ORIGINAL ARTICLE

The Effect of Engineering Design-Based Science Instruction on 6th-Grade Students' Astronomy Understandings

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Abstract*: Astronomy education is essential for STEM education in primary schools, and integrating engineering design-based science education enhances student engagement and achievement in the field of space science. Integrating engineering design into science education is essential for students to excel in astronomy and to meet the requirements of contemporary society. This study investigated the effect of engineering design-based instruction (EDBI) on the understanding of astronomy concepts among sixth-grade students. The study included a cohort of 37 sixth-grade students from a public school. It was carried out using a one-group pre-test, post-test experimental design. All participants received EDBI that was based on the objectives of the 6th grade "Solar System and Eclipses" unit. Statistical analyses were employed to ascertain the effect of astronomy instruction based on engineering design on students' comprehension of astronomy concepts. The results indicated a significant difference in the average scores of students' understanding of astronomical concepts before and after being taught using EDBI.*

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Introduction

THE TWENTY-FIRST century requires more creative and innovative citizens; thus, countries should educate individuals, particularly young children, about the 21st-century needs to deal with evolving science and technology. Countries should prioritize science education to prepare people for 21st-century challenges such as information production, technology literacy, and innovation (Marrero et al., 2014). The significance of science education extends to both individual and societal levels, which significantly influences national objectives, including the advancement of science and technology and the enhancement of educational standards. In other words, scientific and technological advancements have highlighted the importance of revising national education policies (Tabaru, 2017) and directly influenced countries' perspectives on science education. Consequently, the majority of countries have found it necessary to update their K-12 science curriculum (Percy, 1998).

Engineering design-based science education has been proposed as a viable method for incorporating engineering practices into the science curriculum (Barnett et al., 2010; Hynes et al., 2011). The approach aims to provide science classes with processes to help them solve real-world problems. Furthermore, engineering design-based science education seeks to equip students with competencies that allow them to think like engineers when solving real-world problems (Daugherty, 2012). Engineering design-based science education improves students' 21st-century skills by requiring them to brainstorm, think critically, and communicate to complete the design process successfully. It also improves student success in science lessons and inspires them to pursue STEM careers (Hacıoğlu et al., 2016). The engineering design process (EDP) activities teach students to think like engineers, design products, and then develop these products to make them more useful. Design is a fundamental aspect of the engineering field. In other words, engineering cannot be completed without the design phase (Cunningham & Hester, 2007). The EDP allows students to use their theoretical understanding of science in practical contexts, which is especially important given the close relationship between engineering and science (Altan & Karahan, 2019). It includes a start and end interval for problem-solving, contributing to a need's emergence. This process creates environments where problem solvers can learn 21st-century skills such as scientific concepts, engineering insights, communication, idea generation, problem-solving, critical thinking, and information disaggregation (Schnittka et al., 2010; Wendell, 2008).

Engineering design-based science education is crucial to STEM education since it aims to establish interdisciplinary connections with other fields when designing products (Gencer, 2015). Engineering, as a component of STEM, is a profession with the ability and potential to positively or negatively impact people’s quality of life. Although engineering products are ubiquitous daily, studies show that students struggle to understand what engineers do (Frehill, 1997). Understanding the students’ perceptions of engineers and their perspectives on their work is also critical. Because these views shape students’ preferences for careers in engineering (Knight & Cunningham, 2004), engineering-related applications should be implemented in elementary school classrooms to change this and improve students’ engineering career interests. Students can also learn about the engineering profession and its diversity by collaborating with schools, engineering faculties at universities, and other institutions.

Astronomy Education

The first educational research on astronomy was carried out many years ago, and it focused on how students or people understood astronomical phenomena. Piaget began conducting scholarly research in early 1920 (Piaget, 1929). His books influenced subsequent research in this area. The following study examined local or global populations regarding astronomy education (Adams & Slater, 2000). According to the studies, many young children hold incorrect beliefs about fundamental astronomical concepts. Lanciano (2009) discovered that culture and mass media influence children’s lack of or incorrect astronomical knowledge.

The research strongly argues that astronomy should be included in educational curricula. Before incorporating astronomy into the national curriculum, the researchers inquired: “Why is astronomy not included in the curriculum?” (Percy, 2003). The seven reasons given in this research’s response to the question are: a) People do not think astronomy has anything to do with issues like health and the environment. b) Many teachers do not know the basics of astronomy. c) Most astronomical observations happen at midnight, and the tools needed are expensive. d) People in Western societies see astronomy as something only “Western” culture cares about. e) People’s personal beliefs and facts about astronomy differ. f) Because of translation issues, undeveloped and poor countries cannot access available resources. g) Astronomy requires advanced technology.

