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THE EFFECTS OF STEM ACTIVITIES ON 6TH GRADE STUDENTS' CONCEPTUAL DEVELOPMENT OF SOUND

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Abstract. *Engineering design process-oriented STEM activities are activities that involve solving a real-world problem with teamwork by using integrative engineering design and engineering applications using scientific and mathematical concepts and 21st century skills. The research aimed to examine the effects of engineering design process-oriented STEM activities, which were developed for sound concept, on the conceptual development of 6th grade students. In the research, comparative case study design was used. The study group consisted of 40 students attending a middle school in Kayseri, Turkey. The teaching was carried out by the activities in science curriculum in the control group, while it was carried out by engineering design process-oriented STEM activities in the experimental group. Each student was individually interviewed using 11 open-ended questions in a verbal format. The mean of Kappa coefficients of the questions was 0.93. As a result of content analysis, 11 categories, including 21 themes and 81 codes, were obtained. When the differences between pre- and post-interviews were examined, it was seen that conceptual understanding levels of the students in experimental group were more positive than the students in control group. This shows that engineering design process-oriented integrated STEM activities have positive effects on students' conceptual understanding of sound.*

Keywords: *case study, conceptual development, engineering design, STEM*

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Introduction

Societies are dominated and directed by ideas and products from science and technology, and undoubtedly, the impact of science and technology on life will continue to increase in the next years (Jenkins, 2002). Science, technology and innovation are highly interdependent. Our daily needs are met with the information obtained through science, and technology applications are included in almost every step taken to make our lives easier. Societies that do not want to lag behind in scientific and technological innovations aim to educate individuals who understand mathematics and science concepts well and associate these concepts with daily life. Countries that want to advance in science and technology are adopting new teaching approaches that will make students competent in science and technology. In a similar manner, in Turkish science curriculum, one of the eight basic competences that students will need in their personal, social, academic and business life at national and international level is determined as 'mathematical competence and basic competences in science/ technology'. In addition to this update, 'life skills' and 'engineering and design skills' were added to science process skills. Thus, students are expected to show performances such as designing a project, setting models and products, and advertising a product. In the curriculum, which prioritizes the implementing and providing input to the economy properties of science, the topics and learning outcomes are handled with an approach that considers the production of technologies to meet the needs of daily life (MoNE, 2018).

STEM education aims to integrate science, technology, engineering and mathematics with multidisciplinary, interdisciplinary and transdisciplinary approaches (Vasquez et al., 2013). STEM education is thought to be critical for the development of students' 21st century skills (Topcu & Gokce, 2018). Science curriculum aims to enable students to look at the problems from the interdisciplinary point of view by integrating science with mathematics, technology and engineering (MoNE, 2018). In this context, engineering design-based STEM (science, technology, engineering, and mathematics) education, which enables students to gain a multidisciplinary point of view and to achieve the competencies and performances aimed by the curriculum,

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comes to the fore. Wicklein (2006) has emphasized that engineering design provides an ideal substructure for the integration of mathematics, science and technology, and stated that STEM education should focus more on engineering design method. Bybee (2010) has also stated that engineering should be more involved in STEM education.

One of the models for integrating STEM content and applications is Engineering Design Process-oriented Integrated STEM Model (Savran Gencer et al., 2019). Five basic characteristics distinguish the integrated STEM education (Moore et al., 2015, p. 24):

a) The content and practices of one or more anchor science and mathematics disciplines define some of the primary learning goals;
b) The integrator is the engineering practices and engineering design of technologies as the context;
c) The engineering design or engineering practices related to relevant technologies requires the use of scientific and mathematical concepts through design justification;
d) The development of 21st century skills is emphasized; and
e) The context of instruction requires solving a real-world problem or task through teamwork.

The problem is determined in the first step of engineering design process. In the second step, the research is conducted for the problem. In the third step, the ideas are developed to solve the problem. In the fourth step, the best idea(s) is chosen considering its material, practical and economic assessments. In the fifth step, a prototype for the selected solution is created. In the sixth step, it is checked whether the prototype actually solved the problem, and the selected material is suitable or not. In other words, the solutions are tested and evaluated. In the seventh step, the prototype(s)/ solution(s) is presented, and feedback is received from other groups to determine whether there are defects. In the last step, a final decision is made, and the process is completed (Hynes et al., 2011).

Research Problem

The main task of education is to enable students to acquire permanent and applicable knowledge. In this context, international exams such as PISA (Programme for International Student Assessment) and TIMSS (Trends in International Mathematics and Science Study) predict the extent to which students can use their knowledge and skills in their daily lives rather than the degree to which they learn the subjects within the curriculum. Unfortunately, the results of PISA and TIMSS tests have shown that Turkish students achieve lower results rather than the students from many other countries (Martin et al., 2015; Organization for Economic Co-operation and Development [OECD], 2019). Undoubtedly, classroom practices that students encounter in their schools are at the top of the factors affecting their performance in these exams. Therefore, there is a need to improve science education through new teaching approaches like STEM.

Science is a fear or concern for many students. Previous research has revealed that students' success in physics subjects is lower than the biology and chemistry subjects (Bahar & Polat, 2007; Gagić et al., 2019). As the reasons for their difficulties in physics, students have stated that physics contains many abstract concepts, the concepts cannot be related to the daily life, and teachers mostly use direct instruction (Gagić et al., 2019). Therefore, students are often unmotivated to learn these concepts and they have difficulty in gaining meaningful learning. Sound is one of the most difficult (Eshach, 2014; Sozen & Bolat, 2014; Timur et al., 2016) and important concepts in physics that can help students understand physical world around them (Eshach, 2014). Therefore, conducting further studies on the conceptual understanding of sound is crucial. However, there is some research on the conceptual understanding of sound (Yerdelen & Sungur, 2020).

