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# Teaching the concept of time: A steam-based program on computational thinking in science education

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**Abstract:** The aim of this research was to develop a STEAM-based program for teaching middle school students the concept of time to enhance their computational thinking skills. The proposed Time Teaching Program (TTP) consists of modules and activities on the definition of time, historical development of time measurement tools, universal time measurement system, space–time theory, and time as a fourth dimension. To determine the effectiveness of TTP and its effect on middle school students' computational thinking skills, a mixed methodology was adopted in which both a quasi-experimental design including a pretest–posttest control group and an observational case study were used concurrently. The study group consisted of eighth-grade students from a public middle school in Turkey, selected according to the convenient sampling method. A computational thinking test was used to collect quantitative data, and observations and semi-structured interviews were utilized for the collection of qualitative data. According to the results of analyses, when the effects of the pretest scores were not considered, there was a significant difference ($F_{.469}$, 1, $R^2$ = .518) between the final test scores of the experimental and control groups in favor of the former. Based on these findings, it can be stated that the proposed STEAM-based program significantly improves the computational thinking skills of eighth-grade middle school students.

## ABOUT THE AUTHORS

We all as science researchers working in Turkey are more interested in the theoretical and pedagogical direction of STEM approach and designing teaching materials and classroom activities for including mathematics, science, and technology-design courses in accordance with the nature of STEM. In addition, we focus on the development of computational thinking skills of students in science classes. Therefore, we designed and implemented the Time Teaching Program. The aim of this research was to develop a program in accordance with STEAM model which covers the topics of time concept, historical development process of time measurement tools, universal time measurement system, space–time theory, and time as a fourth dimension. Now, we are planning a new program based on "communication" theme to the development of computational thinking skills of students on topics such as working principles of communication tools, light, sound, waves, frequency, period, media literacy, etc.

## PUBLIC INTEREST STATEMENT

You have read in many places that our education system has to support multidisciplinary teaching in order to develop our children sophisticatedly and gain them twenty-first-century skills. In that case, what are these twenty-first-century skills? Why are they important? How can they be earned? Are our schools and teaching programs sufficient to achieve this goal? Unfortunately, generating ideas for shaping our future is easier than realizing them, and often these ideas cannot be effectively made real because they cannot fit into the right theory or curriculum plan based on students' developmental characteristics. In this research it is examined that how can the computational thinking skills, as one of the twenty-first-century skill mentioned above, be acquired at the secondary school level through multidisciplinary approach. Additionally, an interdisciplinary curriculum model was proposed and discussed for this purpose. The results of the research are important in terms of providing a concrete and developable teaching model.

**Subjects: Education; Curriculum Studies; Science Education**

**Keywords: science education; STEAM; computational thinking; time**

## 1. Introduction

The educational environment provided for individuals and the targeted characteristics students should achieve in this environment have varied according to the requirements of the particular era. Today, individuals are expected to have a wide range of abilities, such as taking responsibility for their own learning, thinking, questioning, transforming what they have learned into skills, analyzing events, establishing original connections, interpreting results in light of scientific data, cooperating, and using technology effectively and appropriately. Skills in relation to creativity, intellectual curiosity, critical thinking, knowledge and media literacy, cooperation, entrepreneurship, flexibility, intercultural interaction, and social responsibility are defined by educational scientists as twenty-first-century skills (Ananiadou & Claro, 2009; Rotherham & Willingham, 2010). Countries need to revise their education programs in light of these skills, not to fall behind technological developments and to increase their competitive capacities (European Parliament Communities, 2015; President's Council of Advisors on Science and Technology, 2010). One way of achieving this is to integrate different disciplines and real life into education programs because an interdisciplinary approach supports meaningful learning (Moye, 2011). This approach is not new for multidirectional training of individuals (Çorlu, Capraro, & Capraro, 2014; Frykholm & Glasson, 2005). Specifically, the multidimensional development of students based on an interdisciplinary approach has been long investigated in relation to science education, science–technology–society, and socioscientific issues (Sadler, 2004; Walker & Zeidler, 2007; Zeidler & Keefer, 2003; Zeidler, Sadler, Simmons, & Howes, 2005). However, in the twenty-first century, information and communication technologies have assumed even a more significant role in social and economic life. For this reason, science–technology–engineering–mathematics STEM education, which is considered to enable individuals to become multifaceted, has gained importance. STEM is a systematic approach integrating these four subjects at primary and secondary school levels (Çorlu et al., 2014). In addition, STEM covers a wide range of professions and disciplines, including agriculture, physics, psychology, and automotive engineering (Ashby, 2006). The STEM approach has two main objectives: first to increase the number of students who are ready to be employed after high school and encourage them to choose careers in science, technology, engineering, and mathematics, and second is to increase the competence of all students in basic STEM areas (Thomasian, 2011).