Astronomy encourages curiosity, imagination, and exploration; the universe helps young people develop their imaginations (Percy, 2006). Engaging in inspiring astronomy issues allows young people to broaden their perspectives and develop a holistic worldview (International Astronomical Union [IAU], 2012). On the other hand, astronomy is a dynamic science contributing to advancing science, mathematics, and technology. The most exciting science news today is primarily about astronomy. It is an excellent tool for encouraging students to become interested in science and technology.

Space exploration and life beyond Earth are fascinating subjects in their own right. These subjects can be integrated into science and mathematics education and linked to engineering and technology studies. Similarly, according to Percy (2006), astronomy provides an integrative approach across disciplines. In this way, it promotes connections and learning across different curricula. Astronomy, for example, makes use of a variety of mathematical concepts. Students who study basic motions in the celestial sphere can use math-based positioning and timing tools. Furthermore, astronomy allows for applying scientific methods, particularly observation (National Research Council [NRC], 2012; Percy, 2006). It also includes numerous examples of simulation and modeling in science. Astronomy topics are an excellent and exciting way for young people to begin rational and logical exploration of nature (IAU, 2012). Göğüş (2010) argues that primary and practical applications of astronomy not only enhance learning but also make it more lasting.

In this context, astronomy has a dynamic structure that promotes the advancement of science, technology, engineering, and mathematics, as well as feelings of curiosity, imagination, and discovery, including topics such as our cosmic origin and our position in time and space. It also promotes interest in science, technology, engineering, and mathematics by using scientific methods, conducting rational and logical research on nature, and providing an integrative approach across disciplines. As a result, astronomy is a valuable resource for STEM education. In conclusion, due to the nature of the subjects involved in astronomy, it can be used as an effective tool for both STEM and engineering education processes because it has the characteristics of arousing interest in STEM fields, enabling applications that include the integration of science, technology, and engineering based on the history of science, the nature of science, and scientific methods, and supporting young people’s career choices in STEM fields.

Significance of the Study

Although STEM education is used worldwide, science and technology are more popular than the other components in many countries. Engineering, represented by the letter “E” in the STEM acronym, is critical for developing people with 21st-century skills such as critical thinking and innovative thinking (Bybee, 2010; NRC, 2012). Many countries ignore the engineering component (E) by not incorporating engineering practices into their educational programs. However, the NRC (2010) recommends that nations educate students as future engineers in elementary and middle schools. Engineering activities have been integrated into the science curriculum; however, the goals of these applications are not clearly defined. Although younger ages have greater potential for developing engineering concepts, studies involving the administration of engineering design activities are typically conducted with older students (English & King, 2015). The current study investigated how to incorporate engineering design-based activities into 6th grade science classrooms. However, despite the high interest in incorporating STEM disciplines into lessons, there is little research on the best way to integrate engineering components into formal lessons (NRC, 2012). The current study aimed to fill this gap in the literature by developing engineering design-based activities that addressed various aspects of the engineering design process.

The current study incorporated EDBI into science course. When the literature on astronomy education was reviewed, countries began to prioritize astronomy education after developing space technologies, and as a result, they attempted to incorporate astronomy education into their educational curricula (Percy, 1998). As an elective or unit within the science curriculum, astronomy is often included in national science programs rather than being taught independently. Many countries recognize the importance of astronomy education but students still face challenges and misconceptions when it comes to astronomy (Adams & Slater, 2000; Keçeci, 2012; Lubben, 2009). The existing body of literature indicates that students at various academic levels encounter difficulties in understanding astronomy concepts (Baloğlu Uğurlu, 2005; LoPresto & Murrell, 2011). Additionally, there is evidence of misconceptions in the field of astronomy (Ekiz & Akbas, 2005; Göncü, 2013; Korur, 2015).

The present study focused on astronomy topics to enhance students' understanding and determine how their understanding of these topics could be improved. According to Arslan and Koparan (2020), astronomy education holds significant importance within STEM education in primary schools. Additionally, Acut and Latonio (2021) suggest that engineering design-based science education enhances student engagement and achievement in space science. So, it is evident that teaching science through engineering design is essential for students' academic success in astronomy and meeting modern world demands. Students can enhance their understanding of astronomy objectives while learning about the engineering design process (analysis, critical thinking, and brainstorming) through engineering-based astronomy activities (Voss & Dailey, 2012). Despite the fact that engineering design-based science instruction improves students' understanding of astronomy concepts, research into the development of engineering-based education focuses primarily on subjects such as the environment, electricity, and basic machinery (Cunningham, 2009). Given the dearth of research on the topic, the present study opted to focus on engineering design-based astronomy education, even though it is widely recognized that such an approach is well-suited to astronomy education and enhances students' grasp of astronomical concepts.