It is known that engineering design process-oriented integrated STEM activities positively affect students' achievement levels in science (Ercan & Sahin, 2015; Harwell et al., 2015; Wendell & Rogers, 2013). However, a limited number of studies has examined the effects of these activities on students' conceptual understanding of sound. These research studies are generally at primary school level (Barnett et al., 2008; Wendell, 2011; Wendell et al., 2010; Wendell & Lee, 2010). In these research studies, engineering design method has been used to teach the physics of sound. In Wendell's (2011) research, 3rd and 4th grade students from three classrooms have enacted the engineering design-based science curriculum regarding the science of sound topic. Teaching activities on the production, propagation and characteristics of sound have been developed according to engineering design method and have been applied. The pre- and post-interviews have been conducted to examine the changes in students' ideas about sound. As a result of the content analysis, their conceptual understanding of the three categories (production and transmission of sound, and characteristics of the sound) have been divided into six themes. A significant increase has been observed in students' knowledge levels regarding the three categories. Being a limitation of Wendell's

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(2011) research, teaching the physics of sound to 3rd and 4th graders may be difficult since concrete operational stage occurs between the ages of 7 and 11 years. The formal operational stage occurs from age 11 to adulthood. In this stage, individuals have the ability to think in abstract ways. Therefore, teaching the physics of sound to 6th grade students may be more appropriate. Lastly, throughout the research of Wendell (2011), STEM has never been mentioned. However, the physics of sound, which is found abstract by students, is very suitable for engineering design process-oriented integrated STEM activities. STEM education increases the development of not only social and cognitive, but also psycho-motor aspects of the individuals. Moreover, STEM enables students to connect learned theoretical knowledge with real life problems. Based on these facts, it is found necessary and important to examine the effect of the use of engineering design process-oriented STEM activities on middle school students' conceptual development of sound.

Research Aim and Research Questions

The aim of this research was to examine the effect of the use of integrated STEM activities, prepared in accordance with the engineering design process, in teaching sound subject on 6th grade students' conceptual understanding. In this context, research question is determined as 'Does the teaching of sound concept through engineering design-based STEM activities have an effect on the perceptions of 6th grade students?' and the following sub-questions are created:

1) How do the control and experimental group students understand the sound subject?
2) What are the differences/ similarities between the pre- and post-interviews in terms of control group students' conceptual understanding of sound subject?
3) What are the differences/ similarities between the pre- and post-interviews in terms of experimental group students' conceptual understanding of sound subject?

Research Methodology

Research Design

This research was a comparative case study that aimed to determine and examine comparatively the effects of the engineering design-based STEM activities on 6th grade students' conceptual understanding of sound concept. Being one of the qualitative research designs, case study examines in depth the situation(s) that occur within a certain period of time. Case studies, which aim to understand a specific situation in all its parts, often include interview questions (Fraenkel et al., 2012). From this point of view, it was decided to conduct an oral achievement test including open-ended questions in accordance with the purpose and design of the research. The achievement test was conducted in the spring semester of the 2013-2014 academic year.

Sample

The study group, which was selected through convenience sampling, consisted of 6th grade students from a middle school in Kayseri, Turkey. Due to the government's strategy, the class size was decreased in recent years. The average class size in middle schools located in Turkey is 26 (OECD, 2019). Consequently, 40 students participated in this research. Each of the experimental (11 female, 9 male) and control group (10 female, 10 male) included 20 students. The experimental and control groups were determined by looking at the students' 5th grade scores, 6th grade fall semester grades, and scores on the achievement test, which include 19 multiple-choice and 14 open-ended questions prepared by researchers (Dedeturk, Saylan Kirmizigul, & Kaya, 2020).

In the research, the principle of voluntary participation was taken into consideration and the students' identities were kept confidential by using codes. Numbers were assigned in the order that each student was interviewed. For instance, participant 1 refers to a student that was interviewed first on the interview timetable. All participants were informed about the aim of the research and their right to leave the research at any time. Additionally, the parent consent form that included detailed information about the voluntary and confidential nature of participation was signed by the parents of the participants. Also, the necessary permissions were obtained from the Ministry of National Education to which the school is affiliated. All the rules stated in the "Higher Education Institutions Scientific Research and Publication Ethics Directive" were followed in the research.

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Instrument

In Turkey, the topic of sound had been included in the 3rd, 4th, 5th, 6th and 8th graders' science curricula before (MoNE, 2013). Currently, the physics of sound topic is included in the 3rd, 4th and 6th grades' science curricula (MoNE, 2018). In 6th grade science curriculum, physics of sound has basic concepts such as propagation of sound, reflection of sound, echo, absorption of sound, sound insulation and acoustic applications. There are 12 learning outcomes for the topic of sound in the science curriculum (Table 1). In order to determine the 6th grade students' conceptual understanding level about physics of sound, it was decided to develop a valid and reliable instrument including the outcomes.

Achievement test can be of different forms like oral, written or practical test. An oral achievement test has been developed in this study, as it enables a more in-depth investigation of students' knowledge level and restatement of unclear answers. In line with this purpose, firstly an item pool including 14 open-ended questions was prepared based on the learning outcomes. Then, 11 questions were selected among them and an oral achievement test was prepared. A table of specifications was prepared showing the distribution of the questions in terms of learning outcomes and cognitive domains in Bloom's taxonomy (Table 1).

