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TEACHING MECHANICAL WAVES BY INQUIRY-BASED LEARNING

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Abstract. *In this research, the teaching of mechanical waves was realized with inquiry-based learning; the aim was to determine the changes in students' conceptual understanding of spring, water, and sound waves. It was designed as action research. The study group comprised 58 upper-secondary school students enrolled in 10th grade at an Anatolian upper-secondary school in Turkey. Data collection tools used in the research were the form for conceptual understanding of mechanical waves, semi-structured interviews, video recordings and photographs, student journals, and hand-made materials. Moreover, researchers designed an action plan that was composed of activities on spring, water, and sound waves. Descriptive and conceptual content analyses were utilized in data analysis. At the end of the research, it was determined that there was a change in students' conceptual understanding of spring, water, and sound waves. Moreover, it was determined that teaching based on inquiry-based learning contributed positively to students' learning. In this respect, it is thought that such applications should become widespread. There should be online training for lecturers which in return would contribute to students' learning.*

Keywords: *5E learning model, action research, inquiry-based learning approach, mechanical waves, upper-secondary students*

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Introduction

Today, physics education aims to raise individuals who are inquisitive and critical, who can relate their knowledge with daily life, solve problems, and interpret events with a scientific outlook. In other words, it is expected for students to be able to understand the nature of science and use it accordingly. However, this is not a self-running process. For this process to reach the desired objectives, it should be carried out appropriately accompanied by various applications. One such application is thought to be an inquiry-based learning approach because this approach focuses on students' knowledge acquisition process rather than focusing on bringing out an output (Llewellyn, 2007; Russo & Persano Adorno, 2018). Concentrating on students' skills such as asking questions, critical thinking, and problem-solving, this process supports the development of these skills that students might need throughout their lives (van Uum et al., 2016). By developing students' conceptual understanding, it is desired for students to have the chance to discover scientific concepts. At the same time, students are expected to have a more developed scientific attitude (Kang & Keinonen, 2018). It is also necessary for the focus of physics education to be altered; instead of memorizing concepts, students should be encouraged to learn in a manner where they make use of their cognitive and critical thinking skills by inquiry-based learning (Donohue et al., 2020).

National Research Council [NRC] (2007) emphasized that different scientific methods should be utilized in the inquiry. Considering inquiry-based learning and teaching in its most comprehensive form, this process is realized by the following steps: "asking questions and steering," "generating a hypothesis," "planning," "researching," "data analysis and interpretation," "searching for and constructing a model," "conclusion and evaluation," "communication," and "prediction." The application of these steps in class can be done by the 5E learning model (Bell et al., 2010). 5E learning model is composed of five stages; namely, engage, explore, explain, elaborate, and evaluate. In the engage step, the aim is to draw students' attention to a topic by a short activity or discussion. In the explore step, students develop hypotheses by making observations. In the explain step, students,

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with the guidance of their teacher, explain the concepts they have explored, and results are generalized. In the elaborate step, students extend their knowledge and apply it to new situations. In the evaluation step, to what extent the concepts are learned is determined by the teacher and the students. Consequently, with the 5E learning model, which is connected to inquiry-based learning, active learning takes place as students actively use their knowledge and skills (Wilder & Shuttleworth, 2005). The aim is to make sure new concepts are thoroughly learned because it is well-known that the 5E learning model is beneficial for students. In short, this model is student-centered, and it has a structure that provides the necessary information to education environments for teachers. At this point, it is evident the 5E learning model should be utilized in inquiry-based learning, which relies on arousing interest and curiosity in students (Garderen & Decker, 2020). Taking its cue from these, it was decided that in the research the teaching of mechanical waves be realized by using the 5E learning model in the in-class application of inquiry-based learning.

Mechanical waves were selected as the subject matter because it was seen in literature that studies on physics education generally focus on certain areas such as mechanics, electrics, or heat, and temperature (Docktor & Mestre, 2014; McDermott & Redish, 1999). There is a comparatively limited number of studies on waves, especially about the above-mentioned approach. Moreover, although waves are one of the basic subjects of physics, it is also the basis of various fields such as physical optics, acoustics, electromagnetic waves, and quantum mechanics (Kennedy & De Bruyn, 2011). In this respect, it can be said that properly understanding waves as a concept, which the students are taught for the first time at the upper-secondary level, plays an important role in understanding the following subjects in physics (Tongchai et al., 2009). Also, wave and wave movement as concepts influence every facet of life even though we are unaware of it most of the time. Thus, the research aimed to ensure awareness on wave and wave movement as concepts, it also asked students to make sense of mechanical waves after basic teaching of the subject.

Inquiry-based Learning Approach in Science Education

Examining the research in the field of science education, it was seen that most teachings were realized by the teachers with the deductive method, and this was criticized in the literature (Bao & Koenig, 2019; Dykstra et al., 1992). Teaching by the deductive method is defined as teaching in which the teacher transmits theoretical information first and then presents mathematical models, and in which the process is completed by solving the exercises in the coursebook. Research put forth that in this teaching method students find it difficult to make sense of complex or abstract expressions and lose their motivation as well as interest in the course (Djudin, 2018). Nevertheless, students should be made aware of the importance of subjects in science education, meaningful learning should take place, and students should be motivated. To this end, the deductive teaching method was suggested in the literature. (Hayden et al., 2011; Rahayu et al., 2011). The deductive teaching method was defined in literature as starting with the teacher telling a story, a problem sentence to solve, or a demonstration experiment. It was emphasized that the teacher plays a guiding role and moves forward by giving students directions and clues. It was determined that students reach knowledge by themselves in this process (Russo & Persano Adorno, 2018). Deductive teaching and learning have been used in literature as an umbrella term that includes several constructivist teaching methods (Prince & Felder, 2006). Inquiry-based learning is also under this umbrella because it was determined that students' view on science has changed for the better and that they learned science by exploring scientific concepts with teachings realized with this approach (García-Carmona, 2020; Meyer & Crawford, 2015). It was indicated that in inquiry-based learning, teachers and students are involved in the process by asking questions so that students can actively think. In this respect, it was underlined that students' cognitive skills improved along with their critical thinking skills because they now had the skills to transmit knowledge from one field to the other (Kingir et al., 2012; Kulo & Bodzin, 2013). In longitudinal research, it was determined that inquiry-based learning affects the development of students' various skills (Chen et al., 2016). In literature, it was mentioned that one of the main objectives of this approach is to deepen students' absolute knowledge, and it was determined that this process would begin when students are faced with a problem or a question (Ibrahim et al., 2017). In the upcoming steps of the process, students would deepen their knowledge by getting into an inquiry cycle. Conceptual understanding would take place at this point (Sotáková et al., 2020) because it can take place only when students' process-

