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Reverse Engineering in Robotics Classrooms: Boosting Creative Thinking and Problem Solving

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Abstract

This study explores the impact of robotics activities on the creativity and problem-solving performances of secondary school students. The participants consisted of 10 students from a computer science class at a secondary school. The robotics activities utilized Lego Ev3 kits and incorporated reverse engineering principles. Data were gathered using open-ended forms created to evaluate students' perspectives on creativity while engaging in tasks and their robotics problem-solving performances. The findings revealed that, most of the students demonstrated proficient skills, particularly in recognising problems, and creating alternatives, while their reasoning, applying the solution, and sharing skills were adequate. We hope this study will offer a valuable example of how to incorporate robotic activities within the reverse engineering approach.

Keywords: reverse engineering, robotics, creativity, problem-solving, secondary school students

1. Introduction

There is an increasing body of research highlighting the potential of educational robotics to enhance various problem-solving skills (Evripidou et al., 2020; Sun & Zhou, 2023). Educational robotics activities are implemented across all educational levels, from elementary to graduate, encompassing design, programming, application, and experimentation. Educators typically utilize robotics kits to construct robots and develop programs for specific tasks (Jung & Won, 2018). These activities can be structured as interventions, after-school programs, elective classes, or comprehensive course modules focused on robotics (Gubenko et al., 2021). For instance, Mblock is utilized for easy coding and control of robots. Lego Mindstorms allows students to design robots to enhance STEM skills and Lego Wedo 2.0 is another tool to develop children's dexterity. Mbot and Makey Makey are other tools for younger students to help them gain computational problem-solving experience. While mBot helps students to learn hands-on experience in the fields of graphical programming, electronics, and robotics; Makey Makey allows students to turn everyday objects into computer interfaces. Additionally, Vex IQ can be integrated with engineering challenges, making it a notable tool in educational robotics. Arduino is another educational robotics platform that requires basic knowledge of electricity and can be used to address simple real-life problems, such as watering plants or creating a door lock using various sensors. Students need to understand how to connect sensors, input-output devices, jumpers, and cables on a board, as well as use its programming language.

Robotics activities are used to enhance various skills and their potentials are closely related to how they are applied in the course process. In this sense, problem-solving and creativity skills are current key competencies that students need for their lives and professions in the future (Partnership for 21st Century Skills, 2009) and can also be enhanced through robotics. Thus, educators should help students keep up with these skills that is often referred to as twenty-first-century skills to meet challenges in the modern world. In a previous study, Costa and Fernandes (2005) applied robotics to space science, finding that students developed practical solutions to problems, which enhanced their critical thinking and logical reasoning skills. Similarly, Petre and Price (2004) demonstrated that robotics effectively helps primary and secondary school students grasp programming and engineering principles. Their findings indicated that students were able to define the essential principles and concepts related to programming and engineering. Strawhacker and Bers (2015) reported how successful using the Lego WEDO robot set was in teaching basic programming concepts such as loop and decision-based to preschool students. In addition, Vatansever (2018) documented that using robots positively affected the problem-solving of fifth and sixth graders. Most of the aforementioned studies show that, in most of the robotics activities computational problems are given to students to be solved via educational robotics, and while acting in the robotics activities students gain various skills in the context of problem-solving and creativity.

The rest of the paper is structured as follows: Section 1.1 discusses creativity and problem-solving in educational robotics, while Section 1.2 covers descriptions and related work in the area of reverse engineering within educational robotics. We examine the relevant literature and identify research gaps in creativity and reverse engineering in computer science education. Following this, we present our research design and findings. Finally, we conclude with implications and suggest potential directions for future research.

