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Research article

Impact of Arduino Based STEM Education on Cognitive Domain Level of Mechanics and Scientific Creativity

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Abstract: The aim of this study is to investigate the impacts of Arduino-based STEM education on cognitive domain level of mechanics and scientific creativity regarding mechanics, specifically on vectors, kinematics, dynamics and work-energy sub-topics. Throughout the study, one group (32) pre-test post-test research model was involved. The cognitive domain level of mechanics progress is measured by using the Cognitive Domain Scale of Mechanics (CDSM) and the scientific creativity is measured by means of Scientific Creativity Scale (SCS). Concerning cognitive domain level of mechanics, statistical analysis has revealed that STEM education has positive impact and statistically significant effects. The average scores of male participants have additionally indicated greater increase compared to the females based on CDSM regarding all sub-topics, however only work-energy has presented a statistically significant difference. Statistical analysis on scientific creativity has revealed 6.76% improvement between the pre and post measurements, nevertheless no statistically significant discrepancy has been detected. Analysis on gender has exposed no difference regarding the scientific creativity. Finally, a positive and significant correlation has been detected between pre and post scores on both scientific creativity and cognitive domain level of mechanics.

Keywords: physics education, mechanics, STEM education, Arduino, cognitive domain level of mechanics, scientific creativity

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1 Introduction

Physics embraces many abstract and difficult-to-understand equations, principles, laws, and concepts. Physics Education Research (PER), on the other hand, principally aims to construct an improved atmosphere and environment in order to teach and internalise problematic concepts and laws of physics more efficiently and perpetually (McDermott & Redish, 1999; Aalst, 2000). In this sense, enriched teaching of physical concepts and improved conceptual comprehension levels are very desirable (Connor-Kuntz & Dummer, 1996). Advanced conceptual understanding is especially very central, because the fundamental aim of PER is not only to memorise physical concepts and laws but also to develop some useful attitudes and capabilities that can be employed to unravel certain daily

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lifetime problems (Hung & Jonassen, 2006). In order to improve the conceptual understanding, various methods were employed in the past and the majority of them report some tiny progress (Linden & Joolingen, 2019; Mason et al. 2019). Accordingly, teaching physics requires more attention and effort in order to reach the desired conceptual understanding levels. Student-centered and constructivist approaches are considered important strategies for enhancing the effectiveness of physics education. These approaches enable students to actively participate in the learning process and construct their own understanding, rather than passively receiving information.

The literature likewise expresses that the undesired results arise from the student's difficulties of interpreting the concepts of physics and difficulties of associating the textbook knowledge and phenomena with daily life (Widiyatmoko, 2018). Additionally, misinterpretation of complicated concepts, incorrectly planned physics courses and some awkward teaching approaches basically lead to additional problems on conceptual understanding (McDermott, Rosenquist & Van Zee, 1987). The other apparent cause of conceptual difficulties is due to the fact that physics deals with exceptionally intricate behaviour of matter which cannot be measured easily. In spite of recent great progress on educational research, most instruction activities over the globe employ outdated teaching approaches. In the traditional education approaches, commonly hearing-based passive teaching activities are engaged, restricted instructional techniques are typically existing and truthfully speaking in-classroom communications and interactions are few and unidirectional (Konopka, Adaime & Mosele, 2015). The traditional educational procedures also assume that all the students have virtually same qualifications, regardless of their personal abilities. In this case, the students' skills such as creative thinking, critical thinking and problem solving cannot naturally be progressive.

Scientific creativity basically means producing original scientific solutions to difficult and unresolved daily and scientific problems. Scientific creative thinking processes involve abilities such as understanding the problem, describing scientific problems, analysing, resolving, evaluating and producing specific solution(Jones & Weinberg, 2011). In addition, scientific creativity ought to involve the ability of handling a topic in terms of many aspects and the ability of thinking on abstract issues and producing clear provisions that match common sense and scientific evidence. Creative thinkers can combine any data obtained by means of written or verbal terminologies, observation, experimentation and reasoning and can easily produce clarity, logic, depth and reliability (Hu & Adey, 2002). Improving scientific creativity has thus been at the leading edge of physics education and obviously seems to be even further important for the students. Recently, a number of studies are published which report on how to improve creative thinking attitudes of physics students, however the issue is still raw and needs to be tackled in more detail (Mihardi, Harahap & Sani, 2013; Adawiyah et al. 2019; Rizal et al. 2020).

In the field of education, educational outcomes that are aimed to be taught to students are classified (Forehand, 2010). In this way, the behaviours that are aimed to be transferred to the students are grouped according to their specific characteristics. The first comprehensive studies for the classification of teaching objectives started in the USA in 1948 by a group including Bloom and other expert educators. As a result, cognitive domain behaviours including mental activities were classified. This classification is known as Bloom's taxonomy (Sosniak, 1994). Within the scope of this classification, the targeted training outcomes are divided under the subheadings of Knowledge, Comprehension, Application, Analysis, Synthesis and Assessment. The first three levels, Knowledge, Comprehension and Application, include low-level behaviours, and Analysis, Synthesis and Assessment include high-level behaviours. From simple to complex cognitive domain steps are listed as Knowledge, Comprehension, Application, Analysis, Synthesis and Evaluation. These 6 digits have a connection among themselves according to this order (Forehand, 2010). It is important to develop cognitive domain elements in order to gain 21st century skills in students. In particular, the more complex gains in the Analysis, Synthesis and Evaluation stages directly overlap with the very important competencies required by the age, such as higher-order thinking skills and problem-solving skills (Adams, 2015).

STEM education is one of the teaching methods that aims to provide students with the important skills required by the age and there are many studies showing that they are successful in this direction (Butler et al. 2014; Faris, 2019; Firdaus & Rahayu, 2019). STEM comes from the abbreviation of the initials of the words Science, Technology, Engineering and Mathematics (Bybee, 2010; Dugger, 2010). The general purpose of STEM education is to provide an integrated teaching process in which the gains in the fields that make up its name are together (Gonzalez & Kuenzi, 2012). STEM activities enable students to easily apply their knowledge and gain high-level thinking skills to solve real-life problems (Farwati, et al. 2021). The use of Arduino in the teaching process for Technology and Engineering in STEM studies carried out within the scope of science education can lead to very beneficial results (Hoffer, 2012; Sarı et al. 2022). Arduino is a microcontroller where people of all levels can make robotic applications. Systems using Arduino cards can respond to a stimulus from the outside world as a result of reading the incoming data and converting this data into output data by interpreting it (Badamasi, 2014). The Arduino software Arduino IDE is used to program the board by sending instructions to the microprocessor on the board according to the algorithm to be used, and the programming language used in the program is C++ (Arduino, 2015). A large-scale community around the world is working with this open source platform. The card is suitable for both novices and experts to perform studies (Banzi & Shiloh, 2022). Teachers and students use Arduino microcontrollers for different purposes, such as creating low-cost scientific tools, analysing physical systems, or running beginner-level applications on programming and robotics (McRoberts, 2011; Badamasi, 2014; Çoban & Çoban, 2020). Considering the aims of the STEM education approach and the advantages offered by Arduino microcontrollers, it may be beneficial to integrate Arduino microcontrollers into STEM education applications in high school and university level physics courses.