STEM education is at the forefront in the United States and Europe (Gonzalez & Kuenzi, 2012; Kuenzi, 2008) while the Korean primary education system (K-12) focuses on STEAM education (Jin, Chong, & Cho, 2012; Yakman & Hyonyong, 2012), which is an interdisciplinary approach that incorporates the field of art into STEM education (Armknech, 2015; Park & Ko, 2012). Thus, STEAM aims to provide an understanding of the relationship between science, technology, engineering, art, and mathematics (Yakman & Hyonyong, 2012). In order to create a balanced STEM program, it is necessary to attach more importance to the field of art than to acquire communication skills, such as reading, writing, and speaking (Armknech, 2015). By criticizing the STEM approach for overlooking the creative nature of man, this approach aims to raise manpower which will contribute to the development of society and increase the competitive power of societies. Yakman (2008) describes STEAM education in two ways. First, it is an education in which the fields of science, technology, engineering, and mathematics are approached in a multidisciplinary manner in addition to their individual standards. Second, STEAM education is holistic aiming at current fields and teaching subjects (Park & Ko, 2012). Yakman (2008) created a pyramid to present STEAM education more concretely.

The pyramid consists of five steps. The lowest order constitutes the subject content of the STEAM training areas in particular, and the contents described in this step form the basis of the disciplines given in the higher step. While the areas covered by STEM education are presented in the multidisciplinary step, the disciplines covered by this approach, i.e., state of the art integrated into STEM, are given in the integrative step. The top step refers to life-long learning. The subject areas covered in the first step of the pyramid are related to high school and professional education areas, the multidisciplinary step is appropriate for the secondary school level, and the integrative step for primary and secondary school education (Park & Ko, 2012).

In a STEAM-based education program, it is crucial to first determine the components to be included. Park and Ko (2012) referred to the following seven steps in the content organization of STEAM education:

(1) The processes of association, combination, and integration between the existing educational programs and the five STEAM disciplines should be undertaken without creating any conflict. In addition, integrated thinking or combined activities on thinking can be organized either separately or together for the fields of STEAM.

(2) For a creative STEAM education, various thinking systems concerning science, technology, and engineering should be introduced. For this purpose, it is important for students to learn how to apply a basic scientific theory to different technologies and how these technologies can be used in real life from an engineering perspective. Therefore, the relationships between the STEAM fields, as well as those between education and practice, are vital.

(3) For effective and creative teaching, teachers need creative tools. It is therefore important to develop various creative methods, learning tools, and experiments in STEAM education. Recently, creative experiments have also been used outside STEAM education. These activities should be integrated into STEAM education.

(4) One of the main objectives of STEAM education is to develop the ability to see the big picture, i.e., see the forest, as well as the trees in it.

(5) With the technological world rapidly changing, overlooking the philosophical nature of education and psychological nature of human beings in science, technology, and engineering education would be mechanical and meaningless. Therefore, a STEAM education system should be able to quickly respond to changing technologies and adapt to the requirements of the day.

(6) For STEAM education, a practical and realistic system should be developed, which can systematically predict the future based on not only science, technology, and engineering but also politics, environment, society, and economy. It should also take into consideration other integrative thinking systems, creativity, and values.

(7) The concept of integrated design in engineering may be an important turning point for STEAM education. This concept should aim to train not only future scientists and engineers but also future politicians and social leaders by developing students' systematic experimental skills in science, technology, and engineering, as well as nurturing other skills and traits related to ethics, communication, sociability, cooperation, leadership, and empathy.

### *1.1. Computational thinking*

Computational thinking (CT) has a long history in computer science. Historically, *algorithmic reasoning*, as CT was known in the 1960s and 1970s, was defined as the process of formulating algorithmic relations by treating problems in the context of inputs and outputs (Knuth, 1985). Today, this concept has extended to many levels of abstraction and has been concentrated on utilizing mathematics to develop algorithms and determining how solutions to problems of different magnitudes best work (Denning, 2009). In order to better understand this concept, it is necessary to first define *informatics*. The Turkish Language Society defines the concept *informatics* as "the regular and logical electronic processing of knowledge, which is used by human beings for communication in technical, economic and social areas, and constitutes the basis of science." According to Denning (2009), information science is not merely computer programming but a deeper concept requiring the ability to think like a computer scientist. CT is very useful in formulating problems in an appropriate format to solve them using computers and other tools; logically organizing and analyzing data; displaying data using abstraction, such as models and simulations;

generating results through algorithmic thinking; showing, analyzing and applying possible solutions; and generalizing and transferring problem-solving processes to the solution of problems in many other areas (Barr, Harrison, & Conery, 2011; Wing, 2008). CT is one of the key areas of application in computer science, but not unique in the processing of information nor does it cover the entire information processing cycle (Denning, 2009).