Table 1

Distribution of the Questions in Terms of Learning Outcomes and Cognitive Domains

Learning outcomes (MoNE, 2006)	Question	Cognitive domain in Bloom's Taxonomy
1. Notices that the sound is propagated in waves in all directions.	1	Analysis
2. Discovers that the sound is reflected when it encounters an obstacle.	2	Comprehension
3. States that an echo occurs as a result of sound reflection.	3	Comprehension
4. Gives examples of how s/he benefited from the reflection of sound in science and technology.	4	Comprehension
5. Detect that the sound that encounters matter can be absorbed.	6	Analysis
6. Determines that sound loudness decreases through absorption.	6	Evaluation
7. Realizes that different materials absorb sound differently.	7	Evaluation
8. Realizes that the materials used in sound insulation and prevention of echo formation absorb sound well.	8	Comprehension
9. Explains why a material medium is needed for propagation of sound through granular structure of the medium.	5	Comprehension
10. Indicates that when the sound encounters matter; passing, absorption and reflection may occur together at different rates, depending on the properties of the materials.	9	Comprehension
11. Gives examples of acoustic applications in the places like theater, concert hall and historical buildings.	10	Comprehension
12. Develops and presents projects that can prevent echo formation in closed spaces.	11	Application

In order to ensure the content validity, a table of specifications and a rubric were prepared for the open-ended questions and were checked by three science education experts. In the light of the feedback received from the experts, the necessary adjustments were made in table of specifications, questions and rubric. Additionally, corrections were made regarding the intelligibility of the questions and their suitability to the student level. The pilot study was conducted with 35 sixth graders. The students were interviewed individually in a verbal format. These students had learned the subject one month before the students in the study group. In order to ensure construct validity, discrimination and difficulty indexes were calculated by applying item analysis to the data obtained from 35 students. According to Table 2, difficulty indexes of the questions are in the range of 0.50-0.69. Hence, all of the questions are of medium difficulty. Since the discrimination indexes of all questions are greater than 0.40, they are very good questions.

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Table 2
The Difficulty (P) and Discrimination (R) Indexes of Interview Questions

Item	*P*	*r*	Item	*P*	*r*	Item	*P*	*r*
1	0.61	0.78	5	0.64	0.72	9	0.58	0.83
2	0.69	0.61	6	0.58	0.61	10	0.50	1.00
3	0.61	0.78	7	0.58	0.72	11	0.61	0.78
4	0.50	1.00	8	0.53	0.94			

The 11-item achievement test, which was finalized as a result of the pilot study, was applied verbally and individually to each student twice before and after the two-week implementations. Each face-to-face interview lasted about 10 minutes and they were recorded with a voice recorder with the permission of the students.

Procedures

Following the pre-interview, sound subject was taught for 9 course hours over a 2-week time interval, in both groups. During this period, all the activities used in the courses were prepared to meet 12 learning outcomes in the curriculum and for each learning outcome, identified course hours in the curriculum were followed.

The research-based activities in the curriculum were applied and the instructions in the textbook were followed in control group. Students sometimes worked individually and sometimes in groups. They usually listened to the teacher during the courses and reached the result indirectly by experimenting with simple materials without using any measuring device. Activities that do not include graph drawing, data interpretation, and robotic applications are poor in terms of scientific process skills and they do not include life skills, and engineering and design skills. The learning activities of control group are given in Table 3.

Table 3
Lesson Titles and Overviews Regarding Control Group's Learning Activities

Lesson title	Overview
1. Let's observe the propagation of sound	The students put a 30 cm ruler on the end of the table, pressed and pulled their hands on the other end of the table and observed the vibration of the ruler, and listened to the sound of the ruler. Then they placed a container of water under the ruler and observed the fluctuation in the water.
2. Sound is an energy.	The students stretched the thin nylon bag onto the cylindrical can with the help of rubber band and poured salt on it. They hit the metal tray that they positioned close to the cylinder with a wooden spoon and observed that the salt vibrates as a result of the vibrations of the particles in the air. By this way, they tried to reach the conclusion that sound is an energy.
3. Is the sound reflected?	The students put the cotton in a glass jar and the alarm clock on it. They listened to the sound of the clock from different distances and recorded these distances. Then they listened to the sound of clock by holding the mirror tilted over the jar and recorded these distances. Students observed that sound can be heard from a farther point when there is a reflector.
4. What feature is common?	By examining the photographs given, students explained that the piano's tail is directed towards the audience and that the megaphone is conical, so that the sound was reflected and transmitted to the desired location.
5. Modeling of sound transmission	In order to understand that the sound is propagated through the particles, the students were arranged in groups of 6-8 people in a row facing the same direction. The hindmost student put her hand on the shoulder of her friend in front of her; and he put his hand on the shoulder of his friend in front of him; and the shake was delivered to the foremost student. By opening the gaps, the propagation of sound in liquid and gaseous environments was modeled. In each case, students measured the time it took for the shake to reach from back to front. Accordingly, they reached the conclusion that the speed of sound is slow in gaseous environments.
6. What is the American Indian doing?	The students explained the reason why the American Indian in the photograph tries to find out if there is a danger by resting the ear on the ground as the better transmission of sound in solids.

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Lesson title	Overview
7. Which materials can absorb the sound more?	Students listened to the sound after putting watch into the empty shoe box. Then they put newsprint, cloth and styrofoam into the box, respectively, and listened to the sound of the watch. Students explained why the loudness of sound was different when different materials were placed in the box.
8. I explain with what I have learned.	Students examined the places in the photographs and made explanations about the absorption and loudness of sound.
9. I am comparing sound and light	Students filled in the blanks given in the paragraph about sound and light, and the table prepared for sound and light.

In the experimental group, nine integrated STEM activities focusing on engineering design process developed by the researchers were included. LEGO Mindstorms NXT education set, which includes LEGO-technics bricks, a microprocessor, a software, sound, light, distance and touch sensors, and motors that control movement that allow the students to develop robots on their own, and various materials (sponge, styrofoam, etc.) were used in these activities. Before the implementation, the teachers received training on STEM activities and they were provided with a guide including the important points, learning outcomes, duration of the activity and tools, technology and techniques to be used in each activity. Since they did not have any knowledge and experience about engineering design method, written and oral information were given to the students about subject. In STEM activities, which are rich in scientific process, life, and engineering and design skills, students made original designs to solve problem, made measurements using sound sensors and used LEGO materials as well as simple materials in groups. In interconnected activities, students collected data by making direct measurements, drawn and interpreted graphs, and programmed robots. The activities performed in experimental group are given in Table 4.