1.1 Creativity and Robotics Problem-Solving

The application of educational robotics takes its roots in the constructionist approach (Danahy et al., 2014; Kafai & Resnick, 1996; Papert, 1981). While working in these constructionist situations, students think creatively and analyze the situation for problem-solving in real-world problems. Considering that creativity may be discussed in many broad senses, it is needed to understand the conceptualization of creativity in educational robotics contexts. Thus, general definitions, such as creativity being the generation of new ideas and innovative products (Kerr & Gagliardi, 2006), can be exhibited by engaging in robotics applications. In this process, creativity plays a crucial role in problem-solving, idea generation, conceptualization, theorization, and principle association (Azimpoor et al., 2017), helping to clarify the connection between robotics activities and creative outcomes. Prior research indicates that when given tasks designed to foster creativity in an educational setting, students are able to come up with innovative solutions and gain engineering competences by working through a range of computational issues. In addition to strengthening creativity, support, cooperation, and teamwork, educators seek to improve students' high-level thinking abilities, such as problem-solving, decision-making, and scientific inquiry (Eteokleous-Grigoriou & Psomas, 2013).

The studies on educational robotics in classrooms provided some beneficial effects on creativity (Afari & Khine, 2017; Chetty, 2015). In one of the studies, Adams et al. (2010) interviewed engineering undergraduates who completed a voluntary Lego Mindstorms robotics module involving programming LEGO Mindstorms robot. The results showed most of the participants' perceived that their creative thinking skills had improved. Similarly, Cavas et al. (2012) introduced students to building and programming robots and investigated the effect of a LEGO Mindstorms robotics course on students' scientific creativity and found that students' creativity had increased after the program. Huei (2014) conducted a five-week program where students were introduced to a programming language for coding robots. Following the program, most students reported positive changes in their perspectives on creativity and problem-solving performances. In another study, Jagust et al. (2017) presented the results of workshops for gifted elementary students utilizing LEGO Mindstorms robotic sets. Although the authors did not conduct a psychometric assessment of creativity, their qualitative analysis concluded that the children demonstrated creative productivity. Eteokleous et al. (2018) evaluated the creativity of primary school students after a 36-week intervention and found a significant enhancement in their creative abilities.

However, it is typically challenging to identify creativity in studies that involve problem-solving. Four characteristics of creativity were proposed by researchers: fluency, flexibility, originality, and elaboration. Fluency in creativity is the ability to generate a large number of ideas quickly and effortlessly. In flexibility dimension, the student should be allowed to switch about their group assignments as needed. Originality is used to describe when students approach challenges from many points of view. The goal of the elaboration is to get the learner to value the specifics as they work toward the answer (Almeida et al. 2008; Kim, 2006).

Educational robotics provides experiential and situational learning for problem-solving real-world problems (Benitti, 2012). Students can be encouraged to think critically, analyze situations, and exercise creative thinking by engaging in. Previous studies show that working with educational robotics may allow students to create various solutions for computational robotics problems. However, it is generally difficult for educators to construct learning environments to foster students' creativity. In this context, applying reverse engineering principles is used to support students in providing creative problem solutions in this study. Reverse engineering has been implemented in the field of mechanical components/assemblies, electronic components, and computer programs (Thayer, 2017).

In the educational robotics, students can examine existing robotic products to understand their construction, functionality, and programming. In this context, the potential of educational robotics for reverse engineering applications can provide innovative teaching methods for implementing robotics in education.

1.2 Reverse Engineering in Educational Robotics

Reverse engineering is defined as the process of creating a set of specifications for a piece of hardware by individuals other than the original designers, primarily through the analysis and measurement of a specimen or a collection of specimens. When using the reverse engineering approach, students examine existing systems to identify their components and the relationships among them (West et al., 2015). Thayer (2017) outlined the stages of reverse engineering as determining the design's purpose, observing its functionality, disassembling/distorting it, analyzing the components, and then reporting or redesigning based on the findings.

Reverse engineering helps students better understand the science behind design and the components of engineering design by offering them the opportunity to critically ask questions about design features (West et al., 2015). In this process, an existing product is examined and its detailed characteristics are sought to learn how the product is made and how it works. The reverse engineering process aims to reproduce an existing object by analyzing the dimensions, shape, and properties of the product or object (Batni et al., 2010). Thus, it is recognized as a powerful method for developing students' thinking skills (Dempere, 2009; Verner & Greenholts, 2016). It also enhances students' ability to systematically structure critical thinking (Griffin et al., 2012; Rogers-Chapman, 2014) and improves their logical thinking skills, thereby strengthening their analytical abilities (Klimek et al., 2011).