The purpose of this study was to investigate the impact of engineering design-based science education on sixth-grade students' understanding of astronomy concepts. Consequently, the study was driven by the following research question: What is the effect of EDBI on 6th-grade students' understanding of astronomy concepts?

Methods

The study aimed to investigate how engineering design-based science instruction affected sixth-grade students' understanding of astronomy concepts. A one-group experimental research design was used. The study's data was obtained using quantitative research methods. Due to insufficient participants in both the control and comparison groups, a single-group pre-test-post-test design was employed. The one-group pre-test-post-test design does not allow for participant randomization. According to Campbell and Stanley (1963), this method can be applied to samples that are not very large. The study's independent variable is EDBI, while its dependent variable is sixth-grade students' understanding of astronomy concepts.

Participants

The study comprised 37 6th-grade students enrolled in a public middle school located in a rural city in Turkey. Their ages ranged from 10 to 12 with a nearly equal distribution across genders within the class (19 females and 16 males). Accordingly, the convenience sampling method was used by the researchers. This technique involves selecting individuals readily available for the study and is widely used due to its ease of implementation and accessibility (Fraenkel et al., 2012).

Data Collection

The data were gathered through the Students' Understanding of Astronomy Concepts Scale (SUACS) (Ekiz & Akbaş, 2005). It was used to assess students' comprehension of astronomy concepts. This scale consists of ten open-ended questions divided into four sections, each focusing on specific topics such as the universe, solar system, stars and planets, and orbit.

Treatment

The experimental research design process was carried out with a single group. Each participant received astronomy education grounded in engineering design principles. The treatment process lasted eight weeks and consisted of a total of 26 hours of lessons. The first researcher conducted the instructional process by delivering EDBI. The data collection tools were administered as pre- and post-test. Participants were given these tools during the first and last weeks of treatment. Hence, the participants received six weeks of engineering design instruction. Before instruction, the researchers created three engineering activities titled “Meeting with Engineers,” “Design the New World,” and “Design a Spacecraft.” These activities were developed based on the related science concepts for the topics in the 2018 Turkish Science Curriculum. While the first lesson plan introduces students to the engineering profession and the engineering design process, the final two lessons relate the “Solar System and Eclipses” concepts to the engineering design process. On the other hand, all lesson plans strive to engage students by actively discussing, brainstorming, and questioning; in addition to active participation, these lesson plans were created to pique students’ interest in the topic.

The class instructions for “Design the New World” and “Design a Spacecraft” were developed based on engineering design activities that follow a sequential stage of the engineering design process. This process includes problem definition, identification of potential solutions, analysis, and selection of the optimal solution, testing of the chosen solution, and, if required, revisiting any preceding step. Students were assigned the challenge of constructing and evaluating a prototype as part of these activities, aligning with the implementation of Wendell et al.’s (2010) engineering design process. The researchers developed activity sheets structured around the engineering design process to facilitate the organization of instructional flow. To clarify, the instructions for “Design the New World” and “Design a Spacecraft” provided activity sheets that were centered on the steps of the engineering design process and the specific subjects of each activity. The activity sheets were designed to facilitate students’ comprehension of the steps and enable them to navigate back to previous steps more efficiently, if necessary.

EDBI

In this part, the activities of the study are explained in detail. In addition, the table of instruction schedule was given. The table below shows a detailed instruction schedule (**Table 1**).

Meeting with Engineers. During the second week of treatment, students had the opportunity to meet with two distinct computer engineers. The guest engineers were selected, one being a female and the other being a male, in order to refute the prevalent notion that “the field of engineering should be exclusively pursued by men.” The researchers planned the online meeting with the two computer engineers to align with topics concerning the characteristics of the engineering profession, engineers’ experiences, and the

Table 1. Instruction Schedule.

Week	Administration/Duration	Tool
1st week	A pre-test was conducted using two distinct instruments to assess students' understanding of astronomy concepts.	Data collection Instruments
2nd week	The activity and presentation titled "The Meeting with Two Engineers" were conducted to provide an explanation of the "Engineering Profession" and the "Engineering Design Process." Furthermore, the administration of EDBI, which is based on the objectives of Solar System concepts, was initiated for the class.	Design the New World Lesson Plan
3rd week	1) Describe a problem, 2) Finding possible solutions, and 3) Choosing the best solution 4) Building the prototype; planning prototype activity, planning design activity step of EDP was administered.	Design the New World Lesson Plan
4th week	5) Test the prototype step; evaluation and presentation of each group of EDP step were administered. Also, the project evaluation and self-evaluation sections were administered.	Design the New World Lesson Plan
5th week	EDBI based on the topic of "Solar System" was administered to the class.	Design the Spacecraft Lesson Plan
6th week	1) Describe a problem, 2) Finding possible solutions, and 3) Choosing the best solution 4) Building the prototype; planning prototype activity, planning design activity step of EDP was administered.	Design the Spacecraft Lesson Plan
7th week	5) Test the prototype step; evaluation and presentation of each group of EDP step and, the assessment and self-evaluation sections were administered.	Design the Spacecraft Lesson Plan
8th week	Two distinct assessment tools were administered as a post-test to assess students' understanding of astronomy concepts.	Data collection Instruments