CT is a kind of analytical thinking; it uses the general way of thinking mathematically to solve a problem: designing a large, complex system and engineering it considering real-life situations; it incorporates intelligence, mind, and understanding human behavior into scientific thinking (Wing, 2008). CT focuses on people's ways of solving problems, rather than encouraging them to think like computers. It is not only software and hardware that are physically shown and that touch one aspect of our life but also computational thinking concepts in problem-solving, execution of life, communication, and interaction with other people.

Various researchers identified the subdimensions of CT-related skills. For examples, Weintrop et al. (2014) defined the following four subdimensions of CT skills: data and information, modeling and simulation, computational problem-solving, and system administration. Below are examples of the skills included in each subdimension.

- Data and information skills: collection, generation, manipulation, analysis, and visualization of data.
- Modeling and simulation skills: using computational models to understand a concept, understanding how and why information processing models work, using information processing models to develop and test solutions, evaluating computational models, creating new models, and expanding existing models.
- Computational problem-solving skills: catching and debugging errors, programming, choosing effective computational tools, measuring different approaches/solutions for a problem, developing modular informational computing solutions, using problem-solving strategies, and creating abstracts.
- Systems management skills: Examining a system as a whole, recognizing relationships within a system, thinking in levels and visualizing systems, and defining, understanding, and managing complexity.

### *1.2. Research problem*
The previous sections of this paper addressed the importance and necessity of the STEAM approach and CT skills for the education system. What is even more important, however, is to discuss what should be prioritized and identify the steps to be followed by science educators to adopt an effective STEAM approach. Although science education is closely related to other disciplines, and thus appropriate for an interdisciplinary approach by nature, there are clear challenges to integrating science and other STEAM fields, such as art and engineering, which do not appear to have common skills or objectives. One way to overcome these challenges might be to seek support from experts in the field, but this may create a new problem in that although painting and music courses are taught by teachers qualified in that field, engineering experts are not employed as teachers in schools. However, since the STEAM approach aims to develop students' basic thinking skills in relation to engineering, rather than expecting them to become engineers, the previously mentioned CT skills in classroom activities will help meet the specific requirements of this field. In addition, science applications in the middle school curriculum and the compulsory or elective courses, such as technology design, are very important sources in which to apply an interdisciplinary approach. For the preparation of instruction plans, it would be very useful to work with the teachers of these courses and collaborate with them throughout the academic year.

A review of the literature shows that STEM education practices are mostly focused on technology development and use as in the context-based learning approach, rather than on solving problems from real life. In more concrete terms, both in Turkey and globally, STEM education has been mostly limited to research on software and robot construction (Papanikolaou, 2010; Yamak, Bulut, & Dündar, 2014). This may be because the majority of the software kits used in STEM education are free and easily available (e.g., Arduino IDE and Scratch), and the basic algorithms involved are simple enough for middle and high school students to easily learn (Resnick & Silverman, 2005). In addition, it is clear that both in the hardware and software sense, robot construction addresses all four fields of STEM, i.e., science, technology, engineering, and mathematics. However, we consider that due to most studies being undertaken independently from educational programs, their contribution being primarily to the development of students' CT skills, as well as other skills included in the objectives of the curriculum, is questionable. For this reason, there is a need to prepare and implement a STEAM-based program and evaluate its effectiveness. Therefore, in this study, we aimed to develop a STEAM-based program to teach middle school students the concept of time (Time Teaching Program—TTP) in order to enhance their CT skills. In this context, the main research problem of the study was determined as "Does the proposed STEAM-based TTP have a statistically significant on the development of CT skills of eighth-grade middle school students?"

## 2. Method

In this research, a concurrent-triangulation design (Creswell, 2009) was used as mixed methodology. This pattern is also referred to as "simultaneous attempt" by Newman and Ridenour (2008) and is based on the combined and concurrent use of qualitative and quantitative research methods. For this purpose, a quasi-experimental method was employed with the pre-test and posttest control group (observational case study) (Bogdan & Biklen, 2007). A case study is a method of using a variety of data gathering tools, such as focus group interviews, observations, and examination of documents to analyze one or more situations in an integrated manner within the boundaries of time and location (Yıldırım & Şimşek, 2005). This case can be a single individual, program, module, or school (Newman & Ridenour, 2008). An observational case study is a type of case study in which observation of the participants is the primary data collection tool, and it is undertaken mostly in environments, such as schools and rehabilitation centers.

