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Effects of Robotic Coding Supported Design-Based Science Instruction on Students' Science Process Skills

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This study aimed to investigate the effects of robotic coding supported Design-Based Science Instruction (RC-DBSI) on sixth-grade students' science process skills. One-group pretest-posttest experimental design was employed in the study. Participants consisted of thirty-nine sixth-grade students enrolled in a public middle school located in the eastern part of Turkey. The implementation phase lasted for five weeks during which a Force and Motion unit was being taught. The engineering design process, including the steps of determining the problem, researching possible solutions, determining the most suitable solution, making the prototype, and testing the prototype (Wendell et al., 2010), was followed in the study. Robotic coding activities were incorporated into the "researching possible solutions" step of DBSI. Twin Science Kit was distributed to the participants, and they engaged in robotic coding activities via this kit. Students completed Science Process Skills Test as a pretest and posttest. Paired samples t-test results demonstrated that being exposed to RC-DBSI improved the students' science process skills. Based on the study's findings, some suggestions were presented for science teachers and teacher education programs.

Cette étude avait pour but d'examiner les effets de l'enseignement des sciences basé sur la conception et soutenu par le codage robotique (RC-DBSI) sur les compétences en matière de processus scientifique des élèves de sixième année. L'étude a utilisé un modèle expérimental prétest/posttest avec un groupe. Trente-neuf élèves de sixième année inscrits dans une école publique située dans la partie orientale de la Turquie ont participé à l'étude. La phase de mise en œuvre a duré cinq semaines au cours desquelles une unité portant sur la force et mouvement a été enseignée. L'étude a suivi le processus de conception technique, qui comprend les étapes de détermination du problème, de recherche des solutions possibles, de détermination de la solution la plus appropriée, de fabrication du prototype et de test du prototype (Wendell et al., 2010). Les activités de codage robotique ont été intégrées à l'étape "recherche de solutions possibles" de l'enseignement des sciences basé sur la conception. L'ensemble de Twin Science a été distribué aux participants, qui se sont livrés à des activités de codage robotique avec cet ensemble. Les élèves ont passé un test sur les compétences en matière de processus scientifique en tant que prétest et posttest. Les résultats du test t pour échantillons appariés ont démontré que l'exposition à la RC-DBSI a amélioré les compétences des élèves en matière de processus scientifique. Sur la base des résultats de l'étude, certaines suggestions ont été présentées aux professeurs de sciences et aux programmes de formation des enseignants.

People have developed various engineering applications throughout history to meet their needs and produce solutions to their problems. Design, a product of engineering, has evolved and started to contain many features, such as aesthetics, economy, quality, and performance, not just needs. Today, engineering applications have been blended with science and mathematics fields to solve problems, and engineering has become a high-level skill (De Meester et al., 2021).

National Academy of Engineering [NAE] and National Research Council [NRC] have published several *Engineering Education Standards* reports (NAE & NRC, 2009; NRC, 2012) that emphasized that the areas where engineering and science intersect should be brought together, and interdisciplinary connections should be established. Next Generation Science Standards (NGSS) suggests integrating engineering practices into science courses at all grade levels (NGSS, 2013).

One of the approaches where science education and engineering investigations meet on a common ground is Design-Based Science Instruction (DBSI) (Fortus et al., 2004). DBSI is a method of teaching that begins with a problem, proceeds through many investigations, and concludes with a design (Fortus et al., 2004). DBSI is related to cognitive constructivism, in which people make sense of their own life experiences; social constructivism, in which people form their zone of proximal development in cooperative learning contexts; and pragmatic philosophy, in which the product benefits both the individual and society (Leonard & Derry, 2011). DBSI is also based on grounded theory that supports integrating the learning process into real-life conditions (Leonard, 2004; Wendell, 2008). Abstract science subjects can be materialized through the grounded theory that supports authentic learning (Leonard, 2004). While performing their design tasks, students comprehend science concepts (Fortus et al., 2004).

Due to its dynamic nature, education is constantly changing, and one of the factors triggering these changes is technology. With the Industry 4.0 revolution, robotics and coding have started to be used in educational environments (Donmez, 2017). Basic knowledge and skills concerning technology have been integrated into the education of young individuals owing to the coding education that originated in the United States (Code.org, 2019). Coding education supports students in producing their own solutions to problems and creating their own algorithmic designs (Grigg & Benson, 2014). On the other hand, robotic education materializes solutions produced for problems through coding (Demertzi et al., 2018). With robotic education, individuals gain meaningful and permanent learning by integrating technology and science (Wood, 2003). Indeed, using technology and science together in schools positively affects individuals' ability to prepare for real-life conditions, think critically, and solve problems (Choi & Hong, 2015).

