		
Self-identification	Experimental group	24	4.17	.697	.080	.936
	Control group	24	4.15	.652		
Teacher teaching	Experimental group	24	4.15	.655	-.158	.875
	Control group	24	4.18	.800		
Overall satisfaction	Experimental group	24	4.24	.440	.745	.461
	Control group	24	4.13	.432		

6. Discussion

6.1. Improvements in creative thinking abilities

This study incorporated remote-control cars into integrated activity lessons. The students were instructed to use the cars on the maps of their neighborhoods they had drawn as a method of combining technology into the integrative activity curriculum. The activities combined programming with explorations of new environments, enabling students to learn from practice and to practice while learning (Dorst & Cross, 2001). The curriculum was designed to promote the creative thinking skills of second-grade students through peer discussions and integrative learning involving the assembly of remote-control cars, ideation, and programming (Hasanah & Surya, 2017). Creative thinking skills were assessed in terms of fluency, flexibility, and originality. In the post-test, total creative thinking scores significantly improved; therefore, the introduction of the remote-control cars strengthened the students' creative thinking skills. People with flexible thinking ability exercise diverse thinking processes and can make inferences. Therefore, this course diversified students' thinking.

As Syahrin et al. (2019) noted, technology courses using remote-control cars can improve creative thinking skills. The use of remote-control cars in the curriculum was a similar approach as that in other curricula incorporating elements of programming to facilitate the learning of advanced concepts and to strengthen students' creative problem-solving skills (Johnson et al., 1994; Rahmawati et al., 2019; Torrance et al., 1970).

According to the results, the interactive methods used by the experimental group, such as map drawing and group discussions, helped the students develop new, creative ideas (Webb et al., 2006). Davidson and O'Leary (1990) determined that programming classes in which students can practice elements of design improve creative thinking skills and learning motivation. The use of authentic materials (Rego et al., 2012) helps students to learn quickly in integrative activities involving remote-control cars or programming (Madden et al., 2013) and promotes active engagement, collaborative learning, and peer discussions, which enhance creative thinking and ideation. The process of assembling remote-control cars and engaging in discussion, exploration, and discovery with peers and teachers to find solutions enabled the students to have a unique experience using their creative thinking skills (Palanica et al., 2019; Taylor, 2016).

In the control group, the mean score for creative thinking skills increased considerably. This result demonstrates the effectiveness of lessons using remote-control cars to develop creative thinking skills. The innovative curriculum introduced several opportunities for the students to engage in creative thinking (Capraro & Nite, 2014), stimulated their creativity, and strengthened their problem-solving skills (Li & Yang, 2009). Both groups engaged in discussion, programming, exploration, and discovery while assembling the remote-control cars, which improved their performance in the creative thinking assessments; the results of the independent-samples *t*-tests indicated that the difference between groups was nonsignificant. The results also indicate the benefits of the techniques, viewpoints, and methods the students adopted to solve problems for their creative thinking abilities; such abilities are essential in science and engineering (Murcia et al., 2020).

The total post-test scores indicated significant improvements in both the experimental group and the control group; therefore, the programming activities, whether through map drawing or the use of the cars, were successful in developing the students' creative thinking. Although the post-test scores of the experimental and control groups did not reach statistical significance, the mean scores of each item in the experimental group were higher than those of the control group. In the comprehensive activity course of constructing driverless cars, students used authentic course learning. They also produced an authentic map. Regarding originality, they broadened their unique and creative perspectives and, in terms of fluency, exercised flexible and coherent thinking, formulating multiple feasible ideas. As for flexibility, they could make inferences and offered different, unconventional views. These results were reflected in their mean scores. This finding is consistent with those of Shatunova et al. (2019) and demonstrates that the use of integrative learning in programming lessons strengthens the creative skills of second-grade students.

6.2. Improvements in problem-solving abilities

According to Vygotsky (1978), concepts must be integrated into cognitive structures in the appropriate social environment. He emphasized that social interaction is crucial in the learning of advanced thinking skills (Choi & Hannafin, 1995). This view is supported by the results of this study, which demonstrated that experiential learning and map drawing improved the higher-level thinking skills of the students in the experimental group (Greenstein, 2012). The students assisted each other to complete the map-drawing activity (Gillies & Haynes, 2011), systematically organized knowledge, and shared their discoveries and ideas for solving problems in discussions (Nickerson & Zenger, 2004). After the map drawing and remote-control car lessons, the students' problem-solving abilities improved. Although the control group was not taught coding through map drawing, the introduction of integrative coding activities in the integrative activity curriculum significantly improved their problem-solving abilities (Çiftci & Bildiren, 2020). By assembling and studying the remote-control cars, both groups improved their problem-solving skills through exploration, discovery, and discussion.