In today's era of technology, nurturing individuals with technological competencies is of critical importance in the race for technological and economic development. The primary and most important way to cultivate individuals with technological skills is through the education system. Therefore, reforms in the education system need to be prioritized.

The implementation of necessary reforms in the education system is directly dependent on the quality of teachers, and the fundamental way to achieve any transformation in education is to train teachers in a manner that suits this transformation (Darling-Hammond, 2006).

Courses conducted with a constructivist approach have significant potential in designing the teaching environments of the future, in terms of their effects on the cognitive levels and scientific creativity of prospective teachers. Determining the effects of robotics-based STEM Education on teachers and prospective teachers and measuring their attitudes is of great importance for revisions to be made in teacher training programs (Gavrilas & Konstantinos, 2024). Cognitive level and scientific creativity are two of the main variables especially desired in teachers who will nurture future generations. Unlike traditional teacher profiles, teachers with high levels of cognitive domain and scientific creativity will not only transmit knowledge but also demonstrate how this knowledge can be applied in various fields, adapt to evolving technologies, and use their high scientific creativity to shape the educational environment when necessary. These teachers play a key role in equipping future generations with the desired skills. On the other hand, teachers who are aware of current technologies and can use them with high proficiency will move STEM teaching environments, especially laboratories, away from their traditional structures to a more advanced level (Luciano et. al, 2019). The use of robotic coding in STEM education for teacher training not only enhances the cognitive and technical skills of teacher candidates but also significantly contributes to the economic development of nations. In today's world, technology and science have become one of the fundamental pillars of economic progress. In this context, training teachers proficient in areas such as robotics and coding encourages younger generations to pursue careers in these fields and to produce innovative solutions. This, in turn, increases the competitiveness of countries in science and technology sectors, contributing directly to their economic development. Therefore, the integration of robotic coding in STEM education into teacher training programs not only improves the quality of education but also should be considered an investment towards the future development of national economies.

In this study, the effects of using Arduino-based STEM education in the mechanics unit on the mechanics cognitive domain levels and scientific creativity of science teacher candidates were investigated. Although there are many studies focused on developing materials for using Arduino in physics experiments, there are only a limited number of studies investigating its impact on learning. Moreover, most of the existing research has been conducted with age groups below the university level. Therefore, this study is significant as it explores the effects of Arduino use on learning outcomes within physics courses conducted with pre-service teachers at the university level.

In-class experimental activities involving material development, data collection and data analysis processes were carried out in the lessons conducted within the scope of STEM education. After the lecture was given in these classroom activities, the physical systems in which the Arduino microcontroller was integrated were designed and programmed together with the teacher candidates in the classroom. Physical systems have been developed within the relevant subject. In this system, Arduino microcontrollers and sensors are used for data collection. These collected data were analysed with the help of mathematical equations within the scope of the subject and results were obtained. This application, which includes the skills of all fields (Science, Technology, Engineering and Mathematic), can fully meet the aims of the STEM approach.

Additionally, another objective of this study is to analyze whether the effects of Arduino-based teaching processes on learning vary based on gender. Gender-related differences in learning within STEM fields have been a significant research topic in terms of both academic achievement and career choices. Studies suggest that male students generally demonstrate higher levels of conceptual understanding in STEM fields such as physics and engineering. However, this gap can be influenced by teaching methods and environmental factors (Sagala et al. 2019). Furthermore, research indicates that female students' motivation and career interest in STEM education are shaped by social factors, parental support, and the gender balance within the educational environment (Mau et al., 2020). Therefore, identifying gender-related differences in the learning process is crucial for promoting gender equality in STEM fields.

The main purpose of the study is to investigate the effects of the Arduino-based STEM education approach in the teaching of vectors, motion, Newton's laws and work-energy units within the fundamental subtopic of mechanics. Therefore, the research questions posed throughout the work are formulated in the following form:

> RQ1: What are the impacts of Arduino-based STEM Education on scientific creativity of pre-service science teachers?
> RQ2: What are the impacts of Arduino-based STEM Education on cognitive domain level of mechanics of pre-service science teachers?
> RQ3: What is the impact of gender on cognitive domain level of mechanics and scientific creativity?

2 Method

2.1 Research model

In order to measure impacts of the Arduino based STEM materials one group pre-test post-test research model, which is one of the semi-experimental research models (Cohen, Manion & Morrison, 2007), is selected and employed. Independent variables of the research were determined as cognitive domain level of mechanics and scientific creativity level. Therefore, cognitive domain level of mechanics and scientific creativity level of the participants were measured before starting the actual teaching process by applying the CDSM and SCS scales as pre-tests. In order to determine possible progresses concerning the independent variables, the same measurement tools were employed as post-test. The teaching process between the pre and post-test measurements was obviously carried out smoothly by employing Arduino supported STEM education teaching approach which will be detailed in the forthcoming sections of this report.

This study was conducted in accordance with the ethical standards of Dokuz Eylül University and under the supervision of the second author within the scope of the corresponded author's PhD thesis. Ethical approval was obtained by Dokuz Eylül University, Institute of Educational Sciences.

All participants were informed about the purpose of the study and participated voluntarily. Informed consent was obtained before participation. Participants were assured that their responses would remain confidential and that they could withdraw at any time without any negative consequences. All data collected was anonymized and stored securely to protect the participant's privacy.

2.2 Participants

The sampling of the research consists of 32 science teacher candidates, categorically 8 males and 24 females, studying in the department of science education at a state university. This group was determined by means of the typical case sampling method which is one of the purposive sampling methods (Campbell et al. 2020) of social sciences. The reason of selecting this sampling was based on students' backgrounds. Specifically speaking, all of the students in the group are registered to the department according to their scores of national university entrance examination therefore they are presumed to have nearly same cognitive levels and scientific creativities. Table 1 shows pre-test results of the participants concerning the independent variables of the research. As the standard deviation values given in table 1 is low, it can be accepted that the prospective science teachers have almost the same level on scientific creativity and cognitive domain level of mechanics.

Table 1. Pre-test results of the participants concerning Scientific Creativity (SCS) and Cognitive Domain on Mechanics (CDSM)

Test	N	$\bar{X}$	σ
Scientific Creativity Scale (SCS)	32	17.91	6.74
Cognitive Domain Scale of Mechanics (CDSM)	32	21.52	9.79

2.3 Data collection tools

Independent variables of the research are cognitive domain level of mechanics and scientific creativity level and any progresses on cognitive levels and scientific creativity levels of the students are measured by two distinct data collection tools. Specifically, Cognitive Domain Scale of Mechanics (CDSM), which was developed by the researchers before the study, is engaged to measure the cognitive field levels. Scientific creativity is on the other hand measured by means of Scientific Creativity Scale (SCS) which was developed by Şişman (2019). Both scales are briefly explained in the following sections.