Previous studies support positive effects of DBSI on students' science outcomes such as academic achievement (e.g., Doppelt et al., 2008; Roth, 2001; Tas et al., 2019), science process skills (e.g., Sadler et al., 2000), and metacognitive strategies in science (Tas et al., 2019). Some studies have also incorporated robotics into the engineering design process. For instance, Barak and Assal (2018) integrated science and engineering disciplines into a STEM-focused robotics course activity for middle school students. They found that students showed high motivation to learn robotics, providing an efficient and enjoyable learning environment. In another study, Rusk et al. (2008) prepared robotic coding activities through workshops organized for children, young people, families, and educators. They pointed out that robotic coding activities, which were combined with art, engineering, and Lego offer rich educational opportunities. However, more research is needed to understand the influence of robotics within an engineering design process, especially regarding students' science process skills. Furthermore, since students create designs in DBSI, various materials are needed for design tasks, increasing cost. On the other hand, robotic coding materials can reduce costs since most design tasks can be performed with a single material. In the present study, the objective is to reveal the influences of robotic coding supported-DBSI (RC-DBSI) on sixth-grade students' science process skills.

Design-Based Science Instruction and Robotic Coding

Design, which is an engineering product, is a process that begins with identifying a need and concludes with providing solutions that meet specific criteria (NAE & NRC, 2009; NRC, 2010, 2012). There are different suggestions on how the design process works and what steps are followed (Brunsell, 2012; Massachusetts Department of Education [MDOE], 2010; Mentzer, 2011; NRC, 2012; Wendell et al., 2010). The present study followed the engineering design process proposed by Wendell et al. (2010). Accordingly, the steps of the engineering design process are: (1) determining the problem, (2) researching possible solutions, (3) determining the most suitable solution, (4) making the prototype, and (5) testing the prototype. Indeed, all the steps are interrelated and support each other in the process (Wendell et al., 2010).

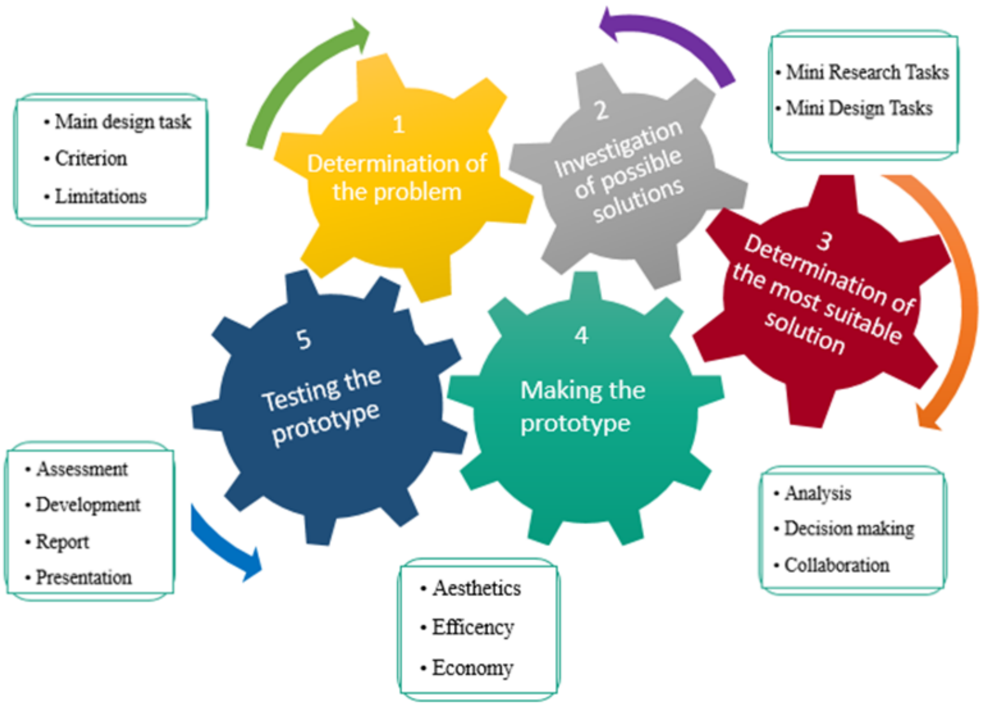
DBSI starts with a problem which is including the "main design task". Students express their knowledge about the task based on previous learning and experiences, and state what they need to learn to solve the problem. After the problem is detected, "mini-research tasks" come into play. While performing these tasks, students' research visual, written, and audio sources, benefit from the teacher's guidance, and take various notes. Students are also presented with "mini-design tasks" linked to the main design task and are required to complete them (Wendell et al., 2010). Mini-design tasks can consist of written and visual elements, possibly in the form of a physical product (Ercan & Şahin, 2015). After completing these mini-research and mini-design activities, group members compare their solutions for the main design task. Students select the best solution for the main design problem based on predetermined criteria. They then move to the "making prototype" stage, and develop and "test" their designs. Students present their designs, which are evaluated by a jury using design rubrics (Leonard & Derry, 2011; Wendell et al., 2010). This process is presented in Figure 1.