The groups exhibited significant improvements in their total scores for problem solving and in their scores for all three domains, namely solutions, problem reasoning, and problem prevention. Thus, the remote-control car lessons significantly affected the acquisition of basic knowledge and techniques and were effective in the domains of solutions, problem reasoning, and problem prevention (Johnson & Johnson, 1987; Johnson et al., 1984). The change in the problem prevention scores in the experimental group was more significant than that of the control group. The experimental group also had higher mean scores in all areas of the post-test. This demonstrates the effectiveness of introducing elements of authentic learning to problem-solving tasks (Popat & Starkey, 2019).

The activities strengthened the students' logical thinking, improved their judgment and reasoning, and enhanced their problem-solving skills considerably (Schunk et al., 1987). The results also indicated that creative thinking and problem-solving skills are inextricably linked (Siegle, 2017). The curriculum helped the students strengthen their creative thinking and problem-solving skills (Tuomi et al., 2018). The innovative design of the integrative activity curriculum enabled students to learn through discussion and interactions with their peers (Huang, 2019), which significantly improved their problem-solving skills.

6.3. Student satisfaction

Both groups reported high levels of satisfaction with the course, the process of self-identification, and the teaching. The groups did not significantly differ in terms of satisfaction. Therefore, programming tasks did not have a significant effect. The semi-structured interviews conducted at the end of the course revealed that students thoroughly enjoyed the course. Although some students found the course challenging, they were still enthusiastic about the activities. Appendix 2 documents some of the interview content.

7. Conclusions and future research

The results of the TTCT and problem-solving test indicated that the course improved the creative thinking and problem-solving abilities of both groups. Thus, teachers should encourage students to participate in a diverse range of activities to hone their creativity, increase their interest in a subject, and expand their knowledge; higher levels of engagement result in more effective learning. Students experienced different learning methods. Regardless of whether authentic course learning was applied, students were presented with the correlation between driverless cars and the course and understood this correlation in the context of the course, community, and life. Moreover, they learned simple programming to solve life problems. Future research can investigate correlations with other dimensions of creativity and problem solving, such as students' abilities to engage in trial and error, evaluate a problem comprehensively, and understand the contents of a lesson. A detailed description of the analysis of the results of the experimental and control groups is provided in Appendix 4.

Because of the time constraints, the lesson-course lasted only 7 weeks, In the future, if time allows, the experimental duration may be extended, which may reveal more substantial differences between the experimental group and control group. Demonstrative inquiry is more likely to be effective if the lessons are held over a longer period of time in which students have more opportunities to practice. This study involved only 48 student participants, and the interviews produced only a small amount of data. In the future, if the number of students was increased, the amount of interview data would likely be larger. Future research can also investigate the relationship between integrative programming curricula and problem-solving and critical thinking skills. When delivering integrative courses, instructors should identify connections between creative thinking, problem-solving, and critical thinking skills. This type of research can elucidate the effects of different education practices on the development of creativity.

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Appendix 1

Difference between the experimental group and control group in terms of the curriculum design, content, and process.

<table>
<tr><th></th><th>Experimental group</th><th>Control group</th></tr>
<tr><td>Curriculum design and tools</td><td>1. Remote-control cars
2. Learning coding (Scratch)
3. Authentic learning</td><td>1. Remote-control cars
2. Learning coding (Scratch)</td></tr>
<tr><td>Curriculum content</td><td>1. Authentic learning is integrated into the course through the use of remote-control cars.
2. The process of programming is integrated into real-life situations.</td><td>1. Using the remote-control cars to learn.
2. Program coding using a general program chart.</td></tr>
<tr><td>Curriculum schedule</td><td>
<table>
<tr><th>Week</th><th>Learning process</th></tr>
<tr><td>2</td><td>Students in the experimental group receive lessons based on the content of the textbook with integrated authentic learning.</td></tr>
<tr><td>3</td><td>Simulation-based learning: The students use real-life examples (drawing community maps) to learn how to operate a remote-control car.</td></tr>
<tr><td>4.5</td><td>Peer-based evaluation: Program flowcharts and real-life situations are used to teach the students to code. Students were encouraged to discuss problems with each other.</td></tr>
<tr><td>6</td><td>The students provide feedback on how the course is meaningful to community life.</td></tr>
</table>
</td><td>
<table>
<tr><th>Week</th><th>Learning process</th></tr>
<tr><td>2</td><td>Students in the control group receive lessons based on the content of the textbook.</td></tr>
<tr><td>3</td><td>The students assemble and operate the remote-control cars.</td></tr>
<tr><td>4.5</td><td>Program flowcharts are used to teach the students to code.</td></tr>
<tr><td>6</td><td>The students provide feedback on their experience of using a remote-control car as part of the course.</td></tr>
</table>
</td></tr>
</table>