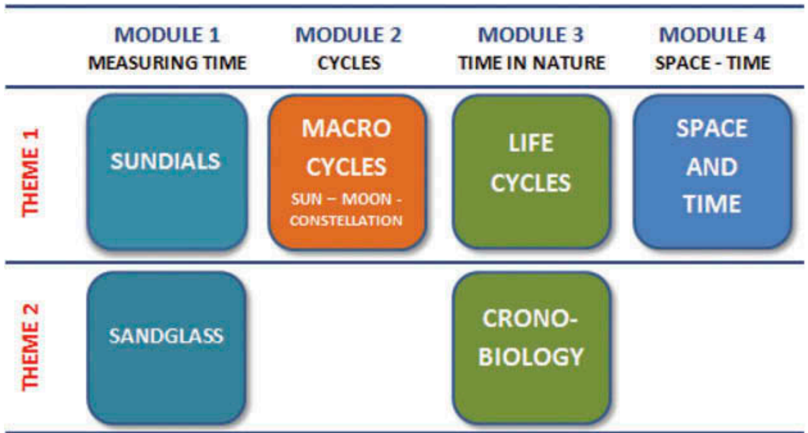
### *2.1. Program preparation and application*

TTP was developed based on the STEAM model in order to develop the CT skills of eighth-grade middle school students. The idea of developing TTP emerged from the need to integrate CT knowledge and skills into the curriculum. Both in Turkey and in the rest of the world, research into how to improve the CT skills of students is usually driven by a focus on the attempts to develop robotic systems and is generally based on information and technology-oriented courses and topics. However, this is not in parallel to the objective of developing problem-solving skills that are at the center of CT skills. It is believed that in order to successfully develop CT skills and integrate them into daily life, students should relate these skills to the curriculum content. This indicates that the content of the elective science applications course in middle schools should be revised since the current curriculum only covers science and mathematics topics, with other STEAM disciplines; e.g., engineering and technology being overlooked. Therefore, when developing a STEAM-based program for this course, we chose to focus on a concept that is related to every aspect of life and thus concerns multiple disciplines: the concept of time. We first prepared modules for teaching this concept and then decided on activities and content according to these modules. The activities were finalized after the evaluation of science teachers and field experts. Figure 1 presents the modules and the course content.

#### *2.1.1.* Module 1: *measuring time*

The measuring time module aims to develop the concept of the day-time clock from the past, the examination of the developed tools, and the creation of the future, from the focus point of how time progresses and how it can be measured. For this purpose, the students are asked to

**Figure 1. Structure of TTP.**




create a sandglass and a sundial to measure time and explore the working principles of the both objects.

*2.1.2.* Module 2: *life cycles*

The cycles module aims to make students aware of and able to use information about the natural cycles that they have observed, measured, and recorded in order to make sense of time from past to present. The aim of this approach is to examine and compare the circles of the sun, moon, other planets and constellations, and to observe and compare the calendars prepared based on these observations. The purpose of this theme is that by making their own observations recording their observations and creating their own calendars from these records, the students will be able to understand these natural cycles.

*2.1.3.* Module 3: *time in nature*

In this module, the students should gain knowledge and skills about the natural temporal cycles and natural habitats of time and make meaningful relations between nature and time by observing and making inferences using these knowledge and skills. The time module in nature consists of two entities: the life cycle of living things and examination of age rings of trees (dendrochronology) in the scope of life cycle subjects and comparison of the biological clocks of the individuals of different ages and sexes to discover their chronobiology based on the 24-h observations of the students.

*2.1.4.* Module 4: *space–time*

The space–time module aims to encourage the students to think and consider what time might actually be together with the content of the course and enriched by scientific theories and models of time, time-of-the-moment, twin paradoxes, informative learning of subjects, such as time, nature of research, and documentation.

Table 1 presents the scope of TTP and the targeted skills. The program was implemented during the fall semester of 2016–2017 in the elective science applications course at the eighth-grade level. The activities related to each model were carried out by one of the science teachers in the school. This aimed to minimize threats to internal validity of the research. The activities in the control and experimental groups were undertaken simultaneously in accordance with the curriculum of the science application course. Furthermore, in addition to the students, the teacher was observed by the researchers during the implementation of the TTP activities to prevent any adverse effect on internal validity.

### 2.2. Data collection tools

The data of the research were obtained using both qualitative and quantitative tools due to its mixed methods design. The measuring instruments used are explained below.

#### 2.2.1. Observation notes

During the implementation of the program as an observational case study, which constituted the qualitative dimension of the research, one researcher was assigned to observe the students and the teacher during the activities to identify potential factors that might affect the internal validity of the research.

#### 2.2.2. Semi-structured interviews

Semi-structured focus group interviews were held with the students from the experimental group to determine their preliminary knowledge about the subjects; elicit their curiosity, interest, views, and recommendations concerning the activities; and identify their post-TTP levels about conceptual gains related to the modules. Participation in these was voluntary. The questions of the semi-structured interview are given below.