engineering design process. Students met with engineers and learned how they apply the engineering design process to their projects shared by guest speakers. To pique the students' interest, the second lesson began with the question, "Do you want to be an engineer for your future career?" and then moved on to "What type of engineering have you heard of?" The researcher presented the concepts of "Nature of Engineering" and "Engineering Design Process" to the students. The researcher facilitated discussions among students regarding the engineering profession, including the different types of engineers and their key characteristics. The second aspect of the presentation was the Engineering Design Process (EDP), which was presented as a diagram to assist students in visualizing and understanding the circle of process. After thoroughly reviewing each step of the EDP with the students, the researcher asked them to relate their experiences to those mentioned by the guest engineers. The presentation ended with the question, "If there were no engineers, what would happen to the world?"

Design the New World. During the subsequent two lesson hours, the participants were provided with engineering design-based science instruction on the topic of the "Solar System" The lesson began by assessing the students' prior knowledge of the solar system gained in previous academic years. They were asked the following questions: "What is our celestial body called?" "Does the Earth possess any natural or artificial objects orbiting around it?" and "Can you name any celestial bodies that orbit the Sun in our solar system?" After background information was gathered, students were introduced to the lesson topic through a video presentation. Furthermore, the researcher taught students about the solar system, encompassing topics such as the Sun, planets, orbits, and asteroids.

The third week of class started with the engineering design process activity titled "Design a New World." The researchers prepared the activity by following the steps in the engineering design process. In addition, "The Handbook of Engineers Team Activity Sheet" was developed serving as a valuable resource for both students and the researcher to manage the lesson more effectively. At the beginning of the lesson, students were divided into small groups of three or four and each group received a copy of the activity sheet. They were told to act like engineers throughout the activity and follow EDP steps. The researcher initiated the activity by presenting the scenario while displaying it on the smart board. Following the scenario, the lesson covered three EDP steps: 1) describing a problem, 2) identifying potential solutions, and 3) choosing the best EDP option. To ensure students followed the EDP steps during the activity, the researcher projected the engineering design process steps onto the smart board. Students collaborated as a team to identify issues in a given scenario.

After identifying the problem, students were expected to investigate potential solutions by analyzing previous solutions or brainstorming new ideas. While researching possible solutions, students determined where humans could live in the solar system and built a living space. The students used their knowledge of the solar system's planets, stars, asteroids, and satellites to locate an appropriate living space. They identified the properties of these celestial bodies, such as temperature (hot or cold), terrestrial or Jovian planets, physical features (mountains, caves), and suitability for human use. The student groups evaluated their potential solutions and then conducted research using computers and scientific magazines to explore the advantages and disadvantages of each option. After conducting research, brainstorming, and group discussions, the groups determined the best solution to the scenario's problem. After completing the first three steps, students moved on to the next phase of EDP, which involved building and testing prototypes over the next two lesson hours of the third week. Student groups created model drafts that incorporated details such as the materials utilized and brief descriptions introducing the systems or components of living spaces. As a result, the choice of materials used was determined based on these detailed drawings. Then, each group developed a prototype of the best solution identified in the previous step. In the first two lessons of the fourth week, students tested their prototypes using the activity criteria. The evaluation criteria rubric provided in the activity sheet was used to evaluate each group's prototype. Subsequently, students were asked to answer conceptual questions in the "Project Evaluation" and "Self-Evaluation" sections of the worksheet. These sections asked questions about the design process, potential redesign concepts, and engineering design process steps.