Table 4
Lesson Titles and Overviews Regarding Experimental Group's Learning Activities

Lesson title	Overview
1. How is sound propagated?	Students estimated how sound was propagated. Then they made measurement, recorded data and compared the results with their predictions to reach a scientific idea.
2. Does the sound get reflected? How?	Students reasoned out whether sound was reflected and conducted experiments regarding the reflection of sound using the given materials and recorded data. Students made a minimal design about the reflection of sound.
3. How does an echo occur?	Students made a design about echo formation. They tested and observed echo formation through this design. They got an idea of how echo occurred due to their design.
4. What are the technologies produced using the reflection of sound in your daily life? In which fields does science use them?	Using LEGO, students made and tested a design that works owing to the reflection of sound. Then they ran their designs with sound using LEGO programming.
5. What is the most important condition for the propagation of sound? Why?	Students designed using LEGO and other materials to investigate what was needed for propagation of sound. They wrote a hypothesis for this design and tested it, then they drew a graph and reached a scientific idea.
6. Why is the loudness levels are different in front and at the back of the obstacle when the sound meets an obstacle? Which side of the obstacle has a louder sound? Why?	Students made a design including a sound source and an obstacle. Based on this design, they made measurements and recorded the data, and concluded that the sound had been absorbed by the obstacle.
7. Does each material has its own sound absorption rate? What are the properties of noise insulation materials? What happens when sound encounters a matter?	Using data obtained from their design, students investigated which events occur when sound meets matter. They decided which materials should be used in sound insulation by grouping the materials they used in their designs.
8. What are the acoustic applications you notice in the places you go?	By examining the given spaces, students discovered what kind of acoustic applications could be made.
9. How can you solve the echo problems in closed spaces?	Students developed and presented a project using the scientific ideas they had until that time.

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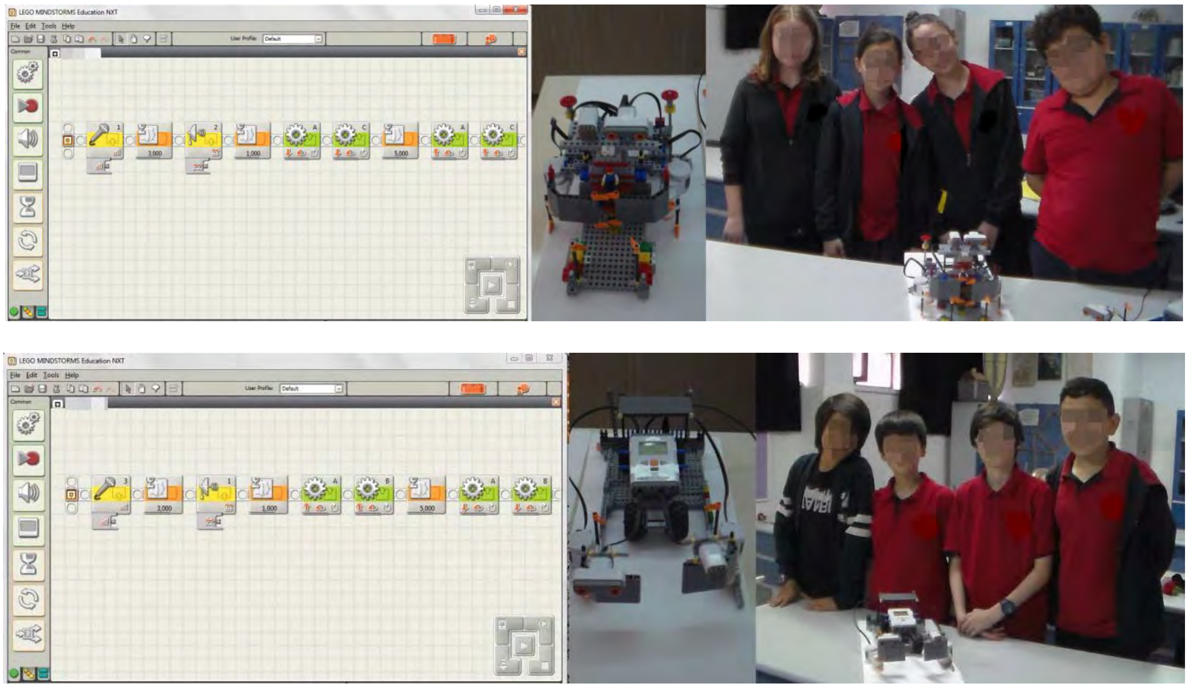
Figure 1 shows the robot design, programming and presentation stages of different groups belonging to the activity-4 in the experimental group.

Figure 1
Robot Design, Programming and Presentation Stages of The Lesson-4 in Experimental Group



Data Analysis

Within the scope of the research, students' answers were scored independently by two science education experts using the rubric, and Kappa (κ) coefficient was calculated by looking at the consistency between the raters. This coefficient, which is the proportion of observed agreement that exceeds what would be expected by chance alone, was found as 0.93. Hence, agreement between the raters is almost perfect (Landis & Koch, 1977). Accordingly, it was revealed that the rubric was understood by different raters in the same way with the high agreement rate.