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related skills are developed and all steps of inquiry-based learning are completed. As such, students who have the skills to scientifically explain phenomena could be reached (Mutlu, 2020). Ensuring cognitive and sensory development, this approach was determined to be effective in students' career planning and to contribute to their interest in science-related fields (Burgin et al., 2015; Meyer & Crawford, 2015). As their motivation for science increased during the inquiry-based learning process, it was seen that students were willing to be interested in the reality of scientific experiments (Kuo et al., 2019; Scogin, 2016). Moreover, since students' conceptual understanding developed and changed, it was seen that it was an advantage for students to easily manage the process by being inquisitive and making sense of concepts (Morrison et al., 2015; Shi et al., 2020). Consequently, it was evident that inquiry-based learning would maintain its popularity in literature due to its positive effect on science education (García-Carmona, 2020).

Teaching Mechanical Waves

When the basic studies on mechanical waves were examined, it was seen that students had a hard time understanding mechanical waves and had certain misconceptions (Admoko et al., 2019; I. S. Caleon & Subramaniam, 2010; I. Caleon & Subramaniam, 2010; Goodhew et al., 2019; Kennedy & De Bruyn, 2011; Maurines, 1992; Tongchai et al., 2009; Tumanggor et al., 2020; Wittmann, 2002; Wittmann et al., 2003). Goodhew et al. (2019) and Maurines (1992) focused on the formation and expansion of mechanical waves and determined students' conceptual understanding of this. According to their findings, students focused on certain reasoning processes in spring waves and thus had incomplete and incorrect knowledge. Tumanggor et al. (2020) also indicated that students had misconceptions about the basic concepts of mechanical waves. Wittmann (2002) and Wittmann et al. (2003) examined undergraduates' conceptual understanding levels of wave movement and the superposition principle. Researchers indicated, supporting Maurines' (1992) views, students were not able to interpret the superposition principle and that they related the form of a beat with the speed of the wave. Tongchai et al. (2009) designed a conceptual test on mechanical waves and found out misconceptions after the application of the test. It was determined that students were not able to make sense especially of the speed of the wave. Indeed, in another research, Tongchai et al. (2011) determined that students thought the speed of the mechanical waves was dependent on frequency. Different from other studies, Kennedy and De Bruyn (2011) developed several teaching activities and applied them to students. After the application, they examined whether misconceptions were dissipated by using the Wave Diagnostics Test. They determined that most misconceptions listed in literature were dissipated although some of them still existed. Similarly, Admoki et al. (2019) examined whether an activity involving virtual lab applications would be effective in dissipating misconceptions. At the end of the research, it was determined by simulation programs that students' misconceptions on mechanical waves decreased. Consequently, as Barniol and Zavala (2017) suggest, literature shows us that students have misconceptions and incomplete knowledge of mechanical waves. It is noteworthy that studies on mechanical waves mostly focused on determining students' conceptual understanding of the process. It is believed that determining the changes in students' conceptual understanding by way of the action plans designed according to the inquiry-based learning approach would bring a fresh outlook in literature. It is also believed that determining and then eliminating misconceptions and deficiencies in this matter at the upper-secondary level is important. As such, it would provide support to students' making sense of upper-secondary level subjects.

Research Aim and Questions

In the research, the teaching of mechanical waves was realized with inquiry-based learning; the aim was to determine the changes in students' conceptual understanding of spring, water, and sound waves. Mechanical waves, which are part of secondary education physics classes in Turkey according to the 2013 teaching program, were made appropriate to inquiry-based learning by the researchers (Ministry of Education [MofE], 2013). This research sought answers to "How does students' conceptual understanding change with the teaching of mechanical waves according to inquiry-based learning?"

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Research Methodology

Research Model

The research was designed as action research. Due to action research being pre-planned, designed, and easily shared, it was realized in an actual class environment (Johnson, 2012). Moreover, as action research made sure the quality of teaching was both comprehensible and open to development, it also made it possible to obtain information scientifically and systematically, and applications were designed in the process. Throughout the process, objectivity was maintained; planning was done before data collection and a calendar was formulated for the data collection process. A four-step model was adopted in the research; these steps were "Determining the research problem, data collection, data analysis and interpretation, and designing an action plan." Each of these steps was approached about one another and in a continuous cycle. Different pictures were created concerning the environment in which the research was carried out so that readers could have a grasp of what that environment was (Mills, 2014).

Participants

For the application of the research, the researchers applied to Ankara Directorate of National Education, which is affiliated with the Ministry of Education, and it was decided that the research be conducted in an Anatolian upper-secondary school approved by the directorate. In line with this, the research was carried out with the participation of 58 10th-graders from this school in Ankara (aged about 17-18 years; 30 girls, 28 boys) in the Spring semester of the 2017-2018 academic year. The study group was determined according to criterion sampling, which is one of the purposeful sampling methods; and the research was carried out with 10th-graders (Johnson, 2012). The research was conducted with the voluntary participation of 58 students; and 13 students were selected within this group to do the semi-structured interviews. These students were selected based on their success levels: low success (4 students), intermediate (5 students), and high success (4 students). It was done as such to represent the 58 students in the classroom since the number of students participating in the research was rather high. These students were determined by the teacher responsible for their physics education for the last two years taking into consideration their exam scores and in-class performances. Additionally, students were informed about the ethical procedures, and they were included in the interviews voluntarily.

Instrument and Procedures

In the research, data were collected through experience, inquiry, and examination. The experience was determined by the researchers' role as "participant observer." Researchers examined the activities related to the research and students; they regularly participated in the activities that would benefit the research problem. The semi-structured interviews and the form for conceptual understanding of mechanical waves were the data collection tools. Researcher and student journals, video and photographs, and hand-made materials were examination data (Mills, 2014). Data collection tools were decided on according to the nature of the research problem. Diversifying data meant increased data validity and enriched data results. In this respect, information about the aim and timeframe of the application of data collection tools are presented in detail in Figure 1.