Design a Spacecraft. During the fifth week of treatment, Students were actively engaged in the engineering design process activity titled 'Design a Spacecraft' for two hours. Initially, the researcher used the questioning method to gather students' prior knowledge. After receiving the students' responses, the researcher reviewed each question in detail. The simulation was used to answer questions and visualize concepts about the solar system. Finally, the researcher explained how a planet's distance from the Sun affects its properties. Afterwards, the "Handbook of Engineers for Space Mission" activity sheets were distributed to student groups. Students were expected to act like engineers during the activity and complete each step in groups, as they had done in the previous activity. In the classroom, the researcher introduced a scenario about the solar system, emphasizing an engineering team's experience with a failed space mission. While the procedures for the previous and current activities were identical, the "Design a Spacecraft" task required students to select which EDP steps to begin with based on their proposed solutions. The student groups debated the issue in the given scenario. After describing the problem, the activity led them to identify the most fitting step of the Engineering Design Process (EDP) for their solution. Each group justified their choice of EDP step by providing reasons. One group decided to start by "finding possible solutions," which included researching new solutions to the problem on the Internet and in scientific magazines, as well as analyzing existing solutions to ensure that they met the requirements of the problem. Meanwhile, another group decided to start with "choosing the best solution"; analyzing the given possible solutions in the scenario, and then replacing the best solution with another one from within the possible ones. Each group continued the activity during the next two lesson hours by developing an EDP prototype step. Student groups created detailed model drafts that included mentioning the materials used as well as briefly introducing the spacecraft's parts and components; as a result, the materials to be used were determined by their drawings. Finally, the groups created prototypes using their best solutions from the previous step. In the first two lessons of the seventh week, students tested their models using the activity's criteria. The evaluation criteria rubric presented in the activity sheet was used to evaluate each group's prototype. In addition, one group member gave a brief presentation to the class about their models.

Data Analysis

Given that the study employed a one-group experimental pre-test post-test design, the data from The SUACS was analyzed using the paired sample t-test. The SUACS was a questionnaire that allowed for open-ended responses. The data collected from the SUACS was organized and analyzed using a rubric developed by Ekiz and Akbas (2005), who categorized students' understanding levels into five categories: sound understanding, partial understanding, no understanding, specific misconceptions, and no response. The interrater agreement method was employed to classify students' responses based on the provided scale. The researcher compared their analysis with that of another researcher who possesses both a master's degree in science education and is an active science teacher. Cohen's Kappa statistics were utilized to determine the level of concordance among researchers. The study found that the interrater reliability among the researchers was measured at Kappa = 0.64, indicating a "substantial agreement" level of agreement. To transform the students' responses on the provided scale into numerical data, the researchers categorized the levels of understanding and assigned these categories a numerical value— "No Response", "Specific Misconceptions," and "No Understanding" levels were grouped and assigned as "0 (zero)" point while "Partial Understanding" was assigned as "1 (one)" point. Lastly, the understanding level of "Sound Understanding" was given as a score of "2 (two) points" on the scale.

The normal distribution of the data gathered through the SUACS was assessed using the Shapiro-Wilk test due to a sample size smaller than 50 participants. Results indicated that the data followed a normal distribution, as the obtained value (p = 0.302) was greater than the alpha value (0.05) (Pallant, 2010). Consequently, the assumption was not violated, parametric test was appropriate for the SUACS due to the normal distribution of the collected data. The paired sample t-test was employed to analyze the data.

Findings

This section presents the major findings of the descriptive and inferential statistical analyses of the data obtained after administering the SUACS, measuring the effect of the EDBI on students' understanding of astronomy concepts.

Effects of EDBI on Students' Understanding of Astronomy Concepts

Table 2. Descriptive Statistics of Experimental Group.

	N	$\bar{x}_{pre}$	$\bar{x}_{post}$
Study Group	37	4.63	8.67

Table 3. Paired Sample Statistics of Astronomy Understanding.

	Test	***N***	***M***	***SS***
SUACS	Pre-test	37	4.63	2.643
	Post-test	37	8,67	3.333

Table 4. Paired Samples Test of Astronomy Understanding.

	M	***SD***	***t(36)***	***p***	**Cohen's *d***
SUACS	4.036	2.872	+8.550	0.000	11.586

Descriptive statistics for the pretest and posttest results for the astronomy understanding are displayed in **Table 2** which presents the statistical summary of the study group.

Upon examination of **Table 2**, it was determined that the mean score of the pre-test was $\bar{x} = 4.63$, while the mean score of the post-test was $\bar{x} = 8.67$. As observed, the students' average scores increased after the instructional intervention.

The paired sample t-test was used to determine if there was a statistically significant difference between the mean values of the pre-test and post-test. The mean scores of the students' comprehension of astronomy concepts before and after EDBI were analyzed. **Table 3** presents the statistical data for the paired samples on students' understanding of astronomy concepts.

Table 4 indicates that the p-value for the test is less than the significance level ($p < 0.05$), so there was a significant mean difference in students' astronomy understanding between the pre-test and post-test, t (36) = 8.550, $p < 0.05$ with a large Cohen's d value of 11.586. The results indicated that the post-test results (M = 8.67, SD = 3.333) was significantly higher than pre-test results (M = 4.63, SD = 2.643), t(36) = 8.550, p = < 0.05. This result indicated that students' comprehension of astronomy improved after introducing engineering design-based science instruction. The Cohen's d test was also calculated to find the effect size of the study which was found to be large according to Cohen’s (1988) criteria, as the calculated d value exceeded 0.8, indicating a large effect size.