(1) *What do you think about the activities carried out in the science applications course in the last semester?*

(2) *What kind of awareness did STEAM practices give you?*

(3) *Is there a difference in your knowledge and skills before and after implementing the activities included in the course? If yes, why?*

(4) *During the course, you had an opportunity to create different time measurement tools. What do you think are the similarities and differences between these tools?*

(5) *How can you explain the relationship between time measures and the rotation of celestial bodies?*

(6) *What is the relationship between living creatures and time?*

(7) *You learned about different theories on time in the documentary you watched. Was the concept of time in this documentary the same as the concept of time you tried to measure?*

#### 2.2.3. Computational thinking test

At the beginning of the research, studies in the literature were screened to identify the subdimensions of CT skills, and as a result, the categories of skills described by Weintrop et al. (2014) were chosen for this work. A problem situation was determined for each question prepared for computational thinking test (CTT). The questions were then sent to six academicians: two mathematics teachers, two science teachers, and two measurement evaluation experts at the middle school level, and the specified skills were assessed with regards to solvability, suitability to student level, and understandability. In accordance with the feedback from the academicians, some of the questions were revised and some were excluded from CTT. Furthermore, for the reliability of the final version of CTT, McDonald's $\omega$ was calculated and found to be .779.

#### 2.2.4. Student diaries

The students in the experimental group were asked to keep individual diaries on their experiences regarding the process and their views on TTP. At the end of the process, these diaries were collected and analyzed by the researchers using the content analysis method.

### 2.3. Study group

Using the convenience sampling method, the experimental and control groups were determined from eighth-grade students taking the *Science Applications* elective course in a public school located in Ankara, Turkey. There were five groups in total, two of which were randomly assigned

**Table 1. Scope of TTP and targeted skills**

| Module | Name of activity | Purpose of activity | Skills |
|---|---|---|---|
| Module 1: measuring time | What is time? | To help students understand the concept of time by encouraging to discuss and collect data about time from their daily life | • Data collection<br>• Data creation<br>• Data manipulation<br>• Data analysis<br>• Data visualization |
| | Equatorial sundials | To help students learn about equatorial sundials in their simplest form and create their own equatorial sundials based on what they have learned | • Understanding how and why these models work<br>• Using these models to develop and test solutions |
| | Sundials | To develop students' reasoning and scientific process skills (e.g., observation, estimation, and deduction) through a sundial they have made to understand its working principles | • Data collection<br>• Data creation<br>• Data manipulation<br>• Data analysis<br>• Data visualization<br>• Understanding how and why these models work<br>• Using these models to develop and test solutions |
| | Equation of time | To help students understand how solar noon time changes throughout the year due to the inclination of the Earth's axis, the concepts of chart and graph displaying these changes and use these data to perform their own measurements | • Understanding the relation-ships within a system<br>• Understanding and visualizing the images in a system<br>• Defining, understanding and managing complexity |
| | Sandglass | To help students develop their own sandglass as a standard tool to measure time. In this activity, students are expected to measure all physical quantities necessary to conceptualize the necessity of standard measuring instruments, determine how much time the instrument can measure, and make the necessary calculations for standardization | • Data collection<br>• Data creation<br>• Data manipulation<br>• Data analysis<br>• Data visualization<br>• Understanding how and why these models work<br>• Using these models to develop and test solutions |
| | Time counter | To further engage students in creating and using their own time measurement tools | • Using computational models to understand a concept<br>• Understanding how and why computational models work<br>• Evaluating computing models, and using them to develop and test solutions<br>• Creating new models and expanding existing models |

(*Continued*)

| Module | Name of activity | Purpose of activity | Skills |
|---|---|---|---|
| Module 2: cycles | Universe cycles | To help students discover and understand the cycles of the solar system and the celestial bodies in this system. In this activity, students are asked to construct algorithms of relations between the circumstances of celestial bodies | • Examining a system as a whole<br>• Understanding the relation-ships within a system<br>• Thinking about patterns and visualizing systems<br>• Defining, understanding, and managing complexity |
| | Lunar calendar | To engage students in observing the Moon's movements, making predictions and inferences about these movements understanding that they occur in a cycle, and creating a lunar calendar using the models on the lunar phases and the data obtained | • Examining a system as a whole<br>• Understanding the relation-ships within a system<br>• Thinking about patterns and visualizing systems<br>• Defining, understanding, and managing complexity |
| | Constellations | To enable students about the constellations observed in the night sky as the Earth rotates around the Sun and to use it in the measurement of time understanding that it is a natural cycle | • Examining a system as a whole<br>• Understanding the relation-ships within a system<br>• Thinking about patterns and visualizing systems<br>• Defining, understanding, and managing complexity |
| | Mars calendar problem | To engage students in creating a calendar for the planet Mars by discovering its phases. The aim is to develop students' different modeling skills by comparing their calendars with those of their peers | • Examining a system as a whole<br>• Understanding the relation-ships within a system<br>• Thinking about patterns and visualizing systems<br>• Defining, understanding, and managing complexity<br>• Evaluating information proces-sing models<br>• Using information processing models to develop and test solutions<br>• Creating new models and expanding existing models |
| Module 3: time in nature | Dendrochronology | To encourage students to examine evidence about the time cycles in nature and interpret them by making inferences. In this activity, students are expected to acquire knowledge and skills concerning the science of dendrochronology, which is the scientific method of determining the age of trees and interpreting past events, such as the climate | • Data collection<br>• Data creation<br>• Data manipulation<br>• Data analysis<br>• Data visualization |
| | Chronobiology | To help students observe the routines of their own bodies, record them, and recognize their biological clock | • Data collection<br>• Data creation<br>• Data manipulation<br>• Data analysis<br>• Data visualization |