In this study, robotic coding activities are included in the "investigation of possible solutions" step. Coding is a process that develops mathematical skills and computational skills (using technology in problem-solving), provides the opportunity to look at the solutions related to the problem from a different perspective, and supports individuals to develop various strategies. These skills are needed by individuals dealing with computers and individuals of all professions (Wing, 2006). Indeed, coding and programming skills are among the 21st-century skills (European Commission, 2014), and coding courses are included in curricula in several countries (Code.org, 2015). Educational robotics is generally used to achieve goals of improving science, mathematics, engineering, and technology learning, developing learning skills like scientific process skills, engineering design, productive thinking, problem-solving, and collaborative learning, and lastly for ensuring the acquisition of targeted skills by increasing students' motivation (Chung et al., 2014; Kim et al., 2015; Nugent et al., 2010; Sullivan & Bers 2016).

Today's young people who keep up with the rapid growth of technology can access the internet, utilize smart tools successfully, and play games, but they are unable to make sense of digital media and design their own systems (Resnick et al., 2009). They are somehow "using" but not "producing". Recently, various software programs have been developed to include individuals in the design process. Programs such as *Alice* and *Scratch* are examples of these software programs that can appeal to young people (Resnick et al., 2009). Various studies have demonstrated that

Figure 1

Design-Based Science Instruction Process



Note. Adapted from Wendell et al., 2010, © 2010 American Society for Engineering Education. Paper Authors: Kristen Wendell, Tufts University; Kathleen Connolly, Tufts University; Christopher Wright, Tufts University; Linda Jarvin, Tufts University; Mike Barnett, Boston College; Chris Rogers, Tufts University; Ismail Marulcu, Boston College

robotic coding is abstract for students (Armoni, 2012), yet it becomes pretty embodied with the help of software programs like *Scratch* (Schwartz et al., 2006; MIT Media Lab, 2018). Lego is commonly used in developed countries for robotics training as it supports acquiring skills such as design, construction, and programming in a collaborative and fun environment (Fidan & Yalçın, 2012). Furthermore, learning environments supported by Lego positively affect individuals' science process skills (Çayır, 2010). In many studies with DBSI, Lego has been used (e.g., Li et al., 2016; Marulcu, 2010; Wendell et al., 2010). One of the tools that allows students to make Lego-supported designs and learn basic coding is the Twin Science Kit. Twin Science Kit comprises many electronic modules that perform various tasks and functions and can be easily connected using magnets, allowing the production of various Lego projects. With this kit that supports coding skills by introducing the basics of coding, the infrastructures of the technologies used in daily life can be discovered by students, and students are allowed to design and present their own projects (twinscience.com, 2020). In this study, Twin Science Kit was distributed to the participants.

Previous studies found that robotic coding-based activities enrich the learning environments, improve the quality of teaching, and increase students' academic achievement (e.g., Cuperman & Verner, 2013; Fidan & Yalçın, 2012; Gülbahar & Kalelioğlu, 2014). For instance, Çavaş et al. (2012) found that Lego-supported robotic coding increased 6th and 7th-grade students' science process skills. Another study showed that 7th-grade students' motivation towards science and science process skills improved after performing science practices based on coding with Lego (Koç Şenol

& Büyük, 2015). On the other hand, Williams et al. (2007) examined the effects of Lego-supported robotic applications on middle school students' knowledge of physics and scientific inquiry skills in a summer camp. They found that although students' academic achievement increased, their scientific inquiry skills did not improve at a significant level. Therefore, we can say that some contradictory results exist in the literature regarding the effect of robotic coding on students' science process skills, suggesting that more research is needed on this issue.