The difference between the experimental and control groups:
The learning process for the experimental group integrated authentic learning and remote-control car programming to allow students to make connection between their daily life and the course content. The learning process for the control group centered on remote-control car programming, enabling students to learn programming.

Appendix 2

Semi-structured interviews

The recordings of the interviews were transcribed, and textual analysis was performed. For the first topic—"Personal learning experience: what do you think you have gained from the innovative classes?"— responses frequently focused on whether the content was engaging as well as on time management and course flow. The following are sample responses from three students:
E20-1: "I think it's interesting to explore and study mobile cars."
C10-1: "The time management was good, but some students weren't familiar with the software, so they always asked the teacher, and the classroom was a little noisy."
E18-1: "It took a lot of time to learn the material in this new course, so I think it was difficult."

The second interview topic was "Inter-team relationships: Do you think peer learning helps you learn effectively?" The responses predominantly referenced "cooperation between classmates," "group discussion," and "sometimes the discussion was too noisy." However, some students reported that discussion improved their learning experience. The following are representative responses:
E6-2: "Receiving help from my classmates improved my learning ability."
C5-2: "Discussion can bring more ideas into the course."
C9-2: "Sometimes, the discussion was so noisy that we could not think about the course content."

The third interview topic was "Experience with technology: Did you find it challenging to use the remote-control devices?" The feedback was focused on using the car, and numerous students commented that learning to use the remote control was easy or challenging and that the task was difficult. Example responses from four students are as follows:
E14-3: "I think it was easy to learn the program. However, I think it was a challenge for me to learn [how to use] the computer and remote control cars. Sometimes, I could not do it."
E8-3: "It was difficult for me. However, if it had been connected to an interesting real-life situation, it might have been easier to learn to control it."
C11-3: "It was alright because the teacher explained it in detail during class."
C22-3: "It was challenging."

Appendix 3

Ver. 2017.04.24, Human Research Ethics Committee of National Cheng Kung University

Consent Form for the Child's Parent or Legal Representative

Dear parents:
We are a research team from the Graduate School of Technological and Vocational Education at National Yunlin University of Science and Technology working under Dr. Ting-Ting Wu, the director of the research program. We would like to invite your child to assist us in understanding whether the integration of self-propelled vehicle activities into comprehensive activity courses can improve students' creative thinking and problem-solving abilities. Your child's participation would benefit other children and their parents. In addition to experiencing new learning methods, your child will learn to absorb knowledge and skills through interdisciplinary teaching, preparing him or her for future challenges.

The research goal:
The 21st century is an era of rapid change and development. To increase the competitiveness of Taiwan, the cultivation of talent has received increasing attention. Numerous countries have introduced educational concepts or reform measures to develop new indicators for children's learning. The remote-control car program involves hands-on problem-solving and exploration-oriented teaching, which can cultivate children's comprehensive abilities, including inquiry, critical thinking, creative thinking, and problem-solving. While solving problems and exploring solutions, the children will inevitably encounter mistakes and failure. At such times, they will reflect on the cause, correct their mistakes, try again, fail again, reflect again, and try again until they succeed. The remote-control car program can assist children in cultivating their patience, willpower, and responsibility. The program will be applied to lower grades to explore its effects on creative thinking, problem-solving, and critical thinking.
Procedure:
(1) Pretest and posttest: Before and after course, creative thinking and problem-solving tests will be conducted