The data obtained were transcribed and analyzed using summative content analysis. Although the summative content analysis involves counting and comparing the frequency of keywords or content and interpreting the content (Hsieh & Shannon, 2005), the open response format of the qualitative items provides more in-depth information in addition to the quantitative findings of the research. This method includes using codes, themes and categories to organize content and arrive at a narrative description of findings (Fraenkel et al., 2012). The interviews generated codes, the codes were grouped into themes, and the themes were grouped into a total of 11 categories. The themes reflected students' perceptions and thoughts about sound, whereas the codes reflected the concepts of sound in their minds.

Research Results

The answers to the interview questions were analyzed by using the rubric. According to Table 5, all students in experimental group answered the questions 4, 5 and 8 correctly in the post-interview. Table 1 shows that these questions refer to 4., 9. and 8. learning outcomes respectively. While the percentages of correct answers for these questions by experimental group students were 0%, 10% and 5% respectively in pre-interview, all of these rates were 100% in post-interview.

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Table 5
Percentages of the Answers to the Interview Questions

Question	Answer	Test	%		Question	Answer	Test	%	
			Control group	Experimental Group				Control group	Experimental group
1	Correct	pre	5	10	7	Correct	pre	15	10
		post	20	70			post	20	95
	Partially correct	pre	55	50		Partially correct	pre	35	45
		post	55	25			post	55	5
	Incorrect	pre	40	40		Incorrect	pre	50	45
		post	25	5			post	25	0
2	Correct	pre	25	30	8	Correct	pre	15	5
		post	30	90			post	15	100
	Partially correct	pre	60	40		Partially correct	pre	35	30
		post	55	10			post	45	0
	Incorrect	pre	15	30		Incorrect	pre	50	65
		post	15	0			post	40	0
3	Correct	pre	15	0	9	Correct	pre	0	5
		post	30	90			post	15	75
	Partially correct	pre	60	80		Partially correct	pre	55	45
		post	55	10			post	70	25
	Incorrect	pre	25	20		Incorrect	pre	45	50
		post	15	0			post	15	0
4	Correct	pre	10	0	10	Correct	pre	5	0
		post	15	100			post	25	95
	Partially correct	pre	10	15		Partially correct	pre	35	30
		post	20	0			post	15	5
	Incorrect	pre	80	85		Incorrect	pre	60	70
		post	65	0			post	60	0
5	Correct	pre	25	10	11	Correct	pre	5	0
		post	35	100			post	10	90
	Partially correct	pre	20	20		Partially correct	pre	65	45
		post	30	0			post	65	10
	Incorrect	pre	55	70		Incorrect	pre	30	55
		post	35	0			post	25	0
6	Correct	pre	10	5					
		post	30	80					
	Partially correct	pre	80	80					
		post	50	20					
	Incorrect	pre	10	15					
		post	20	0					

Table 5 shows that the percentage of correct answers increased for all questions for experimental group. Accordingly, conceptual understanding level of the students in experimental group increased relatively more

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than the control group students. In post-interview, experimental group students gave incorrect answer only to the first question and this rate was 5%. For control group, while the percentage of correct answers of all questions increased, the percentage of incorrect answers of question-6 also increased slightly. In terms of the differences between pre- and post-interviews, the experimental group students' conceptual changes in sound were much more positive than control group students.

As a result of content analysis, 11 categories were obtained: 1) propagation of sound, 2) reflection of sound, 3) echo formation, 4) technological applications of sound reflection, 5) sound propagation-solid environment, 6) loudness of sound, 7) absorption of sound, 8) Materials used in sound insulation and acoustic applications, 9) encounter of sound with matter, 10) acoustic applications, 11) echo problems in closed spaces. There were 21 themes and 81 codes belonging to these categories. The themes and codes for each category are given in Table 6. Each percentage value belongs to a group of 20 students.

Table 6
Generated Categories, Themes and Codes

Category	Theme	Codes	Group	pre (%)	post (%)
1. Propagation of sound	How sound propagates	through waves	C	45	60
			E	45	100
		through vibrations	C	20	25
			E	15	10
		through reflection	C	10	15
			E	5	0
		Linear	C	15	0
			E	10	0
		No idea	C	15	30
			E	25	0
	Direction of propagation of the sound	in all directions (from source)	C	20	60
			E	25	85
		one way (forward)	C	15	10
			E	15	0
		No idea	C	65	30
			E	60	15
	Analogy	Waves formed by drops of water dripping into a puddle/ throwing something into a puddle	C	5	20
			E	10	70
		Spreading of siren of ambulance/ oxygen everywhere	C	5	5
			E	0	20
		Sea waves	C	5	5
			E	10	5
		No idea	C	85	70
			E	80	5
2. Reflection of sound	Sound is/ is not reflected	Sound is reflected.	C	60	85
			E	55	100
		Sound is not reflected.	C	10	5
			E	5	0
		No idea	C	30	10
			E	40	0
	How sound is reflected	By hitting an obstacle/ item/ wall	C	20	10
			E	30	45
		By hitting a hard and smooth obstacle	C	10	10
			E	0	15
		No idea	C	70	80
			E	70	40