(*Continued*)

**Table1. (*Continued*)**

| Module | Name of activity | Purpose of activity | Skills |
|---|---|---|---|
| Module 4: space–time | What is "time"? | To arouse students' interest in "what time actually is" through watching a documentary on time warp called "Beyond the Universe" | • Examining a system as a whole<br>• Understanding the relationships in a system<br>• Thinking about patterns and visualizing systems<br>• Defining, understanding, and managing complexity |
| | Speed of time | To seek answer to questions, such as "Does time have a speed? If yes, is it fast and does it change?". In this activity, students are also engaged in thought experiments and discussing the mental models they create | • Examining a system as a whole<br>• Understanding the relationships in a system<br>• Thinking about patterns and visualizing systems<br>• Defining, understanding, and managing complexity |

as the experimental group and the remainder were assigned as the control groups. There were approximately 25 students in each group; however, due to the absence of some of the students and 4 students not wanting to participate in the study, the study was carried out with 104 students, 44 in the experimental group and 60 in the control group.

TTP developed within the scope of the study was implemented by the teacher of the selected course to minimize any threat to internal validity that may arise from the learning process of the students and the middle school teaching experience of the academicians. Furthermore, the reason for selecting an elective course was the assumption that since the students chose to take this course, they would have a higher interest and motivation in science subjects. Finally, TTP was implemented during class hours in order not disrupt the school schedule.

Table 2 gives the descriptive statistics of the participant students' CTT pretest scores. Of the 104 students included in the study, 44 were in the experimental group and 60 were in the control group. An independent groups *t*-test was used to determine whether there was a significant difference between the pretest scores of the two groups. This aimed to reveal the equivalence or non-equivalence of the two groups of students in terms of CT skills at the beginning of the study.

Table 3 presents the comparison of the pretest scores between the experimental and control groups. A statistically significant difference was found between the groups' mean scores in CTT pretest ($t = 3.88$, $p < .05$). Thus, the pretest scores were assigned as covariant variables for the comparison of the posttest averages, and the difference between the groups was statistically analyzed.

### 2.4. Ethics, internal and external validity

Official permission was obtained from Hacettepe University Ethics Commission and Ankara Provincial Directorate of Education before the research. In addition, volunteer participation forms were distributed to the students and their parents, and they were informed that participation in the survey was entirely voluntary. All selected students and their parents signed the consent form. Pretest and posttest CTT implementation each took 45–50 min for both experimental and control groups. The tests were administered in both groups by the classroom and course teachers. There were 14 weeks between the pretest and posttest applications. Given the total length of the study, it can be stated that the maturation effect did not significantly increase the test scores of the participants. The research compared the pre- and posttest scores of the students to investigate the development of their CT skills.

**Table 2. Descriptive statistics of CTT pretest scores**

| | *N* | Min | Max | Mean | Std. deviation |
|---|---|---|---|---|---|
| Experimental group pretest | 44 | 10.00 | 61.00 | 31.78 | 11.09 |
| Control group pretest | 60 | 3.00 | 58.00 | 23.08 | 11.38 |

**Table 3. Comparison of the CTT pretest scores between the groups**

| | | *N* | Mean | Std. Dev. | df | *t* | *p* |
|---|---|---|---|---|---|---|---|
| Pretest | Experimental group | 44 | 31.78 | 11.09 | 102 | 3.88 | .000 |
| | Control group | 60 | 23.08 | 11.38 | | | |

Since the academic achievement of the students in science courses was not examined within the scope of the research, increasing the students' academic achievement by preparing the subject in advance or increasing the repetition of the subject was not any threat to the internal validity of the research. At the end of the study, the *post hoc* power analysis was calculated as .71,[1] confirming the external validity of the research based on a wide range of power in terms of sample size (Cohen, 1992).

## 3. Results

This research aimed to compare the posttest scores of the control group students who were provided with the standard course content and those of the experimental group students who were taught according to TPP based on a STEAM model. The results of the distribution of the pretest and posttest scores of the two groups are given in Table 4.

The pretest scores of the experimental group and the posttest scores of the control group were not normally distributed (Table 4). Therefore, the data sets were further examined to obtain more evidence concerning this distribution. The *Q*–*Q* plot distributions, histogram curves, and skewness–kurtosis coefficients of the data sets revealed that the distribution of the data sets met the assumptions of a variance analysis.