One of the prior studies emphasized the importance of reverse engineering in robotics education, particularly in fostering creativity and improving learning performance, although it requires careful planning and design (Zhong et al., 2021). Another study matched the numerical data provided by the software interface, using a suitable symbolic model of the robot dynamics. The results showed that including training and validation tests with additional dynamic validation experiments that use the complete identified model and joint torque sensor data (Gaz et al., 2014). In previous studies; while the reverse engineering approach has been explored in various contexts, examples of its application in robotics education for primary and secondary schools are still limited.

Reverse engineering with Lego Ev3 might begin with the robot as a whole so that students can analyze its parts, pieces, software, and other components. They can also work on it by putting it back together from the parts, or they can provide software to make it better or change it. Students may be able to use their creativity in reverse engineering through the robotics applications that incorporate both software and hardware components. By activating their creativity, students have the opportunity to modify the functionality of existing products by adding new components, sensors, or codes. Thus, we hypothesize that utilizing this type of robots could serve as a host for more creative expression.

1.3. Aim of the study

Considering the significance of reverse engineering in robotics activities, we seek to gain practical insights into how this approach impacts creativity and problem-solving. Thus, the following problem guided to research study:

Do robotics activities focused on reverse engineering impact the exhibition of creativity and robotics problem-solving performance among secondary school students?

2. Methods

The study focused on the potential of robotics activities for creativity and problem-solving. Since these experiences can be gathered through qualitative data, an exploratory case study was adopted to generate insights that can inform further investigation, particularly an underexplored area of reverse engineering. Explanatory case studies provide explanatory information to examine situations in detail to answer the questions "why" and "how" the cases occurred (Fisher & Ziviani, 2004).

2.1 Participants

The participants included 10 sixth-grade students (3 boys and 7 girls) enrolled in a computer science class at a private secondary school. Informed consent for participation in the activities was obtained from their parents. A preliminary interview was carried out to select the participants purposefully to ensure that they had no prior knowledge about robotic activities. Students were identified as S1, S2, and so forth.

2.2. Process

Participants were divided into three groups to carry out the activities. Two computer science teachers facilitated the sessions, encouraging students to take active roles. All activities spanned two lesson hours. In the first 15 minutes, students were introduced to the Lego EV3 robot, after which they assembled its components. They were tasked with identifying the robot's purpose, understanding how it operates, and learning how it is constructed. To explore the functions of its parts, students disassembled the robot. They were then asked to design a solution for the given task. Throughout the activities, the teacher posed guiding questions to encourage student creativity. One of the researchers, who also served as the teacher, observed their behaviors during the tasks and helped them when needed. Four activities in the study are Carrying objects, Creating a bridge from objects, Moving the ship, and Unloading from the tower. The activities were associated with the steps of reverse engineering approach practically as presented in Table 1.

Table 1. Robotics Problems Regarding Reverse Engineering

Robotics Problem-Solving	**Reverse Engineering**
Recognizing the problem Articulates the problem in their own words.	Establishing the design objective Monitoring its functionality
Reasoning Employs reasoning (illustrating) in connection with the question or problem. Design solutions Engages in a design project to formulate a solution that adheres to particular design requirements and limitations. For example, students create a piece of the robot (ie carry an object) write codes for the task, and test it by running the robot.	Disassemble/deform Analyze
Problem Solving Addresses the problem by constructing and programming the model, making adjustments as necessary. Sharing Discusses the problem and proposed solution with the peers.	Report/Redesign

For example, in the first activity (Carrying Objects), students were tasked with transporting items. They were provided with a robot and asked to identify its purpose. During this phase, guiding questions prompted students to observe how the robot functioned. Next, students disassembled the robot to examine its parts and understand their functions. They were then instructed to design a robot suitable for the task, taking all previous stages into account. Students made modifications to both the code and design of the robot. Finally, they presented their designs to the class.