The five concepts on the scale (universe, solar system, stars, planets, and orbit) were comprehensively examined. Frequency distribution tables of pre-test and post-test values with percentages are displayed below. Additionally, responses indicating “no understanding,” “specific misconception,” or “no response” were grouped into a category labeled “no understanding level” within the tables. These tables also present student responses on both the pre-test and post-test, frequency distributions.

Universe

The first two questions centered on the concept of “universe” in astronomy. A statistical analysis was conducted to compare the students’ comprehension levels before and after introducing EDBI focused on the concept of the universe. The data on students’ comprehension of the concept of the universe is displayed in **Table 5**.

The statistical analysis showed an increase in students’ partial understanding level and a decrease in students’ no understanding level after the EDBI. Students’ inadequate and illogical understanding of the concept of the universe decreased after EDBI. **Table 6** displays the sample responses of students before and after the implementation.

Solar System

Questions three to five were designed to assess students’ understanding of the solar system concept. **Table 7** displays the statistics regarding students’ comprehension of the concept of the solar system.

The statistical analysis showed an increase in students’ partial understanding and sound level frequency, indicating that students gained a better understanding of solar system components following EDBI. Moreover, there was a decrease in the frequency of students exhibiting no understanding after the implementation of EDBI. **Table 8** provides examples of the students’ responses to the solar system concepts before and after the implementation.

Stars and Planets Concepts

Questions six to eight of the questionnaire were specifically designed to assess students’ understanding of concepts related to stars and planets. **Table 9** displays the statistics regarding students’ comprehension of concepts related to stars and planets.

Table 5. Frequency and Percentage Values for Universe Concept.

	No understanding				**Partial Understanding**				**Sound Understanding**			
	f_{pre}	%	f_{post}	%	f_{pre}	%	f_{post}	%	f_{pre}	%	f_{post}	%
Q1	36	97.3	25	67.5	1	2.7	12	32.4	0	0	0	0
Q2	28	75	26	70	9	24.3	11	29.7	0	0	0	0

Table 6. Example Responses of Students to Universe Concept.

Test Type	**No Understanding**	**Partial Understanding**	**Sound Understanding**
Pre	The universe is our environment. The trees and animals constitute the Universe.	The Earth, the Sun, and the Moon are parts of the Universe.	
Post	The Earth where humans are living on is the Universe.	The Solar System is part of the Universe.	

Table 7. Frequency and Percentage Values for Solar System Concept.

	No understanding				**Partial Understanding**				**Sound Understanding**			
	f_{pre}	%	f_{post}	%	f_{pre}	%	f_{post}	%	f_{pre}	%	f_{post}	%
Q3	30	81.1	14	37.8	6	16.2	17	45.9	1	2.7	6	16.2
Q4	35	94.6	23	62.2	2	5.4	12	32.4	0	0	2	5.4
Q5	8	21.6	2	5.4	7	18.9	1	2.7	22	59.5	34	91.6

Table 8. Example Responses of Students to Solar System Concept.

Test type	**No understanding**	**Partial Understanding**	**Sound Understanding**
Pre	The sky, stars, the Sun, the Moon, the Earth, and the universe are made up of the Solar System. In order to formation of one day.	The Sun is at the center, and eight planets and Pluto, and maybe meteorite are made up the Solar System. The Earth has a path around the Sun, and it has to follow this path.	The solar system consists of eight planets moving around the Sun, their satellites, and asteroids.
Post	All stars and all planets in space come together, and they form the solar system When the Earth revolves around the Sun, the night and day occur.	The solar system has the Sun and eight planets inside of it. The Earth has a rotational path, and it always follows this path without stopping.	The system in which the Sun is at the center and eight planets and their satellites revolve around the sun is called the solar system… The Earth has an orbit around the Sun and follows this orbit periodically.

Table 9. Frequency and Percentage Values for Stars and Planets Concept.

	No understanding				Partial Understanding				Sound Understanding			
	fpre	*%*	*fpost*	*%*	*fpre*	*%*	*fpost*	*%*	*fpre*	*%*	*fpost*	*%*
Q6	21	56.8	17	45.9	16	43.2	17	45.9	0	0	3	8.1
Q7	29	78.4	13	35.1	7	18.9	21	56.7	1	2.7	3	8.1
Q8	17	45.9	8	21.6	20	54.1	25	67.5	0	0	4	10.8

Table 10. Example Responses of Students to Stars and Planets Concept.