Since there were non-equivalent between the experimental and control groups concerning CT skills at the beginning of the research, the pretest scores were determined as a covariant, and a covariance analysis (ANCOVA) performed to determine the differences in the posttest scores that were negligible. The results of the covariance analysis are given in Table 5.

When the effects of the pretest scores were not considered, a significant difference ($F_{.469}$, 1, $R^2$ = .518) was found between the posttest scores of the experimental and control groups in favor of the experimental group (Table 5). Based on these findings, it can be stated that TTP significantly improved the CT skills of the eighth-grade middle school students.

The aim of the proposed program was to determine the extent to which students improved their knowledge of CT skills through the suggested activities and identify the strengths and weaknesses of the curriculum. Thus, qualitative data were collected through diaries kept by the students throughout the process, as well as interviews conducted with the students and the practice teacher. The data were examined based on the codes related to CT skills obtained from the literature. During this review, new codes and themes were created using content analysis. The descriptive values of the codes are given in Table 6.

Table 4. Tests of normality

| | Kolmogorov–Smirnov[a] | | | Shapiro–Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | Sig. | Statistic | df | Sig. |
| Experimental pretest | .197 | 44 | .000 | .944 | 44 | .032 |
| Experimental posttest | .077 | 44 | .200 | .973 | 44 | .393 |
| Control pretest | .101 | 60 | .199 | .967 | 60 | .102 |
| Control posttest | .087 | 60 | .200 | .944 | 60 | .008 |

When the qualitative data obtained from student interviews and diaries were analyzed, the most frequently encountered code was “conceptual knowledge of time.” Although the aim of this study was to enhance students’ computing skills, the students were found to have acquired more knowledge about the concept of time as a result of integrating topics, such as the concept of time and time measurement into the course plan. This also led to a low frequency of codes for CT skills obtained from the literature. For example, in his/her interview, one student made the following comment in relation to the documentary they watched within the scope of the program:

> ...I’ve thought about it before. There’s no time in space. Even going to space is a time problem. What most attracted my interest was the time flow near the black hole. So, it was very interesting. The man had aged after coming back in two minutes. This was very interesting. There are places where time is faster or slower in space.

Data collection and data analysis codes were obtained more often from students’ diaries than their interviews. The code with the highest frequency in student interviews was “enjoyable.” Although such codes are usually frequently seen in interviews with students in experimental studies that involves different applications from the traditional teaching programs, it was still considered to be meaningful as a research finding. An example of this code can be given as follows:

> I have started to think about questions that I had never thought of until today. What happened to people who lived before me? How is time in space? How did the time change what I learned? It was informative and enjoyable.

Table 5. The results of the ANCOVA test

| Source | Sum of squares | df | Mean square | *F* | Sig. |
|---|---|---|---|---|---|
| Corrected model | 6,829.75[a] | 31 | 220.31 | 2.49 | .048 |
| Intercept | 41.49 | 1 | 41.49 | .47 | .506 |
| Experimental pretest | 1,933.18 | 1 | 1,933.18 | 21.86 | .001 |
| Control pretest | 33.89 | 1 | 33.89 | .38 | .547 |
| Control posttest | 4,096.66 | 29 | 141.26 | 1.60 | .197 |
| Error | 1,061.16 | 12 | 88.43 | | |
| Total | 94,844.00 | 44 | | | |
| Corrected total | 7,890.91 | 43 | | | |

[a] $R$-squared = .866 (adjusted $R$-squared = .518).

**Table 6. Themes and codes created by qualitative analysis**

| Themes and codes | % | *f* |
|---|---|---|
| **Codes for computational thinking skills** | | |
| *Collecting data* | 12.2 | 6 |
| *Analyzing data* | 6.1 | 3 |
| *Understanding how and why a computational model works* | 10.2 | 5 |
| *Examining a system as a whole* | 4.1 | 2 |
| *Understanding the relationships in a system* | 4.1 | 2 |
| **Codes related to the structure of the program** | | |
| *Enjoyable* | 18.3 | 9 |
| *Associated with everyday life* | 10.2 | 5 |
| *Conceptual knowledge of time* | 22.4 | 11 |
| *Suitable for the students' level* | 6.1 | 3 |
| *Outside the curriculum* | 4.1 | 2 |
| *Requires materials* | 2.1 | 1 |

The most noteworthy code obtained from the teacher's responses regarding the structure of the program was "association with everyday life." In addition to the intensity and effectiveness of the program in relation to everyday life, the teacher also referred to the difficulty of implementing this program within the science course (coded as "outside the curriculum"). Although this was considered to be a STEAM model and classroom practice related to the curriculum, it was interpreted that the application in mathematics and science courses may cause some problems.