2.3. Data Collection Tools

2.3.1 Open Ended Questions Form

Questions for Robotics Problem-Solving

Open-ended questions were asked to understand thinking processes in robotics problem-solving after being reviewed by two computer science teachers as experts. Six open-ended questions included in the test were asked to determine the problem-solving performances regarding the robotics problems. Some example questions are included in Appendix 2.

Questions for Creativity

To explain the students' exhibition of their creativity, open-ended questions in the form regarding the reverse engineering approach was used. The questions were directed to the students when they were acting on the tasks. Some examples are presented in Appendix 3.

2.4. Data Analysis

The qualitative data on the exhibition of creativity was analysed through content analysis of students' perspectives. Themes and codes were developed based on indicators of creativity and the relationships observed in students' behaviors while engaging in tasks. Robotics problem-solving performances were assessed through a framework regarding problem-solving and scored by problem-solving rubric designed by the researchers.

2.5. Robotics Problem-Solving Rubric

Open Open-ended questions for robotics problem-solving were analysed by using the Robotics Problem-Solving Rubric. The rubric is created by adopting Polya's problem-solving steps. The criteria for the given problems are shown in Appendix 1. Example questions and evaluations are shown in Table 2.

Table 2. Example questions and evaluations about robotics problem-solving rubric

Robotics Problem Solving Steps	**Evaluation of Students’ Statements**
Recognizing the problem	The problem was defined as follows: "How does the robot transport the object from its starting location back to the original point?" This student's statement was recognized as advanced, aligning with the advanced level in the rubric.
Reasoning	The statement, “If we design an additional part to prevent the object from falling and attach it to the robot, it can easily carry the object,” was assessed as a basic-level idea. This student’s response was deemed sufficient, corresponding to the sufficient level in the rubric.
Creating Alternatives	The robot’s ability to make the additional part that it can carry without dropping is considered a basic-level design. This design of the student was accepted as sufficient, coinciding with the sufficient level in the rubric.
Applying the solution	The student's inability to offer an alternative to the designed attachment to the robot to carry the object without dropping it coincided with the sufficient level in the rubric, and this design of the student was accepted as sufficient
Sharing	The students’ evaluations like “The robot was able to take the object from its location and move it to the starting point without any problems. The fact that the part is especially easy to attach and remove from the robot increases its functionality” was accepted as the advanced level.

The scoring was done by two different researchers who compared their scores. In cases where discrepancies arose, the researchers continued to evaluate until they reached a consensus and agreed on the final scores.

3. Findings

3.1. Students' Exhibitions of Creativity

The exhibition of students’ creativity were categorized into themes: reshaping, innovative ideas, leaving the current task, and detailing. Reshaping, one of the themes, focuses on the intention to alter the current design of the robot. Students' responses to the question" How can this robot be constructed differently?" are summarized in Table 3.

Table 3. Students' evaluations about "Reshaping"

Reshaping
Modifying the current *design* (n=3)
Generating alternative solutions by enhancing the current *design* (n=4)
Performing multiple tasks by creating additional components to *design* (n=4)
Creating new one while considering various variables of the *design* (n=4)
Achieving the solution through various approaches by utilizing different *code* blocks (n=6)
Completing the task more efficiently by employing different *codes* (n=2

Regarding the design, S1 stated: "If we change the design of the robot, we can design an additional arm", and S3 expressed: "A long arm can be added". Some other students pointed out the size of the code which was used to activate the robot. For example, S2 expressed that " I think if we use repetition blocks, we can solve more shortly", and S4 expressed that "We should utilize various code blocks for solution". Figure 1 shows a view of the design configuration in Activity 1.

Figure 1. A view from designing additional parts

Figure 1 illustrates students' behaviors as they create new components. The students indicated that while designing these parts, they aimed to enable them to perform multiple tasks. In this section, they created a new design by using various code blocks.

Another way of creativity is found in performing Innovative Ideas. The perspectives of students related to creativity are shown in Table 4.