Data were collected systematically at various times by the data collection tools given in Figure 1. Journals of researchers and students proved to be a significant source to see every step of the research. In the last five minutes of each class, researchers and students were given time to express their experience of the class, what they had learned, and how they felt. With the form for conceptual understanding of mechanical waves, students' conceptual understanding before and after the application was determined, and changes in their conceptual understanding were examined. The application of the form: it was applied to 58 students in about 35-40 minutes in the class environment in one class hour in the beginning and the end of the application. The form was designed by the researchers after a careful survey of the literature, and it consisted of 17 open-ended questions (Caleon & Subramaniam, 2010a; Caleon & Subramaniam, 2010b; Wittmann et al., 2003). It took its final shape after the pilot application and after 12 experts in the field with a Ph.D. in physics education checked it for content and method validity. Some of the questions in this form are presented as examples in Table 1.

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Figure 1
Information about Data Collection Tools

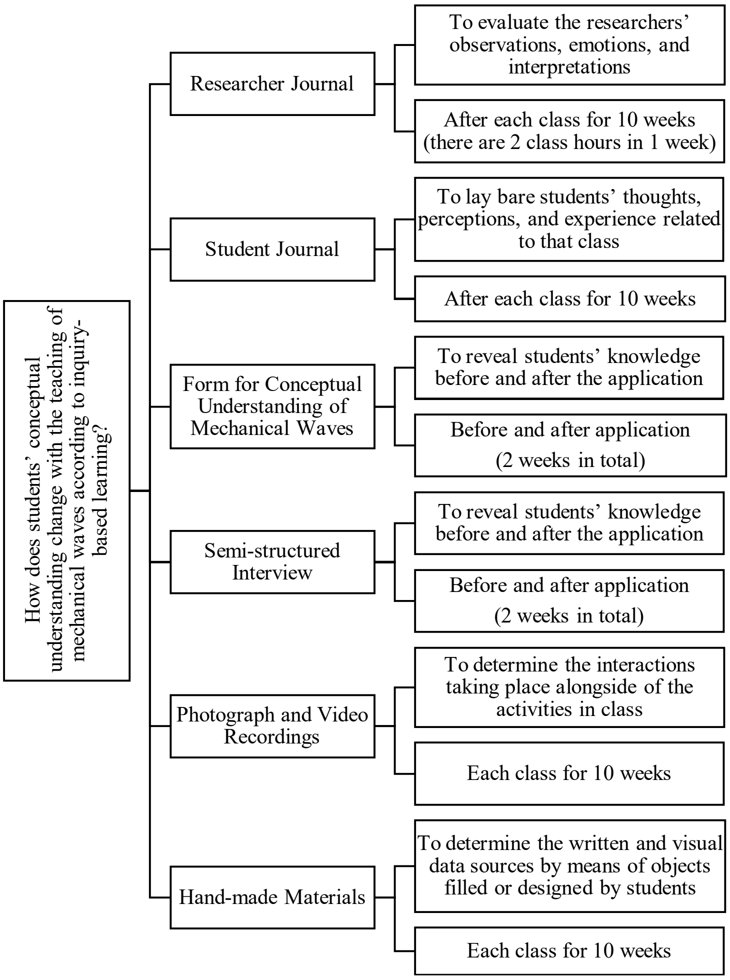
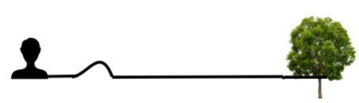


Table 1
Form for Conceptual Understanding of Mechanical Waves, Question Example

Question Example
3. A student ties one end of the rope he holds and then stretches the rope. He then oscillates the rope up and down in the vertical direction. At this point, keeping in mind that the length and tautness of the rope do not change, what, in your opinion, would cause the beat created by the student to hit the tree in the shortest amount of time? 
11. Imagine a kid wanting to go fishing with his family on a small boat. They throw their fishing rod, there is a small breeze at the time. The kid realizes that the distance between waves shortens and waves get smaller as they get closer to the shore. a) What do you think would be the reason for this? b) Explain the changes that take place in the speed and length of the wave as the waves get closer to the shore.
13. In movies, actors listen to the train rails to understand if a train is approaching or not. a) Why would actors feel the need to put their ear on the train rails? Would they not be able to hear if they did not? b) Do you think the characteristics of an environment would affect the pace of sound waves? Explain. c) What would be the pace of sound in a metal that is of the same density as iron but less flexible?

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Semi-structured interviews were realized with the participation of 13 students at the beginning and end of the application by using the same questions found in the form for conceptual understanding of mechanical waves. The interview questions provided flexibility for the interviewer; additional questions were asked to the students during the interviews when deemed necessary. During the interviews, students were left free to answer the questions however detailed they wanted, and the researchers did not use any expressions that might steer the students in any way (Glesne, 2010). These interviews were recorded by a voice recorder, and each face-to-face interview took about 30-35 minutes. Since it was difficult for the researchers to systematically follow the whole process, video recorders positioned at different corners of the class as well as photographs were used during application. Activities were recorded in class for 10 weeks, data were examined, and they were transcribed. Hand-made materials (such as concept maps, etc.) produced during the 10-week learning-teaching process, were also regarded as visual and written data. In this respect, hand-made materials were part of what students did in class as part of their studentship, they were also used as a data source within the scope of action research (Reynolds, 2011).

Action Plan

In the research, an action plan for the teaching of mechanical waves according to inquiry-based learning was developed. Before preparing the activities in this action plan, related literature, and the secondary school level physics education program in Turkey were examined. Then, the type of activities that are founded on inquiry-based learning and what qualities were expected in these were examined. As a result, researchers designed activities that would provide appropriate data and serve the purpose of the research, and these activities were applied in a class by the teacher. The teacher is a graduate of a teacher training school and has 20-year experience in the profession. Before the application of the activities, a pilot research was carried out with a different group, the applicability of these activities was evaluated, problem areas were determined, and recommendations of the teacher were also taken into consideration. After the corrections, the total duration that would be necessary for the actual application was determined, and then activities were applied. In the research, a total of five activities were designed and each activity took two weeks. The names of the activities, teaching techniques used in the activities, and the outcomes of each activity were presented in detail in Table 2.