2.3.1 Cognitive Domain Scale of Mechanics (CDSM)

One of the fundamental driving forces of physics education is to achieve substantial progresses concerning cognitive domain of the students on chosen specific sub-topics. Therefore, in order to measure the effectiveness of the developed STEM materials, it was essential to develop a cognitive domain scale that ought to cover the topics of the educational curriculum. In this case, a well-known globally recognised undergraduate fundamental physics textbook was chosen (Serway & Jewett, 2018). The scale development process was started by initially determining the proposed gains on specifically vectors, kinematics, dynamics and work-energy units based on the source book. The gains were carefully prepared and classified in accordance with the cognitive domain steps. Based on the gains, comprehensive problem cases from daily life are carefully developed for each sub-unit. The scale items, in order to measure the cognitive level on that specific topic, were cautiously prepared for each section. The content validity of the scale was achieved by obtaining views of two experts in the field and the validity studies were completed. The scale was then applied to the students who took the course previously and recently. The answers of the participants were wisely evaluated by two different academics and the Kendal coefficient of agreement between the evaluators was calculated within the scope of the reliability analysis (Field, 2005). The coefficient of agreement between the results of the evaluation made by two independent evaluators was found to be 0.990, which is exceptionally good.

Cognitive Domain Scale of Mechanics (CDSM) covers four separate sections, namely vectors, kinematics, dynamics and work-energy. Each section of the CDSM is comprised of following four sections i) true-false part covers the knowledge level of the cognitive domain, ii) classical question section which is related to the application step of the cognitive domain, iii) multiple choice question section which is related to the knowledge and comprehension steps of the cognitive domain and finally iv) conceptual question section that is related to the analysis and synthesis steps of the cognitive domain.

In order to evaluate the CDSM objectively, a rubric is also developed by the researches and employed throughout the analyses. The maximum points that can be obtained from the items in sections i, ii, iii and iv are 5, 5, 5 and 10, respectively. Therefore, the maximum score that can be taken from each section is 25 and the maximum score that can be obtained from the scale is 100.

2.3.2 Scientific Creativity Scale (SCS)

Scientific creativity in general aims to producing innovative scientific answers to challenging and unresolved daily problems and indeed scientific problems. Physics, as a highly demanding natural science, contains numerous scientific and daily problems that request scientific creative thinking processes which fundamentally involve abilities such as understanding the problem, describing scientific problem, analysing, resolving, evaluation and producing specific solution Therefore, other central aim of the work was to measure the progresses if any on the scientific creativity abilities of the participants. The scientific creativity scale, used in this work was developed by Şişman (2019) and originally developed to measure the scientific creativity levels of pre-service science teachers. The scale consists of 10 open-ended questions prepared within the scope of science education curriculum and Cronbach alpha reliability coefficient was calculated as 0.758 by the researcher. The scale includes items in the following subcategories; Creative Scientific Product Design (items 1 and 8), Scientific Imagination (items 2, 5 and 10), Scientific Problem Solving (items 3, 4 and 9), Use of the Object for Scientific Purposes (item 6), and Creative Experimental Ability (item 7). Each question includes a daily life problem and the students are asked to produce possible solutions to those problems. Some examples of the scale items can be given as follows:

Item 1: *If there was a swamp between your workplace and home, what kind of vehicle would you design to get to work?*

Item 2: *Design as many experiments as you can for students who have difficulty in understanding mechanical advantage concept in simple machines by using the materials available in the classroom environment* (ruler, book, pencil, chair, desk, etc.)

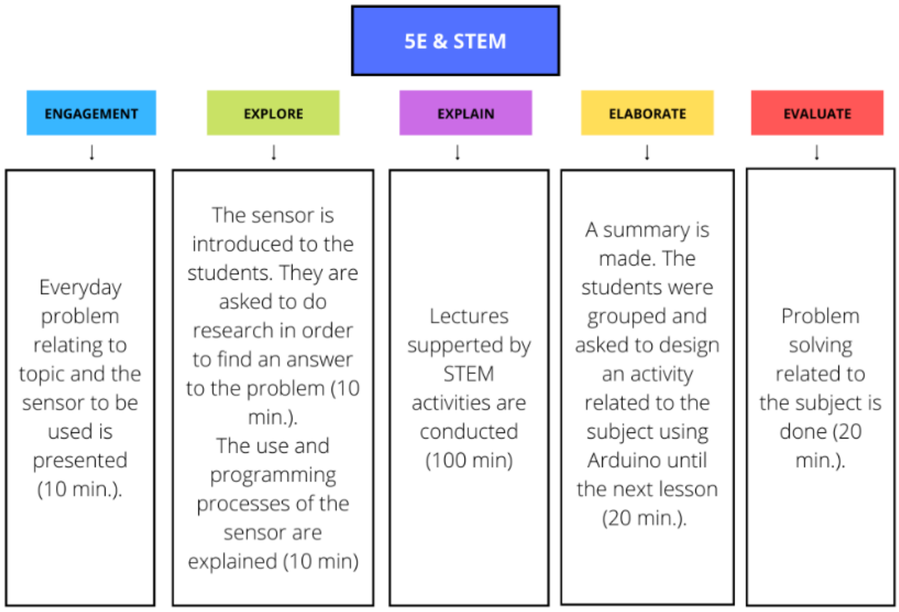
Item 3: *How do you measure the indoor air pressure by using the ordinary tools in a laboratory?*

The evaluation of the scale can be succeeded by following procedure. The scale was developed such that more than one answer can be given to each item in the scale. For each appropriate answer, the student gets 1 point. Then, the responses of all participants to the scale item are categorized. At this point, it is determined what kind of distribution frequency is established regarding the answers given to the item. Depending on the frequency of this distribution, +2 points are given to the answers below 5 %, and +1 points are given to the answers between 5-10% and answers above 10% are not awarded any points. For example, if 3 out of 100 answers to the item are categorized in a different class, students who give these answers get +2 points. If 7 out of 100 answers belong to a different category, students who give these answers also get +1 point. If the total number of answers given to the scale item is small, then the distribution frequency of the answers is determined again, but +4 points are given to the answers below 5% and +2 points are given to the answers between 5-10%. There is no upper limit for the maximum score to be obtained from the scale.

2.4 Teaching procedure

The main objective of the courses was to assist students in achieving the specific goals concerning all sub-fields of STEM while deepening their learning. In order to achieve this, certain activities based on three-dimensional materials were designed in order to engage the students in achieving electronic connections, collecting and analysing data and coming up with results. During the lectures, STEM applications are used with the 5E teaching model. For each topic (vectors, kinematics, dynamics, and work-energy), four different teaching materials were prepared. Each of them consists of five different stages due to the 5E model and the process followed during lectures is set to achieve harmony with STEM aims. These stages are, respectively, engagement, where attention is drawn to the lesson; exploration where exploration and predictions are performed through various activities and experiments; explanation where students define and explain subject concepts by creating an in-class discussion environment; elaboration where students can transfer current learning in different areas and finally evaluation where students' learning level can be tested (Bybee, 1997). The 5E teaching model can be supportive at attracting students' attention and encouraging them to think creatively in STEM-related classroom settings (Dass, 2015). In this study, STEM education was implemented by embedding the STEM within the 5E instructional model. Figure 1 shows the processes of the teaching method for every stage.

Figure 1. Based on the 5E teaching paradigm, a description of how STEM education is taught and how much time is spent on each stage.