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Category	Theme	Codes	Group	pre (%)	post (%)
3. Echo formation	How an echo occurs	When the sound strikes	C	35	45
			E	75	80
		As a result of sound reflection	C	15	10
			E	0	60
		When the sound hits a material at least 17 meters away and returns	C	5	5
			E	0	10
		No idea	C	30	20
			E	5	5
	Example	Echoes in an empty room/ a closed area/ a bathroom	C	55	50
			E	75	80
		Echoes in a cave/ mountain	C	20	30
			E	15	15
		No idea	C	25	20
			E	10	5
4. Technological applications of sound reflection	Technological devices and equipment	Sonar	C	15	55
			E	15	100
		Ultrasound device	C	10	50
			E	5	95
		Telephone/ tablet/ voice recorder/ loudspeaker/ head-phones/ hailer/ microphone/ computer	C	5	15
			E	10	0
		No idea	C	70	45
			E	70	0
	Areas of usage	Field of medicine	C	10	50
			E	5	95
		Marine	C	15	30
			E	10	100
		Fishing	C	15	30
			E	0	100
		Mining	C	5	10
			E	10	35
		No idea	C	70	0
			E	75	0
5. Sound propagation- solid environment	Necessary condition for the propagation of sound	Granular materials	C	40	50
			E	20	100
		Speak loudly	C	20	5
			E	20	0
		Nongranular materials/ vacuum/ space	C	10	5
			E	5	0
		No idea	C	30	20
			E	65	0
	Reason	Transmission of sound by vibration of the airborne particles	C	10	50
			E	20	100
	Example	the alarm clock inside the deflated bell jar	C	5	15
			E	10	85
6. Loudness of sound	The side with the higher loud-ness of sound	in front of the obstacle	C	40	45
			E	45	100
		behind the obstacle	C	15	5
			E	10	0
		No idea	C	45	25
			E	45	0
	In front of the obstacle- rea-son	The sound is absorbed to some extent by the obstacle.	C	30	45
			E	20	80
		The sound source is in front of the obstacle.	C	25	45
			E	45	10
		The sound is reflected/ came back by hitting the obstacle.	C	45	10
			E	35	10

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Category	Theme	Codes	Group	pre (%)	post (%)
7. Absorption of sound	The reason why the sponge transmits sound less than paper	The sponge absorbs the sound more.	C	20	35
			E	25	60
		Sponge is soft, while paper is hard.	C	5	10
			E	5	60
		Sponge is a better insulating material than paper.	C	20	20
			E	25	35
		Sponge is rough/ porous, whereas paper is smooth.	C	5	10
			E	5	20
		The spaces between the particles of the sponge are slightly more than that in the paper.	C	5	5
			E	5	0
		The sponge is thicker than paper.	C	20	0
			E	15	0
		No idea	C	35	20
			E	25	0
8. Materials used in sound insulation and acoustic applications	Properties of the materials used in sound insulation and acoustic applications	rough	C	20	35
			E	10	90
		Soft	C	20	20
			E	5	95
		Smooth	C	20	5
			E	10	0
		No idea	C	50	40
			E	55	5
	Reason	to absorb sound	C	40	55
			E	45	95
		to prevent echo formation	C	0	15
			E	5	90
		to provide a more uniform sound propagation	C	25	10
			E	15	0
9. Encounter of sound with matter	The result of sound-matter interaction	Reflection/ echo occurs	C	50	65
			E	35	100
		If the material is rough, the sound is absorbed.	C	15	40
			E	30	80
		If the material is soft, the sound is absorbed.	C	0	15
			E	0	85
		If the material is smooth, the sound is reflected/ echoed.	C	0	20
			E	0	45
		Sound and matter collide.	C	0	5
			E	10	5
		Sound is transmitted.	C	15	5
			E	20	0
		No idea	C	70	40
			E	60	10
	The reason why the interaction has different consequences	Shape of the material/ angle of incidence of the sound waves	C	85	80
			E	85	25
		Type/ properties of matter	C	15	20
			E	15	75

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Category	Theme	Codes	Group	pre (%)	post (%)
10. Acoustic applications	Examples of acoustic applications	Rough ceiling of the theater hall	C	15	5
			E	0	55
		Soft ceiling of the theater hall	C	15	10
			E	0	40
		Domes of different sizes in mosques	C	0	10
			E	10	30
		Stepped seating arrangement in theater and cinema	C	0	0
			E	0	35
		Use of reflective plates in concert areas and theaters	C	5	0
			E	5	5
		No idea	C	50	60
			E	40	0
11. Echo problems in closed spaces	Solutions for the echo problem	Use of sound-absorbing materials	C	10	40
			E	10	85
		Narrowing the area	C	10	40
			E	25	5
		Increasing the number of the belongings in the room/ place	C	20	35
			E	30	5
		Speaking in a low voice	C	10	0
			E	5	0
		Covering the place with aluminum foil	C	5	0
			E	5	0
		No idea	C	15	10
			E	25	0

Category-1 emerged from data analysis of the first interview question. As can be seen in Table 6, according to the findings, the majority of the students thought that the sound is propagated in waves. As a result of teaching practices, the number of students explaining sound propagation with this code increased in both groups. As a remarkable finding, it was observed that all the students in experimental group had the knowledge that the sound propagated waves during the post-interviews. Moreover, in pre-interview, more than half of the students did not know the direction of sound propagation. However, in post-interviews, 85% of students in experimental group and 60% of students in control group had the knowledge that the sound was propagated in all directions. The findings revealed that almost all of the students could not make an analogy about the propagation of sound in pre-interviews. In post-interviews, it was seen that only 20% of students in control group and 70% of students in experimental group resembled the propagation of sound to the image that occurred when water dropped, or stones were thrown into the pond.

Category-2 emerged from data analysis of the second question. While 60% of students in control group gave the correct answer *"Sound is reflected"* to the first theme in pre-interview, this ratio increased to 85% in post-interview. In parallel, 55% of students in experimental group gave the same answer in pre-interview and all of them in post-interview. On the other hand, when the codes regarding how the sound is reflected were examined, it was seen that the majority of the students in control group were abstainers in both pre- and post-interviews. In post-interview, 40% of students in experimental group were abstainers, whereas 45% of them stated that sound was reflected when it encountered an obstacle, material or wall.

Category-3 emerged from data analysis of the third question. The students who answered the first theme correctly stated that *"Echo occurs as a result of sound reflection."* In both pre- and post-interviews, most of the students stated that echo was caused by strike of sound. In post-interview, 10% of students in control group and 60% of students in experimental group stated that the echo was the result of sound reflection. In the second theme, approximately half of both group of students gave examples of echo formation in an empty room, in a closed space or in the bathroom.