Table 2
Explanations about Activities

Name of Activity	Teaching Methods Used	Activity Outcomes (MofE, 2013)
Let's jump rope	Demonstration Experiment, Simulation, Question &Answer, Video Show, Animation, Discussion	- By creating a beat and periodic waves their difference is explained - Reflection of beats from the fixed and free ends are examined. - Variables on which the pace of the beat formed on a stretched spring is based are analyzed.
Superposition	Discussion, Study Sheets, Simulation, Question &Answer, Whisper Groups, Educative Games	- Characteristics of the beats that are reflected and the beats that are transmitted are compared - Situations, where two beats meet, are analyzed.
Tsunami	Video Shows, Simulation, Question &Answer, Discussion, Whisper Groups, Study Sheets, Lecture, Problem Solving, Educative Game	- Direction, wave crest, and wave trough are examined for linear and circular water waves. - The reflection of linear and circular water waves from a plane or parabolic obstacle is examined.
Stroboscope	Discussion, Simulation, Question &Answer, Video Show, Guess-Observe-Explain, Concept Map	- Variables on which the water wave's speed depend are analyzed. - The behavior of water waves, when they pass from one environment to the other, is analyzed. - The relationship between depth and speed is examined.
Will the Bosporus Bridge Fall Down?	Demonstration Experiments, Discussion, Simulation, Animation, Question &Answer, Video Show, Case Study, Concept Network	- The formation of sound and the requirements for its spread are analyzed. - Resonance, possible problems it may create as well as the advantages it may bring are discussed. - A discussion on sound insulation and decreasing echo is held.

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With these activities, students were able to actively participate in class. The application of in-class activities was realized by the 5E learning model. As an example, the planning of "Will the Bosporus Bridge Fall Down," one of the activities in the research, is explained below:

In the *engaging step of the activity,* first of all, students were told that there would be two demonstration experiments and that they would be able to find the answers to the questions when they carefully followed these experiments. Students were asked to take notes while following the experiments. Demonstration experiments were performed in class and they were as follows: "*Feel the vibrations:* we turn on the radio and put a balloon 10 cm away from it. We turn up the volume and bring the balloon in front of the radio. Well, what do we feel now?" and "*Let's observe how sound travels:* cut the bottom of a plastic bottle. The back of the bottle is tightly closed by a plastic bag so that we have a small drum. A small candle is lit at the mouth of the bottle and is kept at 2.5 cm away from the bottle. What happens to the flame when we sharply hit the piece of plastic with our fingertips?" Students were asked questions after these demonstration experiments and to think about them. They were expected to explain that the sound was formed because of vibrations and that it expanded in the shape of waves. Then, the students were given the chance to actively work on the simulation for the related concept (Link: https://phet.colorado.edu/sims/html/waves-intro/latest/waves-intro_tr.html). They then listened to the sounds made by a dog, a human being, and a whale; and they were asked "In which environments do you think the sound spreads?" Students answered the question as "solid, liquid, and gas." They were then asked whether the sound would spread in the emptiness, and this was discussed in class. At this step, students were guided to understand that the sound is a mechanical wave and that it can be transmitted in material environments.

In the *explore step,* students were asked "when lightning falls, do we feel scared when we see the light or when we hear the sound?" This was discussed in class and then students actively work on the simulation (Link: http://www.vascak.cz/data/android/physicsatschool/template.php?s=kv_rychlost_zvuku&l=tr&zoom=0). Then, the students were asked, "What could be the factors that affect the speed of sound?" At this point, students were guided to explore the correct answers (i.e. temperature and environment). Afterward, "volume of sound" was tackled and students could work on the simulation for the concept (Link: http://www.vascak.cz/data/android/physicsatschool/template.php?s=kv_zvuk&l=tr&zoom=0). After students explored that the volume of sound is related to frequency, another demonstration experiment was carried out; "*water bottles:* two identical water bottles are brought to class. They are filled with different amounts of water. By hitting them with a spoon, high-pitched and bass sounds are produced. Which bottle produces a more high-pitched sound?" Then, students were asked, "Which one do we hear better, someone whistling outside or playing the drum?" Students' answers were discussed in class and animation on the subject was shown (Link: http://www.animations.physics.unsw.edu.au/jw/sound-pitch-loudness-timbre.htm).

In the *explain step,* students were asked again what sound is. They were shown a video about the timbre of sound and animation in which they could hear the timbre of different musical instruments (Links: https://www.youtube.com/watch?v=SFxRbY9E3oI, http://www.animations.physics.unsw.edu.au/jw/sound-pitch-loudness-timbre.htm). During this, students were allowed to make a comparison between the information they have explored and the explanations they have been given. Then, they were asked, "Have you ever thought about how opera singers break glass with their voice?" Students were expected to explain the concepts they have explored while answering the question. Following this, resonance was explained. Here, students were asked "Why do you think experts claim it is dangerous to organize running activities on the Bosporus Bridge?" and were shown a video (Link: https://www.youtube.com/watch?v=kikZdENuj10). Finally, they were told that resonance may have disadvantages although it has an advantage as it helps us understand that melody comes from two different sources.

In the *elaborate step,* students have distributed a case study text. In this case study, during a studio recording, artists talk about how they prefer amphitheaters for concerts. Students were asked about the reasons for such a preference. They were given time to find the answer by discussing it among themselves. During the discussion, they were asked "When there is no object/furniture in a flat our voice is heard more, and it is heard less when there is furniture. Why do you think is the reason?", "Why do you think our voice is barely audible in class while it is highly audible in the school corridors and the gym?", "How is the voice of actors quite clearly audible to the audience sitting at the back of the theatre?", and "You are tired of your neighbor's noise every day. What can be done to the building to prevent you from hearing your neighbor's noise?" All these questions were discussed in class, and students were helped to transfer their knowledge to new situations.

In the *evaluation step,* students were given an in-class evaluation activity. In this activity, they were given a central concept – Sound – and were asked to create a concept network for it. A concept network was formulated with the participation of all students. At the very end, the teacher shared her ideas about the process with the class, and the activity was concluded.

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Data Analysis

Data were analyzed with descriptive and conceptual content analysis. A rubric was prepared for the form for conceptual understanding of mechanical waves; data were analyzed by conceptual content analysis by taking into account this rubric. Data were collected under two categories by the rubric, namely, "scientifically acceptable" and "scientifically unacceptable." Then, these answers were considered in themselves under certain themes. Students' answers were also presented in tables under themes and categories. Moreover, the semi-structured interviews, which were developed to support the conceptual understanding form, were analyzed by employing a descriptive analysis method; and data were transmitted by direct quotations without any additional commentary. Researcher and student journals, hand-made materials, and video and photographs were analyzed by descriptive analysis. While describing data, they were transcribed by considering the date, place, and time. Events in class, student performance, comments, and in-class interactions were taken into consideration in the analysis. The analysis of this data was presented to the readers by direct quotations and visuals (J. W. Creswell & Creswell, 2018). In the analysis of all data, two experts who hold a Ph.D. in physics education were consulted. These experts are experienced in qualitative and quantitative research. Their transcriptions were examined separately and were compared in terms of consensus and dissensus. Arrangements were made due to the dissensus, and reliability calculations of data were carried out (Yin, 2014). It was determined that the consistency between the experts was 85%. Miles and Huberman (1994) contend that results that are 70% and over indicate that the research is reliable.