to evaluate the effects of the program.
(2) Remote-control car program: The program allows students to participate in interdisciplinary activities in different courses, thus improving their creative thinking.
(3) Interviews: In one or two classes before the end of the course, a 20-min interview will be conducted with the children regarding their experience and take-aways from the course. For data accuracy, the interviews will be recorded. If you would not like the interview to be recorded or wish to end the interview at any point, please notify us. After the course, you (and those who withdraw from the study) will receive stationery as a token of our gratitude.
(4) Recording: We will request that review the verbatim transcript of the audio. We assume the responsibility of confidentiality. Your real name will not be used in the results, and we will deidentify the data to the best of our ability in resulting publications. However, your identity may be disclosed in unexpected circumstances; therefore, please carefully consider the terms of the interview. The recordings and verbatim transcripts will be stored on a hard disk or computer with a password in the laboratory of Modern Learning Technologies and Applications and will be deleted 5 years after the program (July 31, 2027); they will only be used in this study. If you are interested in the results of this study, a summary of the report can be provided.
(5) Your and your child's information will remain confidential
1. We will request that the students' teachers, who will serve as assistants in this study, distribute the consent form and study materials. The experimental activities will be conducted in both the course implemented by this study and school's normal course. The study course will be integrated into the school course regardless of your child's participation in the study. If you would not like to have your child participate, we will not include your child's learning and test results in our results. This course will not affect your child's academic performance or the teacher's perception thereof. This experimental test and your child's academic performance are separate and unrelated.
2. We will adopt an anonymized approach to the publication and results related to this study and will replace the children's real names with codes.

*** We will fulfill our responsibility to protect and respect your children.**
Participation in this study will not cause physical or psychological harm to the children. We will fully respect your decision should you wish to withdraw your child from the study. If you have any questions after the interview, please contact us. The course will be interdisciplinary and based on themes from the students' class. If a participant withdraws from the experiment, we will continue the study as planned, but the activities and test results of those who withdraw will be excluded from the study data. In such a case, we and the teachers will score your child separately from those remaining in the study. However, the scoring systems will be unrelated.

Human Research Ethics Committee of National Cheng Kung University

※ **Small gifts:**
During the teaching process, if the students are willing to share what they have learned from the course or exhibit strong learning performance, we will reward them with stationery as encouragement.
Please feel free to ask any questions regarding this form. If you agree to have your child participate, please complete the following section and provide your signature. Please do not feel pressured to participate in this study.
Signature of parent or legal representative:
Pretest and posttest: □Agree □Disagree
Remote-control car activities: □Agree □ Disagree
Interview recording: □ Agree □Disagree
Report of results: □Not required □Please mail a report after the study to the following address: ________________________
Signature: __________ Date: MM/DD/YY
Signature of the research team:

Ethical approval for this study was obtained from the Human Research Ethics Committee of National Cheng Kung University commissioned by National Yunlin University of Science and Technology. If you wish to discuss the rights and interests of the participants in this study or file a complaint, please contact the Committee. Tel: E-mail:

□This consent form is in duplicate and will be retained by both parties for their record.
Signature of program director/codirector/researcher: ________Date: MM/DD/YY

Appendix 4

Analysis of results for experimental and control groups:

1. The pretest and posttests scores of the experimental and control groups significantly differed, indicating that the use of the remote-control cars in the course improved the students' creative thinking and problem-solving abilities.
2. Although the comparison of the experimental and control groups in the creative thinking skills test is not significant, it can be found from the experimental activity that the application of remote-control cars can improve the creativity of students. The learning of creativity requires a long period of training and learning. Perhaps the experiment time can be extended to see more results of analysis.
3. A comparison of the average scores of the experimental and control groups for creative thinking revealed that the scores for fluency, flexibility, and originality were higher in the experimental group than in the control group. Although only a slight difference in scores was observed, the use of authentic learning in the course allowed the students to draw community maps, which, along with the course activities, increased their fluency, flexibility, and originality in creative thinking.
4. Although the comparison of the experimental and control groups in the problem solving test is not significant, it can be found that both groups need to carry out problem solving activities in the course. It can be found from the results that both groups are improved problem solving skills after taking the course.
5. A comparison of the average scores of the experimental and control groups for problem solving revealed that the scores for solutions, problem reasoning, and problem prevention were not significantly different after the course. However, through authentic learning, the students in the experimental group used their hand-drawn community maps to connect their learning with their environment. This real-life connection significantly increased the scores for solutions, problem reasoning, and problem prevention.
6. The authentic learning component ensured that the course incorporated real-life scenarios, allowing the students to apply their knowledge. Because the experiment lasted only 5 weeks, detecting significant improvements in creative thinking and problem solving is difficult. In the future, the experiment can be extended to observe differences more clearly.
7. In terms of course satisfaction, both the experimental group and the control group are quite satisfied with the course learning, and there is no significant difference between the two groups. It can be found that the two groups of students are satisfied with the course arrangement, learning progress and course content.