Engagement process of 5E is realised by introducing the students a daily life problem to raise their attention. This problem case is specifically related to the topic that will be taught and the sensors that will be used. The application of 10 minutes during this part is sufficient to get the intended results. In the second part of the 5E STEM procedure, at the *Explore* stage, the sensor that will be used is presented to students and they are asked to do a brief search to get information about its use and working principles for about 10 minutes. Then, the use of the sensor and the coding process are described by the teacher in the next 10 minutes. The *Explain* stage of the 5E model is the most essential process of this study. At this stage, lectures are given to the students with conventional teaching methods first and then the students are asked to design a specific material in which Arduino is used related to the topic through brainstorming. The total time for this implementation is about 100 minutes. After this part, for 20 minutes, a summary of the lesson is performed on the *Elaborate* stage and a group work assignment is given to the students. At this group work, it is asked to design a material that is similar to the designed material in the lesson. Finally, during the *Evaluate* stage classical problem-solving activities are performed for about 20 minutes.

2.5 Arduino based STEM materials

2.5.1 Development and procedure

In the study, Arduino microcontrollers, which let even beginners to practice robotics, have been the most central part of the STEM activities (Kim, Mirdamadi & Guzide, 2016). Cornering the participants, except only one of the 32 pre-service teachers, all of them have no previous programming experience at all. Arduino microcontrollers have been preferred in this study because they can easily be learned and employed by beginners with no previous experience. The materials used in this study are explicitly designed to creating an interdisciplinary teaching environment that embraces achievements in the fields of Technology, Engineering, Science and Mathematics. All activities have been designed and developed within the framework of the relevant physics subject. The lectures are designed such that electronic connections, three-dimensional material design, coding and programming of the microcontroller are incorporated in the teaching processes. The analyses of the collected data were achieved by using the relevant theory and mathematical equations.

As the first step of preparing Arduino-based STEM materials, a source book (Serway & Jewett, 2018) was chosen that was appropriate for the academic level of the students and also suitable for the objectives of the course. Specific goals of teaching for each unit were prepared based on the source book. Teaching activities were planned concerning Arduino applications that can provide the pre-determined target gains. The materials needed for the planned activities were delivered and the activities' usefulness was analysed. In order to replace applications that did not perform as intended, new ones were created. Final preparations were made to guarantee that all activities operated as expected. At the end of this part, an explanation is given as to the reason why the materials that will be prepared in the classroom have been made and tested in before.

The steps below are to see how STEM-related applications were added to explore and explain parts of the 5E teaching model.

1. Introduction of sensors that will be built as part of the course.
2. Expression of subjects.
3. Brainstorming of the whole class about how to set up an experiment on this topic and deciding on the activity based on the teacher's instructions for the material that was already planned to be done in the classroom.
4. Setting up the experiment for the activity that was chosen. The process of setting up an experiment includes designing materials in three dimensions, making electronic connections, writing code and programming.
5. Gathering data about the set-up experiment. Analysis of the collected data leads to results.

The process carried out in the classroom during the stage (iii) is very essential for STEM education to be useful at the university level. During the process, it's important for students to get results by communicating among themselves about the experimental material that needs to be made. This helps them to develop their creativity. The process of programming a device, on the other hand, takes time and has a high chance of making mistakes on the first try. Note that, there may be some problems concerning time period if these things are done in the classroom in addition to lectures. So the scholar ought to prepare the planned and tested activities that can be done for each subject. But bringing these things ready-made to class and giving them to the students was not the best way to teach in a way that encouraged creativity. Taking both situations into account, the scholar asked the students to come up with materials by talking to each other and guiding the students through the process. As a result of this guidance, the students were able to design and test in their minds the materials that he had designed and tested before. So, any problems that might have come up during the development of the material were avoided, and the application didn't go off the planned path. The students were also given ideas for how to design a new material.

2.5.2 Arduino teaching materials

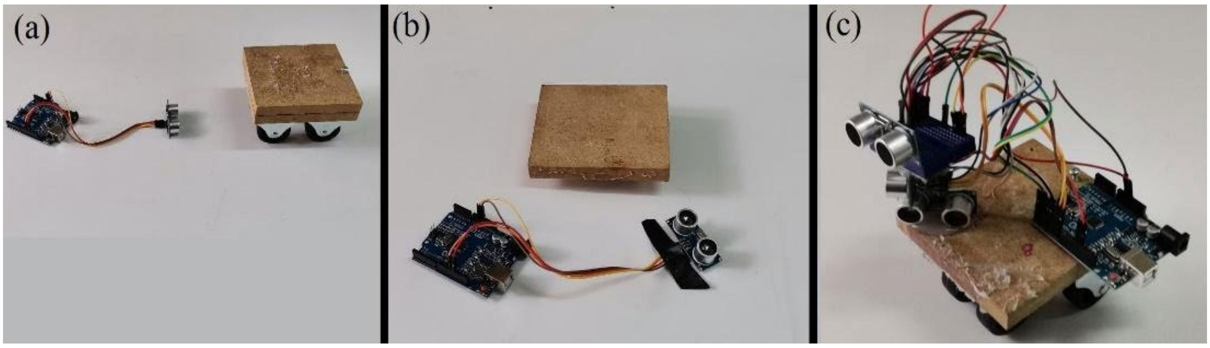
Arduino based teaching materials were developed concerning vectors, kinematics, dynamics and work-energy units by means of Arduino UNO microcontroller consisted mainly of HC-SR04 distance sensor, Load-cell weight sensor, tracker sensor and HC05 Bluetooth sensor. The materials were specifically designed with the aim of gradually improving the students' coding and electronic skills throughout the course. For this reason, applications were made on the vector unit, which is the first unit using the HC-SR04 distance sensor, on which basic level connections and coding activities can be carried out. The sensor used in the applications is shown in Figure 2.

Figure 2. Arduino microcontroller and related systems used to analyse main concepts related to vectors

Position due to displacement is obviously a vector quantity and hence was measured using the HC-SR04 distance sensor appropriately positioned and connected to the main moving vehicle. The measured position data has been tested experimentally and theoretically with the applications included in the vector topic. The sensor is an easy-to-use sensor that requires basic skills and is suitable for the use in the most elementary applications. By using the HC-SR04 in the first lesson, the students were learned the basic working principles of the distance sensor, which will be included in all other applications. In addition, with the distance sensor, which requires easier connection and coding compared to other sensors, difficult applications were avoided and the students were included in the robotic coding process without reducing their learning motivation.

In the applications carried out within the scope of the second lesson, 3 different materials were used for the analysis of kinematics systems. In all three materials, the HC-SR04 distance sensor, which was also used in the first lesson, was used as sensor. With the students who learned how to use distance sensors from the lesson, the processes of analysing the data used in this lesson were carried out in detail. The materials used are as in figures 3a, 3b, and 3c.