Validity and Reliability

In this research, validity and reliability were ensured by the believability, transferability, consistency, and affirmability principles. It was made sure that the research was consistent in itself and meaningful for the readers. The believability of the research was ensured by staying in the research environment from start to finish, by carefully observing the environment, by watching in detail the video recordings multiple times, by taking into consideration researcher and student journals, by consulting experts, by data variety, by explaining in detail the data collection and analysis processes, by objectively presenting data, and by indicating the relationship of processes with one another. In terms of transferability, important points of the research were turned into a report; objectivity was maintained throughout the identification and interpretation of data. Data were proven by supporting them with direct quotations. The study group was determined by a purposeful sampling method, and the determined criterion was expressed in detail. For consistency, students were interviewed face to face; the process was recorded, validity-reliability studies of data were carried out by the same experts. For affirmability, data were objectively reflected, confirmed by the conclusions, related to literature, and presented to the readers in a logical frame (Mills, 2014).

Ethical Procedures

Before the research, ethical approval was obtained to conduct this research from Hacettepe University's Ethics Commission and Ankara Directorate of National Education, which is affiliated with the Ministry of National Education. In the research, the principle of voluntary participation was observed, and the identities of the participants were kept confidential. All participants were informed about the purpose of the research and the right to leave the research at any time.

Research Results

The teaching of mechanical waves was carried out by an inquiry-based learning approach. Spring, water, and sound waves were handled within the frame of class activities, which were part of the action plan. Changes in students' conceptual understanding of these waves were determined by video and photograph recordings, research journals, student journals, hand-made materials, form for conceptual understanding of mechanical waves, and semi-structured interviews. Findings obtained from the form for conceptual understanding were presented in Table 3. After determining students' conceptual understanding before and after the application, the change in students' conceptual understanding can be seen in the table. Findings obtained from the semi-structured interviews were presented as a support for the form for conceptual understanding; on the other hand, changes in the students' conceptual understanding were presented with the help of direct quotations by giving examples from

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things that happened in class, from students' performance and comments, and their in-class interaction using videos and photographs, researcher journals, student journals, hand-made materials, things that happened in class. In this respect, Table 3 shows that students had incomplete or incorrect knowledge specifically on waves, beats, the speed of the beat, superposition, beat sent from a thin to the thick thread, reflection from a parabolic obstacle, stroboscope, the intensity of sound, expansion of sound and its speed. It was seen that students had readiness for the sound insulation concept in the pre-application. In the final application, it was noticed that most students had a significant change in their conceptual understanding; it was also determined that some students still had problems understanding the speed of the beat as well as the linear water waves hitting a parabolic obstacle. Although there was not a complete change in students' conceptual understanding of these concepts, it can still be argued that there was some improvement.

Table 3
Students' Conceptual Understanding of Spring, Water, and Sound Waves before and after Application

Theme	Category*	Answers	Before Application	After Application
Wave	+	Each atom pulsates with each other; however, if there is an energy transmission from a source to its environment then it can be called a wave movement.		√
	-	All pulsations expand in the form of waves.	√	
Beat	+	The wave movement proceeds periodically while the beat represents just one wave movement.		√
	-	Beat and wave denote the same thing.	√	
Reflection of the beat	+	After the incoming beat overturns at the wall and is reflected, it meets the outgoing beat, and they strengthen one another.		√
		Beats continue their movement in the direction they come from when they reach the very end; however, when a beat meets another beat these two absorb one another.	√	√
	-	The beat returns at the same level when it is reflected on a wall (fixed end).	√	
		When the beat reaches the very end, it will continue to move from the free end by reversing itself.	√	
Speed of the beat	+	The speed of a beat depends on inertia and the flexibility of the environment. Thus, a thinner thread should be used.		√
		Speed is independent of the frequency of the source or amplitude. The speed of the wave changes depending on the width of the wave.		√
		The speed does not change because the volume and tautness of the manilla rope do not change. In an increased frequency only results in the shortening of the wavelength.		√
	-	The beat with a large amplitude has a large pace.	√	√
		If frequency increases, so do the speed of the beat.	√	
The beat sent from the thin thread to the thick	+	The amplitude of the transmitted and reflected beat is smaller than the arriving beat. The speed of the beat transmitted on a thick thread decreases, its amplitude also decreases. The speed and amplitude of a reflected beat are the same as those of the arriving beat.		√
	-	The speed of the beat decreases its width increases.	√	
Superposition	+	First of all, there would be 2 units difference between beats that move one unit per second. Then they would strengthen each other.		√
	-	The two beats strengthening one another is defined by the cumulation of their peak points.	√	
		Beats absorb one another. A	√	
		When beats X and Y move, they create a wave movement one head down, one head up. Consequently, when they reach the fixed end, they would be reflected by turning in the opposite direction; however, their energy would decrease since they would be constantly doing this movement. In the end, they both become a linear line by being absorbed.	√	