Table 4. Students' evaluations about "Innovative ideas"

Innovative Ideas
Completing the task faster with different sensors(n=2) and proposing new project ideas (n=3)
Taking various functions into account (n=2)
Offering transactions that will facilitate the task (n=4)
Thinking alternative functions outside the robot's current role (n=3)

During their work, students were asked questions such as, "What would you like to change in this design?" "Can the designed part be made more functional?" and "Can this robot perform its task more efficiently? What would make that possible?" Some students responded with suggestions like, "We can do it in a shorter time using sensors," and "We can perform several tasks by assigning new tasks to the robot." These responses led to the emergence of innovative ideas.

A view from students exploring new solutions using sensors is shown in Figure 2.

Figure 2. A view from students exploring new solutions using sensors.

In the context of innovative ideas, students modified the codes related to the sensors, achieving the robot's final goal (the task outlined in Activity 2) by proposing new projects that incorporated different sensors attached to the robot. Another theme related to creativity was the Change of the Mission, which was further divided into two dimensions: coding and design. When asked, “Do you want to change the task?” students' responses were categorized under the theme of mission change. The perspectives were presented in Table 4.

Table 4. Students’ evaluations about “Leaving the current task”

Leaving the current task
Refusing the change because of an interest in design (n=3)
Refraining from job changes unless essential (n=3)
Focus on achievable tasks in codes (n=5)
Declining to change tasks due to interest in coding (n=2)
Declining a job change because of inadequate coding knowledge (n=3)

While some students declined to change the tasks, expressing, "No, I don't want to because I don't like to write codes," others agreed to move on to another part of the activity, stating, " No, I don't want to code; I'm not skilled at designing." which reflected their perceptions of coding tasks. Conversely, other students voiced their enthusiasm for design, saying, “I want to be a designer; it's more fun to design,” and “I don't want to change my task; I want to design.”

Some students were more focused on interacting with the robot and assembling the parts, showing less interest in coding. Their comments indicated a preference for creating new solutions by altering the robot's components and experimenting through trial and error. The evaluations of the students are illustrated in Figure 3.

Figure 3. A view from the coding and design tasks

Figure 3 shows that, the students who refused to change their tasks due to their interest in design continued to design tasks. A student working in the coding area accepted the task change and transitioned to the design area.

The last theme is detailing which includes detailing on coding and detailing on design. The evaluations of the students under the detailing theme are presented in Table 5.

Table 5. Students' evaluations about "Detailing"

Detailing
Attending to details in the solution process and *design* (n=4). Utilizing the *design* space with precision (n=4)
Concentrating on the specifics of the *coding* area throughout the process (n=5)

Given the emphasis students placed on details, they were asked: "Is detailing important during the activities?" and "What specific details did you focus on when building the robot?" Students provided responses such as, "Yes, I paid attention to the details, especially in the codes, because even the smallest code error can prevent the robot from starting," and "I focused mainly on the codes; dealing with design isn't my responsibility."

Regarding design, students noted, "The detail of the attachment designed is very important because many features must be considered for the robot to function," and "I paid more attention to the details in the design because coding is ineffective without proper design." These expressions indicate that students recognized the significance of writing accurate code, assembling components, and viewing the robot as an integrated system. They understood that thinking through their tasks in detail would aid in successfully completing them. Students considering the detailing are shown in Figure 4.

Figure 4. A view from the students considering the detailing

Figure 4 shows that students discussed the reason in detail of the attachment and the importance of this attachment in the creation of the event.

Overall, the students' perspectives demonstrate that participating in robotics activities through the reverse engineering approach enhanced their creative problem-solving abilities. Two key components; design, which pertains to the hardware, and code, which refers to the programming blocks, were essential in showcasing their creative ideas and behaviors.

3.2. Students' Robotics Problem-solving Performances

Robotic problem-solving performances were assessed and rated by analysing and categorizing students' solutions. Their perspectives on these solutions were aligned with Polya's problem-solving steps, which were adapted for the robotics challenges. The level of students' in robotics problem-solving performances is shown in Figure 5.