In this study, by using Twin Science Kit, robotic coding activities are included in the "researching possible solutions" step of DBSI. The aim of incorporating robotic coding activities is to support the students to perform mini-research and mini-design tasks more effectively. Therefore, it is thought that researching possible solutions will increase its functionality by including robotic coding activities in DBSI. Thus, students can develop more appropriate solutions. We believe that with the robotic coding supported DBSI (RC-DBSI), the engineering discipline will be more effectively involved in the process, and students' science process skills will be fostered. Science process skills, which include skills such as observation and controlling variables that scientists use while doing science (Padilla, 1990), are positively affected by DBSI, as studies mentioned above demonstrated (e.g., Sadler et al., 2000). In this study, on the other hand, the effectiveness of RC-DBSI will be investigated. In this context, the study aims to examine the effect of RC-DBSI on 6th-grade students' science process skills. The research question is as follows: "After being exposed to RC-DBSI, is there any change in 6th-grade students' science process skills?".

Method

Context of the Study

There are 12 years of compulsory education in Turkey: Primary school covers 1st through 4th grade, middle school level is from 5th through 8th grade, and high school is 9th through 12th grade. Recently, "engineering and design skills" have been incorporated into the science curriculum, covering 3rd to 8th grades. (Ministry of National Education [MoNE], 2018a). Accordingly, students are asked to determine a daily life problem related to the units and consider the criteria such as material and cost while solving the problem. Among alternative solutions, they are expected to choose the solution that meets the criteria and then develop and present their products (MoNE, 2018a). Furthermore, teacher training on robotic coding has started within the scope of the Fatih Project (MoNE, 2018b).

Research Design

One-group pretest-posttest experimental design (Fraenkel & Wallen, 2006) was employed in the study. The experimental process effect (i.e., RC-DBSI) on the group's science process skills was determined before and after the experiment through pretest and posttest.

Participants and the Execution of the Lessons

The study participants are 39 sixth-grade students studying in a public school in the eastern part of Turkey in 2018-2019. There were 16 girls and 23 boys. The school where the study was conducted was determined by the convenience sampling method. At the beginning of the study, students were informed about the goals and procedures of the study. They were told that they could withdraw from the study if they wanted. All of the students voluntarily accepted to participate in the study and students' identities were kept confidential. Ethics committee approval was obtained for the study.

The teacher participating in the study graduated from the Science Education program and had 8 years of teaching experience. Before the intervention, the teacher was informed about how to teach lessons according to RC-DBSI. Additionally, the first author observed the classroom to ensure that the courses were executed as intended. A Design-Based Science Instruction Guide (DBSIG) developed by the researchers was used as teaching material and was provided to every student by the teacher. The drawings created by the students, their decisions, answers to the questions, the information they obtained from their research, and their statements about thoughts proposed are included in the DBSIG. The students were divided into groups of 5 to7 people, and each group was given a Twin Science Kit. Each set contains 30 electronic parts and includes a guidebook containing 10 sample designs. Electronic blocks consist of 4 different colors according to their functions. They are grouped as gray for energy, red for transmission, yellow for input, and blue for output. While the students were building the circuit, color groups facilitated their learning. The set includes parts such as coding modules, sequential LEDs, distance sensors, sound and motion sensors, signal stabilizers, and connection cables. In addition, the mobile application allows students to code via a simple interface. The science set is designed for students at the middle school level, and magnets and Lego pieces have been integrated into the electronic parts for fun (twinscience.com, 2020). In the first two lessons of the experimental group, robotic coding and DBSI were introduced to prepare students for the intervention. Students carried out test designs within the scope of this orientation to learn how to use the Twin Science Kit. The intervention lasted for five weeks, including 20 class hours, and the unit was Force and Motion. Table 1 describes how lessons are taught in the experimental group.