Category-4 emerged from data analysis of the fourth question. Almost none of the students could give an example to the tools produced by using the reflection of sound in pre-interview. In post-interview, all of the stu-

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dents in experimental group gave sonar and 95% of them gave ultrasound device as an example. On the other hand, almost half of the students in control group were able to give these examples. S8, a student who answered this question correctly said that *"In a sonar or an ultrasound, sound waves strike an object and return. Thus, we estimate the existence, location and shape of the object."* In post-interview, all students in experimental group gave marine and fishing, 95% of them gave field of medicine and 35% gave mining as examples. In the control group, the number of students who gave these examples is less. S16, who answered fourth question partially correct, stated that *"We find lost ships or mines with the device that sends sound waves into the water."* S27, who gave wrong answer expressed her thoughts as *"The technologies produced by using the reflection of sound are electronic devices like telephone, tablet and voice recorder."*

Category-5 emerged from data analysis of the fifth question. S12, who answered this interview question correctly, gave the answer *"The most important condition for the propagation of sound is the solid environment. Because sound is produced through vibration of the air particles. Therefore, sound does not travel in space."* All of the students in experimental group and half of the students in control group associated the propagation of sound with the solid environment in post-interview. One of the students exemplified this situation as *"We can't hear the alarm clock inside the deflated bell jar."*

Category-6 emerged from data analysis of the sixth question. S7 answered this interview question correctly and stated that *"Loudness of sound is higher in front of the obstacle. Because when it encounters an obstacle, the sound is absorbed and the loudness decreases."* Also, S9 said that *"Loudness of sound is higher in front of the obstacle. Because sound strikes and comes back; that is reflected."* In the pre-interview, only 40% of students in control group and 45% of students in experimental group thought that the sound loudness was higher in front of the obstacle, while this rate increased to 45% and 80% in control and experimental groups, respectively in post-interview.

Category-7 emerged from data analysis of the seventh question. The students who answered this question correctly, expressed their thoughts as *"Since sponge is soft and rough, it absorbs the sound."* and *"Since paper is smooth, it absorbs the sound less."* S3 and S37, the students who gave a partially correct answer, stated that *"Since sponge is soft and paper is hard, the sponge transmits the sound less than the paper."* and *"Since the sponge is an insulating material, it transmits sound less."* respectively. When findings obtained in post-interviews are examined, it is seen that the students in experimental group have more accurate information than students in control group.

Category-8 emerged from data analysis of the eighth question. S7 and S11 who answered this question correctly expressed their thoughts as *"The materials used in sound insulation and acoustic applications are soft so that the sound is absorbed."* and *"Hard and smooth materials should be used to ensure the reflection of sound in acoustic applications."* In post-interview, 90% of students in experimental group thought that the materials used should be rough to ensure sound insulation, whereas only 35% of students in control group thought this. In addition, in the post-interview, 95% of students in experimental group and 55% of the students in control group stated that it was aimed to absorb sound in sound insulation.

Category-9 emerged from data analysis of the ninth question. The students who answered this interview question correctly gave the answers like *"Sound is absorbed, and loudness of sound is decreased when sound encounters a soft material."* and *"Sound is reflected, and echo may occur when sound encounters a smooth material."* The students who gave a partially correct answer mostly stated that *"Sound is transmitted or propagated when it encounters matter."* The students who answered this question wrong expressed their thoughts as 'Echo occurs when the sound encounters the matter.' and *"These events occur at different rates due to the shape or size of the material."* In the post-interviews, 75% of the students in experimental group and 20% of the students in control group gave the correct answer that the different results of this interaction stem from properties of the material.

Category-10 emerged from data analysis of the tenth question. S8 and S31, the students who answered this question correctly stated that *"With a stepped seating arrangement, the sound is heard better by echoing from stage to the seats on hard and smooth surfaces."* and *"The sound enters into 64 cubes in the dome of Süleymaniye Mosque and is reflected equally and returns to us."* respectively. S5 gave a partially correct answer and said that *"Sound insulation prevents sound from going out"*. S12 who gave the wrong answer expressed his thoughts as *"If we cover all the walls in the house with wallpaper, the wall reflects sound less since it became smooth."* In pre-interviews, the students in experimental group gave examples of acoustic applications as rough (55%) and soft (40%) ceiling of theater hall, domes of different sizes in mosques (30%), and use of reflective plates in concert areas and theaters (5%). On the other hand, the students in control group gave examples of acoustic applications as soft (10%) and rough (5%) ceiling of theater hall, and domes of different sizes in mosques (10%) in post-interviews. Additionally, while almost half of the students in both groups could not give examples of acoustic applications in pre-interview;

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60% of students in control group could not give any examples of acoustic applications in post-interview. In the experimental group, no one left this question unanswered.

Category-11 emerged from data analysis of the last question. S37 answered this question correctly and stated that *"The use of soft and rough materials in closed area prevents sound transmission and causes sound absorption. Thus, no echo occurs."* The students who gave completely correct answers consisted of 85% of experimental group and 40% of control group in post-interview. S13 gave a partially correct answer and expressed her thoughts as *"If sound insulation is made in a closed area, the echo does not occur."* S2 and S28 who gave wrong answers to this question stated that *"Echo formation is prevented by using aluminum foil indoors."* and *"Echo does not occur if you speak in a low voice in a closed area."* respectively.

Discussion

The results of the research provided an evidence on how engineering design process-oriented STEM activities enhanced the students' conceptual understanding levels on the physics of sound. As a result of content analysis, 11 categories including 21 themes and 81 codes were obtained in the research. It was seen that the conceptual understanding level of students in both experimental and control groups had been increased for each category. However, when the findings were analyzed, it was seen that the conceptual understanding of the students in experimental group has changed much more positively than the control group students. Accordingly, the students' learning about the topic of sound was more meaningful when they were able to interact with materials and make designs.