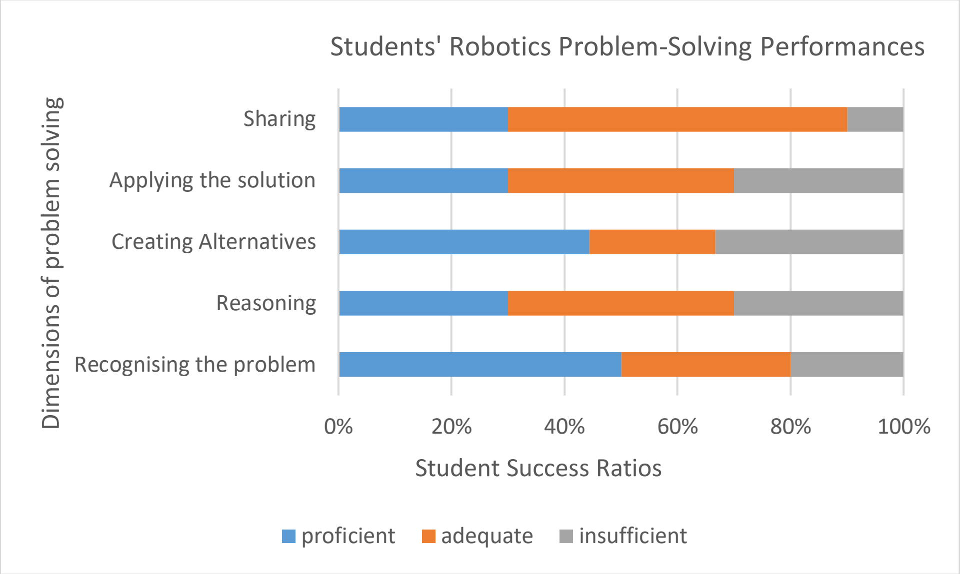

Figure 5. Students' robotics problem-solving performances

In the dimension of recognizing the problem, 5 out of 10 students participating in the research were at the "proficient" level, while 3 students were at the adequate level and 2 students were at the "insufficient" level. Regarding the reasoning, 3 out of 10 students participating in the research were at the “proficient” level, while 4 students were at the “adequate” level and 3 students were at the “insufficient" level. In addition, 4 out of 10 students participating were at the “proficient” level, 3 students were at the “adequate” level and 3 students were at the “insufficient” level. Moreover, in the sharing, 3 out of 10 students participating in the research were at the "proficient" level, while 6 students were at the “adequate” level.

Overall, the results indicate that engaging in reverse engineering positively impacted all components of problem-solving, with identifying the problem and designing solutions being particularly prominent skills during the implementation.

4. Discussion

This study investigated the impact of the reverse engineering approach in robotics activities in relation to creativity and robotics problem-solving. Initially, students built a basic robot using Lego Mindstorms sets, after which they were tasked with designing additional parts for specific challenges. It is believed that the parts created by the students contribute to the originality aspect of creativity. The students generated various designs that successfully met the tasks. This production of diverse ideas and innovative solutions for each activity is thought to positively influence the fluency aspect of creativity. Zhong et al. (2021) also found that students who used reverse engineering did noticeably better than those in the project-based study group and had greater levels of creative self-efficacy, which is consistent with our findings.

The study evaluated students' robotics problem-solving performances on a number of different fronts. It was noted that they had improved in terms of comprehending the issue, making clear the work at hand, and figuring out how to resolve it. Students were given several reverse projects reflecting engineering to understand the purpose of the robots and the assigned tasks during the robotics activities. The majority of students were able to reason, solve the problems, and take into account other viewpoints. Students were urged to come up with various concepts for how the robot would operate in this situation. Because of the variety of ideas that the students present, it is thought that this stage effectively fosters reasoning.

Students created solutions to the problems given in the activities and came up with alternative ideas. It is thought that the students used their different ideas in the reasoning step to design solutions. Students generally did not struggle with the assigned problems and presented various ideas related to reverse engineering. The reverse engineering in the robotics activities enabled students to comprehend the problem, engage in reasoning, and develop solutions. Subsequently, the design activities offered students the opportunity to create new designs and code, taking into account all the stages of the process. Similarly; West et al. (2015) highlighted that employing the reverse engineering approach allows students to ask insightful questions about design elements, enhancing their understanding of the engineering and scientific principles involved in the design process.