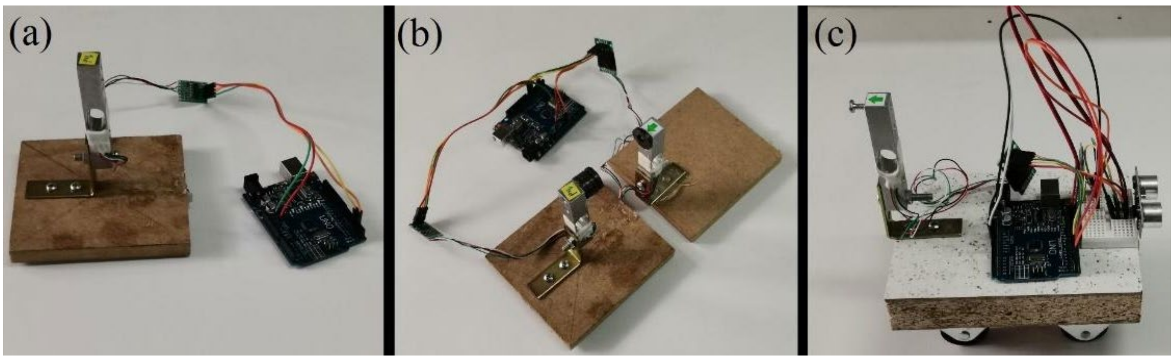
Figure 3. Systems used to analyse (a) main concepts related to kinematics and motion graphs (b) free fall (c) two-dimensional motion



The data obtained using the system in Figure 3a was copied onto Excel, and the basic concepts and motion graphics of kinematics were analysed. The system in Figure 3b was established for the purpose of free fall analysis and the values such as acceleration, velocity, and position during the fall of the wooden block released from a certain height were analysed. With the help of the system in Figure 3c, the motion variables in all three space dimensions were analysed during the motion of a vehicle moving in two dimensions.

In the third lesson, force and uniform circular motion analyses were made within the scope of the dynamic unit. For the analysis made for force, a load-cell force sensor and an HC-SR04 distance sensor are used. The developed materials are shown in figures 4a, 4b, and 4c.

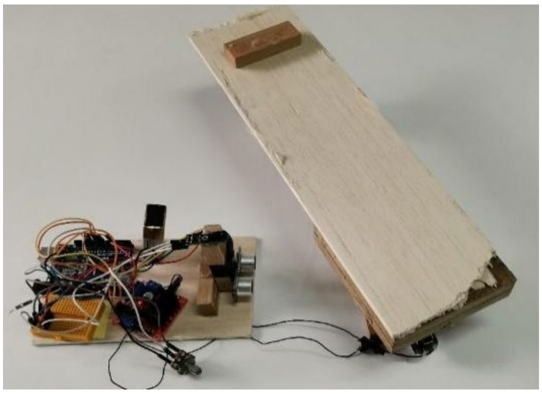
Figure 4. Systems used to analyse (a) main concepts related to force (b) newton's 3rd law (c) newton's 2nd law



After introducing the load-cell sensor to the students, it is attached to the wooden block as shown in Figure 4a. Using this system, vital information about force, such as force characteristics, equilibrium, and friction force, is examined. Figures 4b and 4c demonstrate systems used to analyse the action-reaction law and the fundamental law of dynamics, respectively. During the fundamental law analysis, the Bluetooth sensor is used to transfer data from the load-cell and distance sensor to the computer.

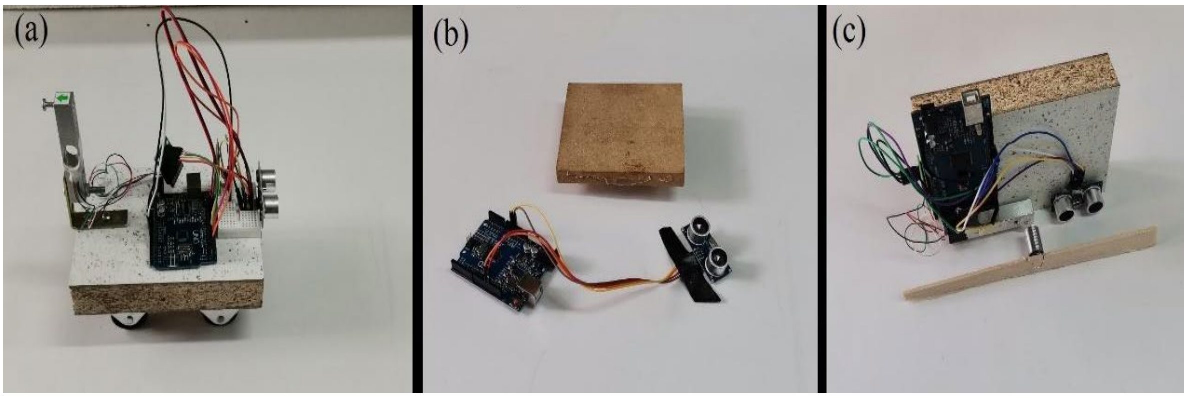
A material with somewhat more complex coding and electronic connection processes than others has been developed for the analysis of uniform circular motion. The purpose of developing this content at this time is to further challenge and develop the creativity of students who have attained the majority of fundamental robotic coding skills. The system used during the teaching process related with uniform circular motion is given in Figure 5.

Figure 5. Systems used to analyse main concepts related to uniform circular motion



With the help of this system, fundamental concepts are introduced. Different from the others, a tracker sensor, a motor driver, and a potentiometer were used in this one. Because coding this from the start can take a long time, it is better to prepare this material before the lesson and introduce coding at written code. An analysis of the concepts in the work-energy unit, which is the last unit, was carried out at the end of the study. 2 of the 3 applications carried out within the scope of these analyses are similar to the materials used in the previous lessons. The systems used in all three applications are as in figures 6a, 6b, and 6c.

Figure 6. Systems used to analyse (a) work and work-energy relation (b) type of energy and energy conservation (c) fundamental of springs and elastic potential energy



The systems in Figures 6a and 6b have the same functionality as the materials previously used in dynamics and kinematics. In these two materials, work, the effect of work on energy and the relationship between work and energy, energy types and energy conservation analyses were carried out, respectively. Using the material in Figure 6c, variables such as elastic potential energy, restoring force and spring constant were analysed.

The processes carried out in the study have been meticulously prepared to address all levels of the cognitive domain. The materials prepared for the teaching process focus on critical cognitive domain skills such as acquiring knowledge, understanding, applying knowledge to different situations, problem-solving, and application. These materials are designed to ensure active participation of teacher candidates throughout the process. The reason for asking students to design an experimental process using sensors related to the subject matter taught in the class before the material design process is to develop the adaptation of knowledge skills, which are dimensions of the cognitive domain, and to encourage teacher candidates to think in these contexts. It is anticipated that such thinking activities could have a direct impact on scientific creativity.

2.6 Data Analysis

In statistical analysis, the normal distribution describes how data are symmetrically distributed around the mean. To decide whether to use a parametric or non-parametric test for analyzing a dataset, a preliminary check for normal distribution is performed. If the data follow a normal distribution, parametric tests are used; if they do not, non-parametric tests are applied (Depuy et al., 2014).