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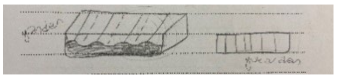
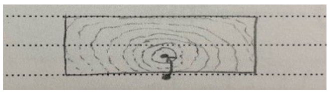
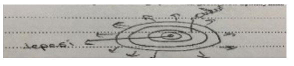
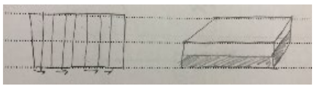
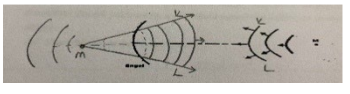
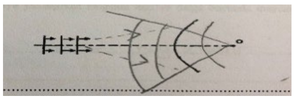
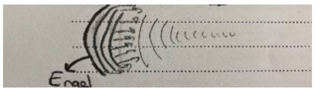
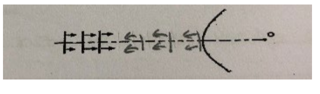
Theme	Category*	Answers	Before Application	After Application
Linear and circular water waves	+	Linear water waves are formed. 	√	√
		Circular water waves are formed. 	√	√
		When children jump into the water, wave formation increases, and wavelength shortens.		√
		Water molecules reach every corner of the pool using waves.		√
	-	Circular water waves are formed. 	√	
		Linear water waves are formed. 	√	
		There is no relation between the time children jump into the poll and the formation of waves.	√	
Circular and linear water waves that hit to the parabolic obstacle	+			√
				√
	-		√	
			√	√
Strobo-scope	+	If Fd>Fy waves move forward, if Fd<Fy they move backward.		√
	-	The waves move in whichever direction we put the stroboscope in the washbowl, and they return in the same manner when they hit the washbowl.	√	
Speed, frequency, and amplitude of the water wave	+	The amplitude of the wave increases depending on how high a marble ball is dropped from; the speed and the frequency of the wave remain the same.		√
		The less the depth of an environment, the shorter the wavelength. Hence, the speed of the wave also decreases.	√	√
	-	Speed of the wave and its frequency decrease depending on how high a marble is dropped from; its amplitude increases.	√	
		The speed, frequency, and amplitude of the wave decrease by half if a marble ball is dropped from higher.	√	
		The less the depth of an environment, the higher the speed of the wave and the shorter its length.	√	
		The less the depth of an environment, the lower the speed of the wave and the longer its length.	√	

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Theme	Category*	Answers	Before Application	After Application
Expansion of the sound and its speed	+	The wheel that touches the train rail transports the sound in waves to the other side of the rail because the sound needs an environment to travel. Moreover, the higher the molecular density the higher the transmission speed.		√
		Density, heat, and humidity all affect the pace of sound waves.		√
		The speed of sound decreases when it passes from a flexible environment to a less flexible one.		√
		Solid things transmit sound better by vibrating. Footsteps directly vibrate the solid thing, and sound expands in gas environments. Since it is thought that solid things transmit sound more quickly, the footstep is heard more easily.		√
		Space is emptiness, sound cannot be reflected.		√
	-	You cannot hear a sound even when you put your ear on the train rail because iron does not transmit sound.	√	
		Sound can move faster in a metal that is of the same density as but less flexible than iron because the closer the particles are to one another and the narrower the expansion area, the more waves are reflected.	√	
		Conversations of the neighbors are more easily audible than footsteps in apartment buildings.	√	
Intensity of sound	+	The intensity of a high sound breaks a glass.		√
	-	The breaking of glass is about the timbre and frequency of sound.	√	
Sound isolation	+	Buildings need insulation so that the neighbors do not hear each other’s television and music.	√	√
		The sound expands in waves through vibration.	√	√
	-	The sound cannot pass through the wall; it can only pass through the threshold. Thus, it expands linearly.	√	

**(Scientifically acceptable answers: +, Scientifically unacceptable answers: -)*

It was determined in the research that students’ conceptual understanding of offspring waves generally changed except for the speed of beat as students still had difficulty understanding this concept. It was revealed that students still related the speed of the beat with amplitude at the end of the application. This problem is evident in an explanation of a student in one of the interviews:

“The beat reaching its destination in the shortest amount of time depends on amplitude. The bigger the amplitude of a beat, the faster it reaches the other side (Ozge).”

Although there were students who had difficulty understanding the speed of the beat, there were also students who were able to give correct explanations:

“Speed is independent of the frequency of the source or amplitude. The speed of a wave changes according to its width. A wide beat has a high speed (Ali).”

Moreover, after analyzing videos and photographs, it was detected that there was a change in students’ understanding of this concept:

> *“In the elaborate step, a spring was brought to class for the demonstration experiment. Springs with different thicknesses were stretched, and necessary measurements were done by a dynamometer. Then, beats were formed on the springs and the arrival times of these beats were calculated by a chronometer. Here, students were expected to explore what the speed of the beat depends. The intensity of the force was changed, and the effect of the same force on different springs were also examined. Consequently, students underlined that the speed of a beat changed depending on the force stretching the spring as well as the mass of the spring. Moreover, it was indicated that a beat with a large width would have a big speed.*

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Finally, students were asked to give examples from real life, a class discussion was held upon these examples. Some of these examples are as follows:
Example 1: For example, if we tie a thread to a tree and hold the other end of it ourselves, the speed of the beat would change depending on the tensile force we put on the spring. Thus, the width of the beats would change as well.
Example 2: When we were little, we used to put springs on our fingers. We then would stretch them at the same level and release them, each spring would fall at a different place. Whoever sent his or her spring to the furthest would win. Everybody would bring spring from home. Now I understand that, if we applied the same tensile force, then whoever had the thinnest spring would be able to send it to the furthest distance."

Another basic concept tackled in research was the wave; the following extracts, which indicate a change in the students' conceptual understanding, were taken from students' journals:

"Dear Diary,
I was extremely excited at the beginning of class; I was curious about what we were going to do. Then, my friends made a demonstration experiment by using a thread. I was unable to mentally visualize the wave as a concept or I would relate it with incorrect examples. However, in this class, I had a better grasp of this concept and learned that we can talk about a wave movement when there is energy transmission in the form of vibration from a source to the environment. I had great fun and I also learned it well" (Aynur).

Inquiry-based learning was effective in students' learning spring waves.

Concerning water waves, students made the following statements about the direction of circular and linear water waves in their semi-structured interviews before the application:

"Linear waves move towards the shore while circular waves move in circles getting bigger from the center to the perimeter (Can, Hasan)."

However, after the application, no such scientifically "unacceptable" statement was given. After the application, it was determined that the only conceptual problem was in the linear water waves coming to a parabolic obstacle. At this point, there was no change in some students' conceptual understanding while many of them easily understood it because, as was evidenced by the video recordings and photographs, during the activity, this concept was handled firstly in a group study and then was reinforced with an educative game. Some of the expressions found in the researcher journal concerning these applications are as follows:

"Students were highly active in this activity. It was seen that group studies and educative games motivated them more for the class. They discussed the subject in group studies by asking questions among themselves. They exchanged ideas about linear and circular waves arriving at a parabolic obstacle. Educative games also proved to be effective. Participation was high in the game. Students contributed to the process by confidently expressing their ideas. Moreover, everybody listened to the speaker carefully and asked for permission to comment afterward. Students seemed especially happy and excited during the educative game."