Data Collection Tool

The Science Process Skills Test (SPST) is a multiple-choice test developed by Aydoğdu et al. (2012) to assess students' science process skills from 6th-grade to 8th-grade. The test consists of 27 items; 9 measure basic skills (i.e., observation, classification, space-time relation, prediction, and inference), 18 address high-level skills (i.e., problem detection, formulating a hypothesis, determining variables, experimenting, and interpreting data). Correct answers given to the test items were coded as 1, incorrect answers or those left blank were coded as 0, and then the total score was calculated. Item analysis was conducted during the test development, and KR-20 was calculated as .84 (Aydoğdu et al., 2012). In the present study, the KR-20 coefficient was also found as .84. A sample item is presented in Figure 2.

Data Analysis

A paired-samples t-test was used to examine whether a significant change in students' science process skills was observed after attending RC-DBSI. Before conducting the analysis, the distribution of difference scores was examined. Skewness (-.08) and kurtosis (-.70) values, and Shapiro-Wilk test ($p = .48$) showed that the assumption of normality of difference scores was met.

Table 1

The Execution of the Course

Class Hour	Experimental Group
1	Engineering and design videos were watched and documents were shared with the students.
1	Orientation studies related to robotic coding and DBSI were done. Students discovered how to use the science kit with the supervision of the teacher.
1	Students were divided into groups of 5-7 people and each student was given a design-based science instruction guide (DBSIG) by the teacher.
	The students encountered the problem status of "My Auto Pilot Vehicle" which was their main design task. Students were expected to move the vehicle automatically in line with the specified route. Students were also told that their designs would be evaluated aesthetically.
2	Students set criteria and limitations for the main design task. They made their first drawings of the main design tasks.
1	Students identified what concepts to learn, researched, and took notes.
2	Students did research for mini design task-1 "Parking Sensor". They sought answers to research problems. Students evaluated possible solutions through robotic coding activities.
	Students made drawings and detailed explanations for the mini design task.
1	Students who were provided with the materials they wanted for mini design task-1 made their first designs.
2	Students made researches on mini design task-2 "Autonomous Car". They sought answers to the research problem. Students seeking solutions for the problem status received support from robotic coding practices.
	Students made drawings for the mini design task and made detailed explanations in the DBSIG.
1	For the mini design task-2, the students who were provided with the materials constructed their designs.
1	If students wanted to make changes and additions in their initial drawings for the main design task, they specified these changes in their DBSIG.
	Students determined the criterion and limitation matrices for solution.
1	The students presented their designs in front of the jury and prepared a report.

Results

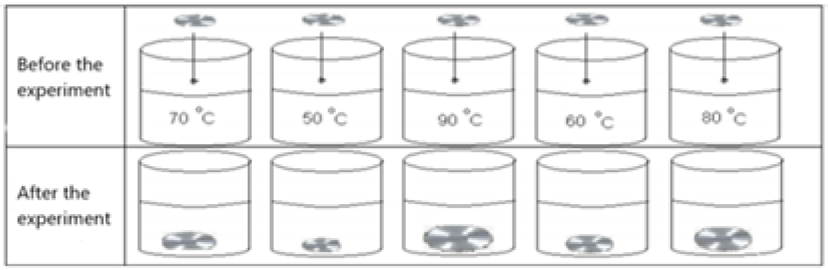
Descriptive statistics for science process skills of the students before and after the intervention and paired samples t-test results are presented in Table 2.

A paired-samples t-test was conducted to evaluate the impact of RC-DBSI on students' science process skills. As mentioned above in the data collection tool, the science process skills test includes 27 items. Correct answers were coded as 1, the incorrect answers or those left blank were coded as 0, and the total score was calculated. The analysis result demonstrated that students' science process skills at the end of the intervention ($M = 23.79$, $SD = 2.15$) were statistically significantly higher than their science process skills before the intervention ($M = 12.33$, $SD = 3.85$), $t(38) = 15.60$, $p < .05$. The increase in the mean score of science process skills was 11.46, with a 95% confidence interval ranging from 9.97 to 12.95. The eta squared statistic (.06) indicated a medium effect size (Cohen, 1988).

Figure 2

A Sample Item for Science Process Skills Test

Identical iron pieces are left in the same vessels containing water at the same amount and density but at different temperatures.



What can you conclude by looking at the figure above?

a) As the temperature of the water in which identical iron pieces are placed increases, the expansion amount of the iron pieces decreases.

b) As the temperature of the water in which different iron pieces are placed decreases, the expansion amount of the iron pieces increases.

c) As the temperature of the water in which identical iron pieces are placed increases, the expansion amount of the iron pieces increases.

d) As the density of water in which identical iron pieces are placed increases, the expansion of the iron pieces decreases.