In this study, to compare two datasets, parametric tests—specifically the dependent-sample t-test and independent-sample t-test—will be used for data that normally distributed. For data that do not have normal distribution, non-parametric tests—such as the Wilcoxon Signed-Rank Test and the Mann-Whitney U Test—will be applied. The dependent-sample t-test and Wilcoxon Signed-Rank Test will used to analyze differences between pre and post-tests (Meléndez et al., 2020). In contrast, the independent-sample t-test and Mann-Whitney U Test will used to determine whether there is a significant difference between pre-test scores of two independent groups and post test scores of two independent groups (McKnight & Najab, 2010).

3 Results

3.1 Normal distribution analyses

It is obviously standard activity to determine the actual distribution of the data in order to decide the course of the statistical analyses. Therefore, the data obtained as a result of SCS and CDSM pre-test and post-test applications are plotted and normal distribution analysis was performed. In order to specifically determine the type of the spreading of the data the skewness and kurtosis coefficients were analysed. It is genuinely accepted that if the coefficients are varying between +1 and -1, then it concludes that the data are normally distributed (Huck, 2012). The skewness and kurtosis values obtained from the results of the normality analysis of the scores are presented in table 2.

Table 2. Pre-test results of the participants concerning Scientific Creativity (SCS) and Cognitive Domain on Mechanics (CDSM)

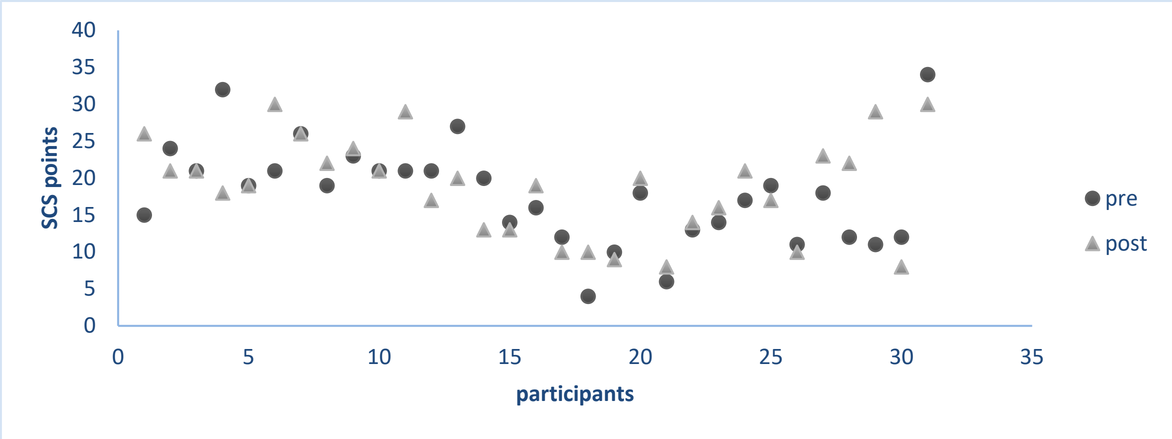
Tests	Skewness	Kurtosis
SCS pre	0.272	0.322
SCS post	-0.117	-0.887
CDSM pre	0.128	-0.577
CDSM post	0.406	0.433

Table 2 clearly specifies that the SCS pre, SCS post, CDSM pre and CDSM post test results demonstrate clear normal distribution. Therefore, parametric tests were employed in the statistical analyses based on this brief distribution analysis.

3.2 Findings related to the scientific creativity

The first problem statement of the research was about the Scientific Creativity and obviously the data are gathered by means of the previously expressed SCS. The pre-test and post-test score spreading are presented in the Figure 7.

Figure 7. Distributions of SCS concerning pre and post-test



It is comprehensible from the graph that the distributions are more less the same and no significant progress between the pre and post tests can be detected. The mean values calculated for the pre and post tests are 17.91 and 19.12, respectively. The overall progress is only 1.21 points which can be assumed insignificant. Nevertheless, in order to confirm this genuine conclusion one sample t-test, which was done by comparing the pre-test and post-test scores of the scientific creativity scale, are presented in Table 3.

Table 3. Results of a dependent sample t-test determined by comparing the scores on the SCS pre-test and post-test

Test	N	$\bar{X}$	p
SCS-Pre	32	17.91	.26
SCS-Post	32	19.12	

Table 3 shows that the pre-test mean score, which was 17.91, very little when the application was completed and became 19.12. The findings of the analysis demonstrate that the difference in mean scores between the pre-test and post-test does not meet the criteria for statistical significance (p=.26 >.05). It can be concluded that scientific creativity skills cannot be changed easily in a few weeks of time.

Other intension of the work was to search for any discrepancy concerning SCS due to gender. Therefore, the data were also analysed to determine the progress on the scientific creativity of male and female prospective teachers before and after the teaching processes. The outcomes of the Wilcoxon signed-rank tests that were carried out for this purpose are presented in Table 4.

Table 4. Wilcoxon signed-rank test results applied to determine the progresses on the scientific creativity levels of male and female students before and after the application

Gender	Test	N	$\bar{X}$	p
Male	SCS-Pre	8	17.38	.36
	SCS-Post	8	20.62	
Female	SCS-Pre	24	18.08	.47
	SCS-Post	24	18.62	

Table 4 plainly reveals that there is no statistically significant difference between the pre-test and post-test scores of both male and female participants (p>.05). The mean score of the male was 17.38 before the application and it is increased and became 20.62. Regarding female participants, this increase is from 18.08 to 18.62. When it is compared for gender it is seen that STEM is more effective for male teacher candidates.

In the section that follows, the findings of the Man-Whitney U analyses, which were conducted to examine the differentiation by gender in better detail will be given. Man-Whitney U tests are conducted to see whether there is a statistically difference in the levels of scientific creativity between the genders and the findings are presented in Table 5.

Table 5. The results of the Man-Whitney U test applied to analyse whether there is a difference in the scientific creativity levels of male and female students before and after the application

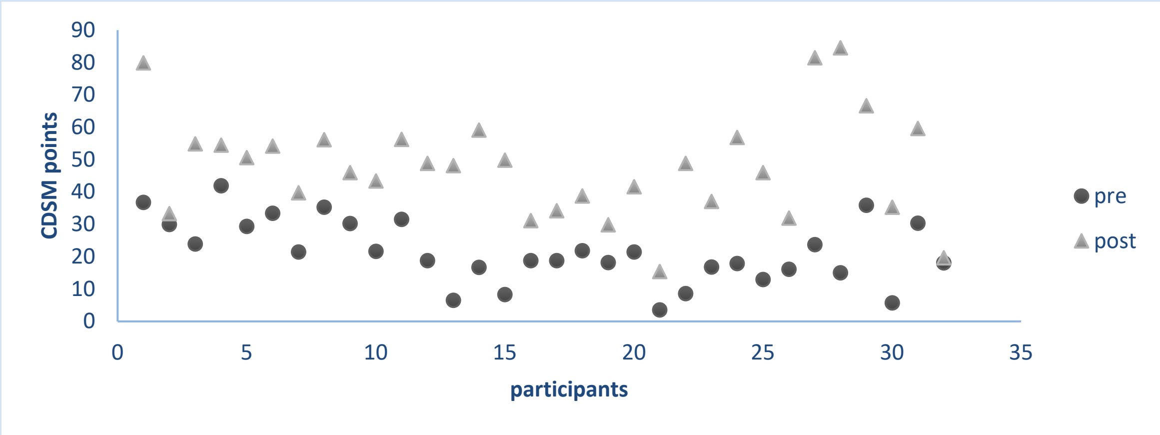
Test	Group	N	p
SCS Pre	Male	8	.46
	Female	24	
SCS Post	Male	8	.38
	Female	24	

As can be seen in Table 5, there is no statistically gender-related difference in scientific creativity levels both before and after the application (p>.05).