Students presented their solutions with their group members after finishing the assigned assignments. For the most part, students met the requirements for sharing. The students were given opportunities to participate actively in group settings within the parameters of the activities. Students with various ideas are thought to generate a creative environment through discussion, and the presentation the students made to evaluate the design they created at the end of the session was deemed sufficient. Similar to the current study, reverse engineering was shown to improve academic performance, increase the self-efficacy in programming, and have a favorable impact on their analytical and holistic thinking abilities when it comes to problem-solving (Abdüsselam, Turan-Güntepe & Durukan, 2022). Additionally, Taşçı and Şahin (2020) found that reverse engineering applications can enhance students' academic performance and problem-solving skills in science classes. Klimek et al. (2011) also explored the application of reverse engineering to teach scientific concepts, alongside engineering principles related to biomimetic robots. They reported that students gained both conceptual knowledge and practical mechanical engineering strategies through this approach.

Overall, the results supported the possibility of implementing reverse engineering activities in educational robotics. The beneficial effects on creativity and robotics problem-solving suggest that teaching problem-solving through robotics might be accomplished through reverse engineering. The activities in this study were modified to fit the phases involved in addressing problems. This could be one of the causes of the innovative solutions that have been developed.

This study is not exempt from limitations. The research was carried out with 10 students. Since the study is explanatory, a small sample provided to ensure analyzing the students' robotics problem-solving performances and creativity in detail. Since the study sample was small size, the effects with larger sample sizes should provide more sensitive results. In the activities, a limited number of robotic sets were used and the activities were carried out as group work as well as individual work. It should be noted that; concentrating on viewpoints gave us important information on how to use reverse engineering in educational robotics applications. Only the one type of the robots were taken into consideration while applying reverse engineering in this study. To learn about the building of robots and the possibilities of reverse engineering, alternative educational robots can be utilized.

5. Conclusion and Implementations

The study examined the impact of the reverse engineering approach in robotics activities on creativity and problem-solving skills. In terms of creativity, it can be concluded that reverse engineering activities can provide task-based flexibility. It has come beforehand to offer processes that will facilitate the task in the coding process. The reverse engineering approach facilitated to thinking of new functions of the robots using different sensors. The ability to do more than one task by designing an additional part by paying attention to many variables came forward. The situation of solving in different ways by using different code blocks is a contribution of the approach. One can infer that reverse engineering activities provide reshaping in terms of originality and the students act in more detail in the coding area and using the design. Considering the stages of problem-solving; students demonstrated performances in recognizing the problem, reasoning, creating alternatives, applying the solution, and sharing their results. The findings revealed that the reverse engineering approach had a positive impact on the recognizing problem, where students needed to fully understand the task by illustrating the problem with various examples.

Ultimately, the results indicate that the robotic activities based on reverse engineering had a positive impact on students' robotics problem-solving performances. Both the findings and limitations offer potential pathways for future educational robotics activities that focus on creative problem-solving strategies. We hope that the insights from this study will facilitate the future integration of the reverse engineering approach in teaching other computer science topics.

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Appendix 1. Robotics Problem Solving Rubric (RPS-Rubric)

Robotics Problem- Solving dimensions	**Criteria**
Recognizing the problem	Can s/he understand the given scenario and explain it in his/her own words?
Reasoning	Does it offer alternative ideas to find solutions?
Creating alternatives	Can s/he implement his/her solutions ideas?
Applying the solution	Can s/he create new projects by making changes in the design s/he applies?
Sharing	Can s/he share the design s/he created with his/her classmates?

Appendix 2. Questions about Problem Solving

Robotics Problem-Solving

How can this design be done differently? Can this robot run using different codes? Can this designed piece be made more functional? What kind of innovations does the design and code part of the redesigned robot include compared to the first designed robot? Can you introduce the redesigned robot to your classmates?

Appendix 3. Questions about Creativity

Creativity

Can you explain the given scenario in your own words? Does it offer alternative ideas to reach solutions? Can you implement your ideas?, Can you create new projects by making changes in the design you applied? Is its design/coding successful or not? Can you share the design you created with your classmates?