As such, it was clear that most students had a change in their conceptual understanding. Concerning the speed of water waves, video recordings, and photographs were analyzed; and it was seen that there was a student-teacher dialogue at the introduction to the topic. As can be seen in the form of conceptual understanding, students had some gaps in their pre-knowledge:

Teacher: Waves hit our face more frequently in shallow areas, but this is not the case in deep ends. Have you ever thought about what characteristic of the wave this is related to?
Firat: The wind is more effective at the shore, ma'am. Thus, waves get more frequent and they hit our face more frequently at the shallow ends.
Teacher: Then, is the speed of the wave higher at the shore?
Firat: Yes, ma'am.
In engaging the age step of the activity, the answers given above were received. In the explain step, students were asked the same question, and this time Firat provided the correct explanations:

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Teacher: How is the speed and length of the wave in shallow areas?
Firat: The speed of the wave decreases in shallow areas.
Zeki: If the speed decreases, the wavelength also shortens.
Teacher: What would be the speed and length of a wave in deep ends?
Ayse: It would be the opposite of what my friend said about the shallow areas. The speed and length would increase in deep ends.
Teacher: Which formula do you base the ratio between wavelength and speed?
(Firat runs to the board and writes down the formula.)
Firat: λ= V.T
Teacher: Thank you Firat. Guys, as you can see, the wavelength and the speed of a wave are directly proportional to one another.

After the water waves, the focus moved onto sound waves. Looking at the form for conceptual understanding, it was seen that students interpreted the sound wave generally as a water wave and thought of it as an entity. However, this pre-application problem did not occur after the application. In the research, it was determined that students have scientifically accurate pre-knowledge about sound insulation. Students were able to correctly make sense of a concept they have frequently come across in daily life; however, they also had incomplete knowledge about certain concepts related to daily life such as the intensity of sound, speed, and expansion of sound. Keeping this in mind, the teaching of the expansion of sound started with an in-class demonstration experiment. In the experiment, materials that can be found in daily life were used; the experiment also aimed to seek answers for events that we are familiar with yet rarely question. A teacher-student dialogue during this experiment can be found below:

Teacher: Were you able to hear the radio before you covered the radio with the tin can?
Serpil: Yes.
Teacher: Was the balloon vibrating when it was close to or far away from the radio?
Vedat: Yes.
Teacher: What do you think causes the balloon to vibrate?
(Silence)
Mert: Air molecules vibrate, that is why the balloon also vibrated.
Teacher: How do we hear the sound?
Onur: Ma'am, the sound makes the air vibrate and the vibrating molecules make the sound reach our ears.
Teacher: They why were we unable to hear the sound when we covered the radio with the tin can?
Aynur: In that case, the vibrating air was unable to get out, thus the sound could not reach our ears.

This short dialogue between the teacher and the students shows that students could question things using the demonstration experiment and were able to easily answer questions. There were scientifically unacceptable expressions related to the intensity of sound in the pre-application semi-structured interview of a student:

"The glass breaks at a certain sound timbre. If the frequency changes so do the timbre of the sound, thus, the glass does not break" (Suna).

Suna confused intensity and frequency before the application; after the teaching carried out according to inquiry-based learning, she wrote the following in her journal:

"Dear Diary,
In this class, after the animation show and the in-class discussion, I learned that a high-intensity sound would carry more energy and have a bigger amplitude. I used to think that the breaking of glass was related to frequency, but I realized that it is about the intensity of sound. At this point, I can say that when the intensity of sound is low, its amplitude and energy will also below so the sounds coming from afar would not be heard easily. Realizing that I have learned about the intensity of sound in this class has increased my motivation for this class. I was already interested in sound waves, but now I think I have reached the peak point in my learning process of this subject" (Suna).

Finally, students were asked to create a concept network to evaluate the learning of the concept of sound. In

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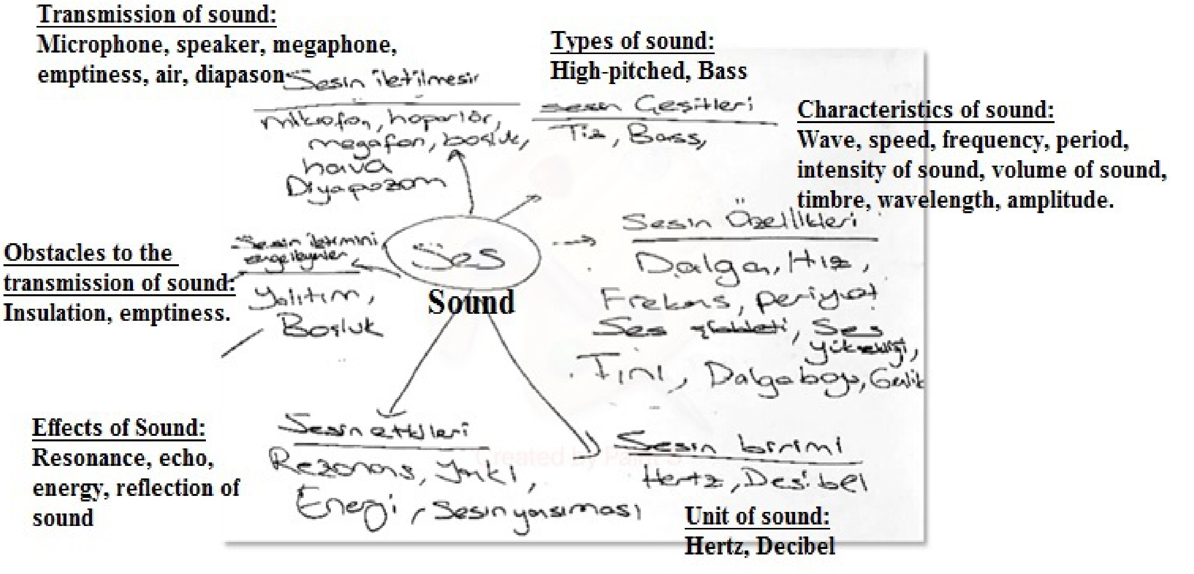
the in-class evaluation activity, students were provided a central concept, namely, "Sound." Students wrote down the concepts related to this central concept onto the edges of the board and then related them to the concept of sound by grouping them among themselves. An example of this hand-made material is given below (Figure 2):

Figure 2
An Example of a Concept Network Created for the Concept of "Sound"



Examining this concept network, it was determined that the concepts indicated by the students were correct and that the students correctly related these concepts. This shows that the approach used in the research was effective for sound waves.