3.3 Findings relating cognitive domain level of mechanics

Another dependent variable of the study is the cognitive domain level of mechanics. CDSM, which is used to measure cognitive domain levels of mechanics, was applied to pre-service teachers before and after the application. The distribution chart of the pre-test and post test scores of the pre-service teachers is as in Figure 8.

Figure 8. Distribution of CDSM pre- and post-test



As can be seen in Figure 8, there is a visible difference between the pre-test and post-test scores of the pre-service teachers. In order to analyze whether the differentiation seen from the image is statistically significant or not, the dependent sample t test was applied. The results obtained as a result of the statistical analysis are as in Table 6.

Table 6. Dependent sample t-test results by comparing CDSM pre-test and post-test total scores

Test	Total			
	N	$\bar{X}$	Cohen's d	p
Pre	32	21.52	1.76	.00*
Post	32	47.97		

**: significant difference*

CDSM consists of four parts, respectively vectors, kinematics, dynamics and work- energy. In addition to the analysis made on the total scores, separate analysis were made on the scores obtained from the sections related to each subject. The results obtained are given in Table 7.

Table 7. Dependent sample t-test results by comparing CDSM pre-test and post-test section scores

Test		Vectors			Kinematic			Dynamic			Work - Energy		
	N	$\bar{X}$	Cohen's d	p	$\bar{X}$	Cohen's d	p	$\bar{X}$	Cohen's d	p	$\bar{X}$	Cohen's d	p
Pre	32	9.73	1.40	.00*	5.17	1.58	.00*	3.00	0.84	.00*	3.61	1.09	.00*
Post	32	19.23			12.22			7.58			8.94		

**: significant difference*

When Table 6 and Table 7 is examined, it is seen that there is a statistically significant increase in both the total scores of the pre-service teachers and the scores they get from each section (p<.05). Concerning the Cohen's d analysis performed to determine the effect of STEM education on cognitive domain level of mechanics total scores, it is seen that the effect value is 1.76, which expresses a high effect. The effects on section scores are also high and are ordered by magnitude as kinematics 1.58, vectors 1.40, work-energy 1.09, and dynamic 0.84.

In order to analyze the effect of gender on learning, the scores of male and female students in the experimental group were also evaluated separately. Wilcoxon signed-rank test results for total scores are as in Table 8 and section scores are as in Table 9 which were made by comparing CDSM pre-test and post-test scores of 8 male and 24 female teacher candidates.

Table 8. Wilcoxon signed-rank test results on total CDSM pre- and post-test scores of male and female teacher candidates'

Gender	Test	N	Total $\bar{X}$	Cohen's d	p
Female	Pre	24	22.12	2.05	.00*
	Post	24	46.15		
Male	Pre	8	19.71	1.55	.01*
	Post	8	53.10		

**: significant difference*

Table 9. Wilcoxon signed-rank test results on CDSM sections pre- and post-test scores of male and female teacher candidates'

	Test		Vectors			Kinematic			Dynamic			Energy		
Gender		N	$\bar{X}$	Cohen's d	p	$\bar{X}$	Cohen's d	p	$\bar{X}$	Cohen's d	p	$\bar{X}$	Cohen's d	p
F	Pre	24	9.79	1.47	.00*	5.14	1.64	.00*	3.19	0.80	.00*	4.00	1.13	.00*
	Post	24	19.57			11.62			7.19			7.87		
M	Pre	8	9.58	1.13	.04*	5.26	1.52	.01*	2.44	0.92	.04*	2.44	1.56	.01*
	Post	8	18.22			14.00			8.72			12.15		

**: significant difference*

When Table 8 and 9 is examined, it is seen that the increase in total scores and sections scores is statistically significant for both male and female teacher candidates. When Cohen's d coefficients are examined, it is seen that STEM education has a high effect on the cognitive domain level of mechanics of female and male teacher candidates in both total scores and section scores. It is also perceived that the effect on women's total scores is 2.05, the effect on men is 1.55, and the effect on women is greater. In the subsections, it was understood that it was more effective on women with a difference of 0.36 in the vectors section, and the difference in the effect in the kinematic section was higher in women with a level that could be considered as low as 0.12. The difference in the effect level in the dynamic section is also low and is 0.12, but this time the effect on men is more. In the work-energy section, it is understood that the effect on men is greater than the effect on women with a margin of 0.43.

The Man-Whitney U test was performed to test whether the scores were at a statistically significant level of difference at both pre and post. The results of Man-Whitney U statistical analysis made on the scores before and after the application are as in Table 10 for total and Table 11 for subsection scores.

Table 10. The results of the Man-Whitney U test applied to analyze whether there is a difference in the CDSM total scores of male and female students before and after the application

Test	Group	N	p
SCS Pre	Male	8	.40
	Female	24	
SCS Post	Male	8	.46
	Female	24	

Table 11. The results of the Man-Whitney U test applied to analyze whether there is a difference in the CDSM section scores of male and female students before and after the application

Test			Vectors	Kinematic	Dynamics	Work-energy	
	Group	N	p	p	p	p	Cohen's d
CDSM Pre	Male	8	.68	.78	.719	.25	0.59
	Female	24					
CDSM Post	Male	8	1.00	.46	.60	.05*	1.04
	Female	24					

**: significant difference*

Examining Table 10 reveals that there is no difference (p>.05) between the cognitive domain level of mechanics of male and female teacher candidates on the pre- and post-tests. From Table 11, one can conclude that the results in the vectors, kinematics, and dynamics subsections are consistent with the results in the overall scores, that there is no statistically significant difference, and that gender has no effect on the scores. Although there was no statistical change in the scores obtained from the work-energy part just before application, there was a statistically significant difference after the application. At this point, at the conclusion of the application process, it is evident that the c cognitive domain level of mechanics of the male teacher candidates in relation to the work-energy unit are statistically substantially higher than those of the female teacher candidates. Similarly, Cohen's d impact coefficient can be found to be low before application but large after it.

Results such as the significant difference in favour of boys in the energy department, higher percentage of male teacher candidates' points increase, the difference in all separate department scores and total scores more in favour of male teacher candidates at the end of the application are signs that STEM education produces more effective results on boys.

3.4 Findings on correlation between scientific creativity and cognitive domain level of mechanics

Pearson correlation analysis was conducted to analyze the correlation between the cognitive domain level of mechanics of the pre-service teachers and their scientific creativity before and after the application. The results obtained are as in Table 12.

Table 12. Correlation analysis results showing the relationship between cognitive domain level of mechanics and scientific creativity

	Correlation	**p**
Pre	0.423	.016*
Post	0.498	.004*

*: *significant correlation*

When Table 12 is examined, it is realised that the relationship between scientific creativity scores and cognitive domain level of mechanics total scores is positive and significant both before and after the application.