Test type	No understanding	Partial Understanding	Sound Understanding
Pre	Jupiter is the biggest planet. The satellites are white, but planets can be different colors. No. Because the stars are only seen at night.	The stars are natural light sources while the planets are not the light source. The planets revolve around the stars, for example, the Earth and the Sun. Yes. Because the Sun sends its light to the Earth like other stars.	The biggest difference between them is that the satellite revolves around the planet, and the planet revolves around a star. For example, solar system.
Post	The planet rotates on its own axis, but stars are motionless The satellites consist of asteroids, but planets are not. No. Because the Sun is bigger than stars.	A planet may have a satellite, but a star does not have a satellite. A satellite revolves around a planet; that is the difference. Yes. The stars and the Sun are shining, and they are natural sources of light.	The stars are a light source, but planets are not. They are hotter and bigger than planets. Planet: revolves around the star (like the Sun). Satellite revolves around the planet (like Earth) Yes. All stars give heat and light to their surroundings. The Sun is the heat and light source of our Earth, so the Sun is a star.

Table 11. Frequency and Percentage Values for Orbit Concept.

	No understanding				Partial Understanding				Sound Understanding			
	fpre	*%*	*fpost*	*%*	*fpre*	*%*	*fpost*	*%*	*fpre*	*%*	*fpost*	*%*
Q9	21	56.8	10	27.0	15	40.5	23	62.1	1	2.7	4	10.8
Q10	17	45.9	8	21.6	15	40.5	23	62.1	2	5.4	6	16.2

Table 12. Example Responses of Students to Orbit Concept.

Test type	No understanding	Partial Understanding	Sound Understanding
Pre	It means around the Earth in the Space. Maybe all meteorites would fall to the Earth.	The path the Earth revolves is called by the orbit. I think the planets collide with each other.	The path is drawn by the body in space around other celestial bodies like a star. The moon hits the Earth first, and then the Earth hits the Sun; it could even burn. I think it would be like this.
Post	There is an orbit between the Sun and the Earth. There would be no planets.	The path where planets constantly travel through space, for example, the orbit of the Earth. The Earth and its twin Venus would collide because their orbits are close together.	The Orbit is the path that a celestial body makes around another celestial body while it is revolving. All the asteroids in the asteroid belt would scatter into space. The planets collide with those asteroids.

The statistical analysis revealed an increase in students' partial understanding and sound level frequency after receiving EDBI. The students distinguished planets from other celestial bodies (stars and satellites) more logically. The incidence of students' comprehension difficulties decreased following EDBI. **Table 10** provides illustrative examples of students' responses to the concepts of stars and planets.

Orbit Concept

The last two questions in the questionnaire focused on assessing comprehension of the orbit concept. **Table 11** displays the statistics regarding students' comprehension of the orbit concept.

The statistical analysis revealed an increase in students' partial understanding level and a decrease in students' no understanding level after the EDBI. After EDBI was implemented, the students gained a comprehension of the components of the orbit concept. **Table 12** displays the students' sample responses regarding the concept of stars and planets.

Discussion

This study investigated the impact of engineering design-based science education on 6th-grade students' understanding of astronomy concepts. According to the findings of this study, students' mean scores after receiving EDBI were higher than before treatment. Furthermore, the mean difference between students' pre-test and post-test scores was significant. In the current study, students were taught through instruction on engineering design process activities based on astronomy topics. These students created prototypes to solve astronomy problems by following the steps of the engineering design process. This experience may improve students' understanding of astronomy after the treatment. In this regard, Wendell and Rougers (2013) reported findings consistent with those of the current study, concluding that engineering education led to an increase students' average science course scores. Students performed better in science classes when engineering design process steps were included (Yıldırım & Altun, 2015), and students who received science education based on engineering design had a better grasp of the material (Guzey et al., 2016). A study that combined engineering education with the aerospace and space fields revealed that this field was a good fit for engineering design-based education. Students also used the engineering design process to develop appropriate problem solutions (English et al., 2013). Based on these findings, it is possible to conclude that the engineering design steps positively impacted the students' success and understanding of the science course. In contrast to the findings of the present study, it was stated that engineering education made a significant difference in the success of only high-achieving students (Doppelt et al., 2008). The lack of consensus among these studies may be attributed to the different measurement tools used in these studies. Unlike the current study, this study collected data using a standardized knowledge test. According to the researchers of the aforementioned study, knowledge tests may not accurately measure students' success because, when the designs of the students were examined qualitatively, it was discovered that students with a low level of achievement had lower test scores than high-level students. In contrast, their designed products could be as suitable for the problem as the other high-level achievement students.