Note. Adapted from Aydoğdu et al., 2012, p. 309. CC BY-NC-SA 4.0

Table 2

Descriptive Statistics for Science Process Skills and Paired Samples t-test Results

	Pretest		Posttest						
	M	SD	M	SD	SE	t	df	p	η^2
Experimental Group	12.33	3.85	23.79	2.15	.73	15.60	38	.00	.06

Discussion and Conclusion

This study investigated the effects of RC-DBSI on 6th-grade students' science process skills. The intervention lasted for five weeks during a Force and Motion unit. By using the Twin Science Kit, students engaged in several robotic-coding activities which were incorporated in DBSI. The students studied a problem that they may face in real life, took responsibility for their own learning while designing, explored potential solutions, collaborated with their classmates, and actively participated throughout the process. Findings suggested that students' science process skills improved after implementing RC-DBSI.

Previous studies pointed out that learning with design promotes students' science process skills (e.g., Bozkurt, 2014; Sadler et al., 2000; Strong, 2013). Sadler et al. (2000) explained that while developing their prototype, 6th-grade students used their science process skills successfully. Moreover, Sungur Gül and Marulcu (2014) suggested that DBSI supports science process skills such as identifying the problem, planning, hypothesis, analysis, and presentation. The RC-DBSI utilized in this study is considered to have offered opportunities for students to improve their science process skills. For example, students faced with the main design task try to understand and identify the problem. Thus, students' science process skills to detect the problem can improve. Yıldırım et al. (2013) explained that students' science process skills could be improved through practicing problem situations. Celep and Bacanak (2013) emphasized that problems and project assignments related to daily life help students acquire science process skills effectively. In the research stage of possible solutions of RC-DBSI, students can use their skills to predict and identify the variables more effectively. In addition, it is thought that the students who collect data about the problem status may improve their ability to record and interpret data. The stages of prototyping and testing may have supported students' science process skills of experimenting and interpreting data.

The Twin Science Set can be used to organize various activities in line with the students' imagination. Indeed, robotic coding activities offer rich educational opportunities for students (Rusk et al., 2008). Scaradozzi et al. (2015) found that the students who received robotic application education at the elementary level improved their logical and creative thinking skills. Lego-supported robotic applications contribute to students' problem-solving skills, multidimensional thinking skills, and logical thinking skills, and at the same time, they increase motivation and academic success (Varney et al., 2012; Zaharija et al., 2013). In this study, robotic coding activities were carried out in the mini-research and mini-design tasks given during the DBSI stage of research of possible solutions. We think that robotic-coding activities promoted students in producing more efficient and effective solutions for their main design tasks. Furthermore, robotic coding materials helped reduce costs because many design tasks now could be performed with Twin Science Kit rather than gathering various materials for the design. Thus, robotic coding seems to possess some financial advantages, as well.

Suggestions and Limitations

This study determined that RC-DBSI had positive effects on 6th-grade students' science process skills. In this respect, science teachers can be given in-service training on RC-DBSI, and teachers can be encouraged to use RC-DBSI in their classes. DBSIG developed for the Force and Motion unit in this research can be used by the teachers. We suggest supplying robotic coding materials, such as Twin Science Kit, to schools in order to enable students to design with ease and fun. Furthermore, preservice teacher education programs can incorporate RC-DBSI into teaching methods courses and train preservice teachers to develop skills of using RC-DBSI in their future teaching.

This study has certain limitations that should be addressed. The study's design is the one-group pretest-posttest design which has several risks for internal validity, such as maturation, history, and subjects' attitude (Fraenkel & Wallen, 2006). A comparison group in which DBSI would be implemented without incorporating robotic coding activities can be included in future studies. As a result, a comparison group can allow for a more thorough study of the impact of introducing robotic coding activities into DBSI. Moreover, the intervention comprised the Force and Motion unit and lasted 5 weeks. It is believed that by planning the intervention to last longer and incorporate more science units, the impacts of RC-DBSI can be better shown. Besides, the convenience sampling employed limited the generalizability of the study's findings (Fraenkel & Wallen, 2006). We suggest that replication studies can be conducted to increase the generalizability of the study's findings.

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