All these findings prove that the teaching of mechanical waves by inquiry-based learning contributed to students' learning. It was determined that before the applications students usually had difficulty with mechanical waves as a subject and that they had incomplete/incorrect knowledge; it was then determined during and after the application that there was a change and improvement in their conceptual understanding.

Discussion

The inquiry-based learning approach was employed in the teaching of mechanical waves in research, and it was determined that students' conceptual understanding of spring, water, and sound waves showed improvement because students were encouraged to reach information themselves and to acquire the skills to inquire and meaningfully learn subjects. The research avoided directly transmitting information to students. Students were given the chance to improve a sense of responsibility, to freely express themselves, to share, and to compare their new knowledge with the already existing one. Similarly, the research aimed to help them acquire new knowledge by increasing their curiosity and make them understand the importance of mechanical waves in daily life. In this respect, it is thought that the research has contributed to the improvement of their advanced logical thinking skills (Schalk et al., 2019). Kuo et al. (2019) also argued that students participated in the learning-teaching process if their curiosity was aroused. Students likewise indicated that the classes excited them and aroused their curiosity and hence participated in the class of their own volition. In the engaging step of this research, students' pre-knowledge was determined. It was thought that this would help prevent their incorrect knowledge and support their learning process because students are known to have difficulty making sense of concepts due to proactive inhibition (Tumanggor et al., 2020). However, activities used in the research contributed to an effective teaching environment as well as a scientifically proper construction of the concepts after the application by employing various teach-

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ing techniques (Sotáková et al., 2020). Thus, it is believed that appropriate and effective teaching helps properly transmitting knowledge to a higher level, just as this research did (Okur & Artun, 2016). Moreover, students who learn by doing, discussing, and thinking were enabled to construct by evaluating in their minds what they had learned on mechanical waves. Palupi et al. (2020) indicated that while knowledge is constructed by inquiry-based learning students' success and problem-solving skills also improve. This indication was supported by the fact that students were able to relate the subject with daily life and to seek solutions for problems. In addition to this, the research provided a safe environment where students and the teacher could easily communicate and supported the development of their communication skills. In this communication, the aim was to enable students to realize their level of knowledge and relate their existing knowledge with the newly acquired one (Wood, 2019). As such, students were given the chance to be active in class with constant communication with their teacher. Mutlu (2020) indicates that providing students a chance to learn by doing/experiencing would positively contribute to their views on scientific research. In the research, it is believed that students' will to do research, observation, and experiment was increased. Moreover, in group discussions, students were able to see others with different views, and they realized that they could respectfully discuss different ideas. Canalita et al. (2019) also contend that peers working together in the inquiry-based learning process is effective. Similarly, García-Carmona (2020) suggested that this would enable students' critical thinking skills to improve.

In light of all these conclusions, it is evident that students were supported to have awareness for inquiry, and inquiry-based learning enabled them to have a positive change in their conceptual understanding. It is believed that by adopting this research model lecturers should provide online training for teachers by showing activities in different topics (Mamun et al., 2020). Indeed, it is well-known that there are difficulties in students' comprehending and constructing concepts in other subjects of physics as much as mechanical waves; there are also difficulties in eliminating misconceptions and changing students' conceptual understanding. The present systems fall short and new and different teaching methods should be tried (Djudin, 2018). Kapon and Merzel (2019) also contend that teachers should be guided with such studies so that students and the field benefit from it. In this respect, in this action research, the researcher collaborated with the teacher; the teacher was never left alone, and she was facilitated to overcome problems. As such, the teacher improved her pedagogical knowledge, and she was given the chance to have a critical look at the applications she will do in the future. At the same time, the teacher was ensured to learn new things and be open to new ideas. This research helps fill a gap between the application and the theory (Johnson, 2012). Finally, the 7E model can be used in the in-class application of the inquiry-based learning approach, which is appropriate to all class levels and all subjects. Moreover, concepts for which no complete change in conceptual understanding took place can be examined in further studies with innovative applications such as augmented reality (Craciun & Bunoiu, 2017).

Limitations

Since there was no control group in this research, there were no dependent and independent variables or hypotheses. Moreover, it was not carried out to prove something or to make comparisons (Johnson, 2012). Thus, the change observed in the 58 students' conceptual understanding of spring, water, and sound waves would not be appropriate to be generalized for all students. To do this, empirical research with a larger sample should be carried out. This research only focuses on understanding the changes in students' conceptual understanding after teaching mechanical waves with inquiry-based learning. It aimed at finding solutions to problems presented in the literature using inquiry-based learning. Data were collected, the teacher applied the action plan, and changes in students were observed. The most important limitation of the research is the fact that there was no way of obtaining information about the process and the results unless the teacher wanted it. The teacher actively participated in the research from the get-go, which makes her rather powerful. To minimize this limitation, researchers preferred to work with a teacher whom they had known and worked before. Keeping in mind the length of the research and its richness for data sources, another limitation of the research is that it took quite long to analyze data and turn it into a report. This limitation causes the researchers, who are unaware of one another, to work on the same topic in several classes at the same time. This is called "waste of time" by action researchers. To prevent this limitation, the researchers kept in mind during the process that problems required effective solutions and that the readers should be informed as soon as possible (Johnson, 2012; Mills, 2014).

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Conclusions

At the end of this research, it was determined that the inquiry-based learning approach is effective in the development and improvement of students' conceptual understanding of spring, water, and sound waves. The importance of inquiry-based learning methods in teaching the basic concepts of physics education was revealed by students mentally evaluating and then structuring information. Such applications should be integrated into education programs to make this rather effective method commonplace, and students' learning should be supported. In the research, students emphasized that this approach was effective in their learning, which suggests that it can be used in the teaching of various other subjects in physics classes. Moreover, students' enthusiasm for the teaching-learning process may not be limited to the mechanical waves and the development of their advanced thinking skills can be supported in other subjects as well. As such, teaching materials on different topics designed appropriately for an inquiry-based learning approach would contribute to the field as well. Such guiding materials would guide teachers which in return would help the process to move forward more effectively and help time to be used more productively. However, it is necessary to know how inclined teachers are to employ such approaches. In this respect, further research on the inclinations of teachers would be beneficial for the field. In conclusion, a rich learning-teaching environment can be ensured only when teachers believe in the benefits of an inquiry-based learning approach and when they are both knowledgeable and willing on this issue.

Disclosure Statement

No potential conflict of interest was reported by the author(s).

Notes

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