## 4. Conclusion and discussion

Meeting the needs of the twenty-first century depends on helping students acquire the ability to connect with everyday life in designing and using new technologies, and applying their problem-solving skills. For this reason, STEM education has recently been focused on educational systems (Balay, 2004; Olson & Labov, 2014). STEM is an educational model for the integration of science, technology, engineering, and mathematics disciplines (Bybee, 2013; Dugger, 2010). In order to increase the number of students who want to have a successful career in engineering or science, they should engage in education consisting of integrated STEM fields (Öner et al., 2014). The twenty-first-century educational visions of countries include the need for training in the field of STEM in order to create career consciousness in students (Thomasian, 2011). Scott's (2009) model on STEM education suggests that the application of technology to science and mathematics contents should be included with career and technical education being supported by academic assignments; furthermore, STEM concepts should be applied in other courses, and science and mathematics should be integrated into the curriculum in a comprehensive way. In the last 5 years, the STEM model has been effectively introduced to education environments and related practices have begun to be undertaken in the process of learning-teaching. However, the results of STEM implementations and associated research confirm that this model is still applied mechanically on learners, which is far from a systematic approach or philosophy (Papanikolaou, 2010; Yamak et al., 2014). Considering an educational model to be independent from the underlying philosophy, target, content, learning-teaching, and assessment and evaluation process may lead to problems in determining the level of learners' development and how to appropriately guide them according to a purpose. Therefore, the STEM model should also be linked to the skill dimensions within the curriculum to be developed in children and adolescents, based on major educational philosophies and approaches. One of the most important twenty-first-century skills associated with STEM education is CT, and according to Yadav, Zhou, Mayfield, Hambrusch, and Korb (2011), it must be introduced to disciplines other than computer science and to the K-12 level. Similarly, Barr et al. (2011) suggested that CT skills have a significant potential in equipping students at the K-12 level with the necessary problem-solving skills. In STEM education, programs designed by taking CT skills into consideration will be effective and meaningful for learners.

Many STEM studies have referred to the lack of emphasis on the creative nature of human beings (Armknech, 2015). Therefore, it is expected that the use of the STEAM approach more extensively than the STEM approach by far eastern countries, such as Japan and South Korea with a higher success in international exams, will contribute to the multifaceted development of students (Jin et al., 2012; Yakman & Hyonyong, 2012). For this purpose, in this study, we developed a program (TTP) for the STEAM model at the middle school level and examined the effect of the proposed program on the students' CT skills. According to the findings, it was determined that the content of the STEAM-based TTP significantly increased the students' knowledge of CT skills and positively affected their interest and motivation in STEM fields. In addition, given the importance of integrating the STEAM approach into the class, it is envisaged that the program developed may serve as a good example for further applications. The challenges that may be faced during the implementation of the program are the difficulty of time management during or outside class hours, insufficient instructional materials, the long duration of some of the activities, and the inability to apply the program directly to science and mathematics classes. For this reason, when designing a curriculum, it is extremely important to develop the content in a way that allows implementing an interdisciplinary approach.

Research studies particularly in the USA have shown that there is an increase in the interest of students in STEM practice; however, at later grades, students may focus on careers that involve STEM areas (Jon & Chung, 2013). In addition to these research studies, the students' interest in these fields can be increased by engaging them in STEM applications in education. In the 2016 STEM Education Report (MEB, 2016) published by the Ministry of National Education of Turkey, it is stated that STEM education should be given to all students and that curious, talented, and gifted students should be identified and given more advanced STEM education. The report also states that STEM training centers could be established and training and event support could be provided to teachers and students in these centers. It is emphasized that in Turkey, STEM education research and projects could be undertaken in these nonprofit-orientated STEM training centers and where there are specialist trainers and academicians in the field of STEM. Furthermore, in-service training on STEM education can be given to teachers in STEM centers. The recommendation of this research is that the STEAM model improves individuals' twenty-first-century skills and supports career development processes by addressing different disciplines and skills; thus, it is necessary to spread this model across the levels of education. In addition, the teaching program in our country needs to be designed considering the STEM vision taking into account the target, content, learning-teaching, and measurement-evaluation dimensions, as well as robot design and material development. To this end, teachers need to be supported by preservice and in-service training.

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**Note**
1. **F tests—**ANCOVA: Fixed effects, main effects, and interactions

**Analysis**: *Post hoc*: Compute achieved power

**Input**: Effect size $f = .25$
$\alpha$ errprob = .05
Total sample size = 104
Numerator df = 1
Number of groups = 2
Number of covariates = 2

**Output**: Noncentrality parameter $\lambda = 6.5000000$
Critical $F = 3.9361430$
Denominator df = 100
Power $(1 - \beta$ errprob$) = .7139650$.

**Correction statement**

This article has been republished with minor changes. These changes do not impact the academic content of the article.

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