Wendell (2011) examined whether the 6-hour teaching activities developed in accordance with engineering design method for the production, transmission and characteristics of sound caused the change in 3rd and 4th grade students' ideas about sound. Some conclusions were reached through the content analysis of the data obtained from the interviews with the students. Students' ideas about sound production were divided into six categories in pre- and post-interviews. These categories were; additional physical evidence of process, vibration as process, movement as cause, static characteristics, human action, no answer or invented component. Students' ideas about sound transmission were divided into six categories in the pre- and post-interviews. These categories were: Sound transmitted via propagation of vibration, interactive role played by medium or matter, sound transmitted via action, sound transmitted as substance, only mentions medium or matter, no explanation of transmission. In Wendell's (2011) research, after the activities using engineering design method, students' thoughts about both production and propagation of the sound increased in terms of percentage of correct answers. In parallel with these findings, according to the results of the current research, when the differences between the pre- and post-interviews were examined, it was seen that conceptual understanding levels of the students in experimental group were more positive than the students in control group. Different from the research of Wendell (2011), current research included the activities that integrated the engineering design process with STEM, rather than just engineering design method, and also the number of activities and much more. Lastly, in the current research, for most of the themes, conceptual understanding level of the students in experimental group were increased much more than it was in the research of Wendell (2011). This result is meaningful since individuals have the ability to think in abstract ways after the age of 11 and the current research was conducted with 6th grade students with an average age of 12.

In the research of Gulhan and Sahin (2016), six engineering design process-oriented STEM activities regarding the topics of light, living beings and electricity were carried out in the experimental group during 12 weeks. The experimental group activities were carried out in groups, and the engineering design process steps that were followed were very similar to those developed by Hynes et al. (2011). The researchers concluded that STEM activities improved 5th grade students' conceptual understanding. Many other research studies that concluded engineering design process-oriented STEM activities positively affected students' success (Doppelt et al., 2008; Ercan & Sahin, 2015; Gulhan & Sahin, 2016; Wendell & Rogers, 2013). In these studies, written achievement tests consisting of multiple choice and/ or open-ended questions were preferred as an instrument for determining the student achievement. On the other hand, in the current research, open-ended questions were used verbally to examine the students' conceptual understanding in more detail. It was seen that the conceptual understanding of the students in experimental group has changed much more positively than the control group students. This situation is parallel to the findings obtained in the above-mentioned studies and shows that STEM activities are highly effective in increasing the success levels of the 6th grade students. The estimated reasons for this situation were discussed separately below.

Owing to the designs they made, the students in experimental group reached at least one scientific idea about sound at the end of each course. In the last lesson, the students developed a project by synthesizing all

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the scientific knowledge they had gained on the subject thus, they reinforced their learning. It is thought that the students' testing the prototypes they developed and improving their prototypes in line with the results they had, have a positive effect on their conceptual understanding. Gerlach (2012) stated that students need more than one chance to be successful and engineering design process-oriented science activities give them that chance (Ercan & Sahin, 2015).

It is known that the motivation of students working in collaborative groups increases and their success increases accordingly (Sung & Hwang, 2013). Considering that control group students sometimes work individually and sometimes in groups during the learning process while experimental group students always make their designs in groups to solve the problem, it is possible to conclude working in groups was effective in increasing the level of conceptual understanding.

The students in experimental group learned the subject by conducting various experiments and solving the problems in order to make the best design in the engineering design process. In this research, it is thought that one of the reasons why the students in experimental group were more successful is that most of their time they actively engaged in the experiments and designs in STEM activities since it is known that STEM promotes active learning and collaboration. On the other hand, in control group activities, a large part of the time was used to answer the questions in the workbook. Therefore, students in the control group were more passive throughout the process. According to Dale's (1969) Cone of Experience, the greater the number of sense organs used in the learning process, the greater the learning and the more information is likely to be retained. Accordingly, in the concretization of abstract concepts, the information obtained through the ways in which student is passive such as reading, listening and watching remain insufficient, this information can only be concretized through experience. In this sense, the fact that the students in the experimental group are more active in the learning process is an important factor in their conceptual development. In the research, the results revealed in detail that the success of the students who participated in integrated STEM activities is not a chance or coincidence.

Conclusions

The advantages of the use of STEM activities in learning different science topics are well known, but this research focused on teaching physics of sound to the 6th grade students through engineering design process-oriented integrated STEM activities, making it specific.

In accordance with the rapidly changing world, it is important to educate the new generation equipped with 21st-century skills and engineering and design skills to play an active role in scientific and economic developments. In parallel with this, keeping up with the technology age is among the objectives of the science curriculum. In order to overcome students' lack of motivation for learning the topics of physics, which they perceive as difficult, appropriate teaching approaches should be used. Engineering design process-oriented STEM is a teaching approach that leads to an increase in students' motivation and achievement level in science.

Implications

This research was an example of STEM education by using engineering design-process. Engineering and design skills have gained importance in the new science curriculum which aims to integrate science with mathematics, technology and engineering. Therefore, it is suggested that teachers and researchers should apply engineering design process-oriented STEM activities and examine the results of these applications according to many other topics in the science curriculum. In this sense, it is thought that experimental activities developed within the scope of this research will contribute to science education in terms of developing and using the integrated STEM activities.

In 2018 science curriculum the statement of 'Education is given not only for knowing (thinking) but also for feeling (emotion) and doing (action)' is included. In this context, research studies should be conducted on the effects of STEM activities on affective characteristics of the students such as attitude, motivation and anxiety.

Limitations

In the current research, only one topic, physics of sound, was discussed. In addition to this, the research is limited to the 6th grade students' conceptual understanding. Lastly, the research was conducted in already-formed classes rather than in randomly chosen groups.

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