This study discovered that after implementing engineering design-based education, students provided more robust scientific explanations for their answers. For example, in the pre-test, students answered that the sun is a star because it is bright, whereas in the post-test, they explained that the sun provides heat and light. While explaining the difference between a planet and a satellite, the pre-test results only included examples of Earth and the moon. In contrast, after receiving engineering design instruction, the students demonstrated the differences between the planet and the satellite using their movements. Similarly, Purzer et al. (2015) found that engineering design-based education improves students' understanding of science content and promotes more meaningful science learning. According to the study, design-based activities helped students provide better scientific explanations. Furthermore, engineering design-based education has improved students' decision-making and critical thinking skills while also developing conceptual understandings of science topics (Fan & Yu, 2015). Guzey et al. (2019) conducted a study to determine the impact of participation time in engineering design-based science education on knowledge development. They found that engineering activities were critical in developing students' knowledge. Another study found that design-based activities effectively structured scientific knowledge and that these designs serve as a bridge for science education (Fortus et al., 2004). Similarly, the current study found that students provided better scientific explanations after receiving engineering design process activities. The current study included activities that followed the engineering design process steps, and it was discovered that implementing these activities improved students' understanding of astronomy.

The activities in this study required students to perform analyses to identify problems. As a result of the analysis, the students researched the concepts they believed they did not fully understand to build a scientific foundation. Furthermore, students compared various concepts to determine a possible solution. For example, they compared stars, satellites, and planets to determine which celestial body can support life based on features like atmosphere, landforms, and temperature. The engineering design process may have provided students with a scientific understanding of astronomical concepts. Furthermore, English and King (2015) emphasized the importance of each stage of the engineering design process, particularly the redesign phase, in developing disciplinary knowledge. Similarly, the presented study focused on the EDP redesign step and required all working groups to explain "what they would change if they wanted to make changes in their models." As a result, students may be able to reflect on their mistakes and identify areas for improvement.

Adams and Slatter (2000) discovered that students struggled to understand the solar system and its components and had numerous misconceptions when it came to astronomy. Although the pre-test of the current study yielded similar results, the post-test results revealed that the frequency of students explaining all correct components of responses increased. In contrast, students with misconceptions and illogical responses to the solar system concept decreased. Students stated that before EDBI, there were many stars in the solar system, the largest of which was the sun. According to the post-test responses, the students believe that the solar system contains only one star, which is known as the Sun. The studies conducted with sixth-grade students and measuring students' understanding of astronomy concepts revealed that students had difficulties in understanding the concepts of orbit and universe in particular and misconceptions about these concepts (Ekiz & Akbaş, 2005; Keçeci, 2012). The pre-test results of the current study were similar to those of previous studies, indicating that students had misconceptions, particularly about orbits. However, when examining the post-test results, it is clear that the students' understanding of the orbit concept has improved because the frequency of students with no understanding has decreased following EDBI. Students' understanding of the orbit concept and overcoming misconceptions may have been aided by the EDBI they received, as one of the problems assigned to them was related to the concept of “orbit.” The students conducted extensive research, group discussions, and brainstorming on the orbit concept while attempting to define a problem and find potential solutions. In this way, students may have gained a conceptual understanding of orbit. The study found that students’ understanding of astronomy topics improved after receiving EDBI. The students better understood astronomical concepts like the universe, solar system, planets, stars, and orbit, and they could provide more logical and scientific explanations. This could be because engineering design-based education was appropriate for teaching astronomy subjects; it encouraged students to think at a higher level, such as decision-making and critical thinking, resulting in more meaningful learning (Arslan & Koparan, 2018; Lin et. al., 2015; Purzer et al., 2015). As a result, the current study can conclude that integrating astronomy-based activities into the engineering design process improved students’ understanding of astronomy topics.

Engineering plays a vital role in the developing world, so engineering education should be integrated into primary school science lessons to produce more skilled individuals (Banks-Hunt et al., 2016). Engineering design-based science education, which includes engineering design process activities, is how the engineering field is introduced into the science curriculum. These engineering design process activities improve students’ performance in science lessons (Fortus et al., 2004), and they gain a better understanding of science concepts and overcome misconceptions (English & King, 2015; Purzer et al., 2015). In the same vein, the present study showed that students’ understanding of astronomy concepts improved positively after receiving EDBI based on astronomy topics, as the mean of students’ scores on the post-test was higher than the mean scores on the pre-test. Furthermore, the pre-and post-test mean scores differed significantly. After EDBI, students gained a better scientific understanding of the universe, solar system, stars, planets, and orbits. According to the current study’s findings, while the frequency of students responding to logical and scientific answers increased, the frequency of students who could not explain their answers or responded to illogical answers decreased in the post-test. Engineering design process activities should be provided to students as often as possible in order for them to overcome misconceptions and develop concepts (Guzey et al., 2019). Thus, it can be concluded that engineering design-based science education improved students’ comprehension of astronomy concepts.

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