In addition to the findings presented above, interviews were conducted with individuals selected on a voluntary basis among the participants after the four-week process. Participants expressed that the practical activities applied in the classroom environment caught their interest, they were curious about the experiments to be conducted in the lessons, and they believed that the experimental activities facilitated the learning process. Specifically, one student mentioned that the applications carried out after the theoretical information increased their interest and understanding of the theoretical content, thus making her/his follow the theoretical lessons more eagerly. However, some students mentioned difficulties in understanding coding and electronic components, indicating that they could not reach the desired level of learning in these areas. One of the participants, who had watched videos about Arduino before, said that initially he had thought that this tool was used for complex projects but thanks to the practical applications in the lessons, he realized that Arduino was an understandable and useful tool. The same student emphasized that the course content and the use of Arduino were very compatible. Another student, who had no prior knowledge about Arduino, mentioned that although he had difficulty understanding the theoretical information in the first introduction lesson, he were able to grasp how Arduino was used and its purpose more clearly through the experiments.

4 Discussion

The incorporation of robotics in STEM education, particularly within teacher training programs, stands as a pivotal enhancement in pedagogical methodologies, addressing the critical demand for educators who are not only proficient in STEM disciplines but are also adept at fostering an environment conducive to developing 21st-century skills among students. This approach is anchored in the premise that hands-on, project-based learning, exemplified through robotics, significantly enriches the teaching and learning experience, cultivating skills such as critical thinking, creativity, and problem-solving.

Research underscores the effectiveness of robotics as a teaching tool in STEM education, highlighting its role in stimulating students' interest in STEM fields, enhancing cognitive flexibility, and promoting teamwork and problem-solving skills (Valko & Osadchyi, 2021; Jarboe et al., 2022). Specifically, robotics competitions have been identified as a dynamic method of engaging students in STEM, where the practical experience gained transcends theoretical knowledge, fostering a deep understanding and appreciation of STEM concepts (Jarboe et al., 2022). Furthermore, low-cost educational robotics initiatives demonstrate the feasibility of introducing robotics into the curriculum, offering a practical, hands-on approach to learning that aligns with the pedagogical goals of STEM education by making abstract concepts tangible (Abidin et al., 2021).

In this study, the effectiveness of Arduino supported STEM education on pre-service science teachers' mechanical unit cognitive domains and scientific creativity was investigated. This study has three main focuses. Firstly the use of the Arduino-based STEM education approach in the teaching of vectors, kinematics, dynamics and work-energy, which are the main topics of the mechanical unit, secondly to examine the changes in the cognitive domain level of mechanics and scientific creativity of the pre-service teachers as a result of this teaching, and thirdly to reveal the effect of the gender of the pre-service teachers on the application outcomes.

The first analyses were made on the levels of scientific creativity based on the findings obtained in the study. The scientific creativity scale scores applied to the pre-service teachers were 6.76 % higher after the application compared to the pre-application. However, despite this increase, it was concluded that there was no statistically significant difference between the two mean scores. Based on this result and Cohen’s coefficient, it can be accepted that Arduino-based STEM education has no effect on scientific creativity. Although there was an increase in the post-tests in a 4-week application, this increase was not enough to reveal a statistically significant difference.

Relating this conclusion, Mahadi and Ariska (2022) have recently concluded that online problem-based learning activities that they conducted with students in an 8-month period were statistically significantly superior to traditional lectures in developing scientific creativity. Aktamış and Ergin (2008) also concluded that trainings on scientific process skills in a 12-week period had positive effects on scientific creativity. The teaching practices carried out in both studies are processes that can be considered long. The applications carried out in this study lasted 4 weeks and were not sufficient to develop effective scientific creativity. However, it is possible to continue similar applications in other subjects in the mechanical unit. In this way, long-term studies to be carried out during the term may have a statistically significant effect on scientific creativity.

The obtained scientific creativity scores were also analysed by comparing the genders of the pre-service teachers and the effect of gender on scientific creativity was investigated. From the findings, it was seen that gender did not create a significant difference in the level of scientific creativity. Although there is no clear result in the literature on the effects of gender on scientific creativity, there are also studies that reach the result not only in favour of women (Matud, Rodríguez & Grande, 2007; Wahyudi & Astriani, 2014) but also in favour of female participants (Okere & Ndeke, 2012; Perdana, 2019). In addition, there are study results revealing that there is no gender-related difference on scientific creativity (Bakır & Öztekin, 2014; Bart et al. 2015; Aruan, Okere & Wachanga, 2016).

As a result of the statistical analyses made on the findings collected in order to test the effect of Arduino supported STEM education on the cognitive domain levels of mechanics, it was concluded that STEM education had a positive and statistically significant effect on the cognitive domain both in total scores and in sub-unit scores. This result is compatible with other studies that concluded the positive effects of STEM education on student achievement (Samsudin et al. 2020; Yuliati et al. 2020; Tenti, 2021).

During the application, the level of change in the cognitive domain levels of mechanics of the pre-service teachers' depending on their gender was also tested with regression analyzes. In the results obtained, it is seen that the cognitive field levels on work-energy are statistically significantly related to gender and are higher concerning males. This result shows that the concepts on energy are better understood by male pre-service teachers, and it is consistent with studies that state that men's understanding of physics concepts is higher than that of women (Seyranian et al. 2018; Sagala et al. 2019). In another study, it was concluded that the science literacy levels of male students after STEM education were higher than female students, and it was stated that male students had higher motivation during STEM education (Afriana, Permanasari & Fitriani, 2016).

The scores of male pre-service teachers showed a higher increase compared to the scores of female pre-service teachers in terms of other subject scores other than energy and in total scores. However, as a result of regression analysis, it was seen that gender did not reveal a statistically significant difference on these scores. Therefore, it was concluded that gender did not have any distinguishing effects on total scores, vectors scores, kinematics scores, and dynamics scores. This result is similar to the result of the study conducted by Samsudin, Zain, Jamali, and Ebrahim (Samsudin et al. 2018), which reveals that there is no difference between the effects of project-based learning activities prepared with the STEM approach on the physical achievement of men and women.

Finally, it was seen that the scientific creativity levels of teacher candidates and their cognitive domain level of mechanics had a positive and significant correlation both before and after the study. Based on this result, it can be said that scientific creativity and cognitive domain level of mechanics are directly proportional to each other. This result is in line with other results in the literature that reveal the positive relationship between creativity and achievement (Wahyudi & Astriani, 2014; Fatmawati, Zubaidah & Mahanal, 2019).

In conclusion, the infusion of Arduino-based STEM education, embodying robotics, into teacher training paradigms heralds a transformative stride towards enriching educational experiences and outcomes. This research substantiates the proposition that such an educational approach markedly advances the cognitive domain levels of mechanics, underscoring the critical role of hands-on, project-based learning in cultivating a deeper, more engaging understanding of STEM subjects. While the enhancement in scientific creativity remains statistically indistinct, the overarching findings illuminate the profound potential of robotics in STEM education. In addition, in the semi-structured interviews, prospective teachers stated that experimental activities facilitated learning, increased their awareness of Arduino, had high retention in coding and electronic connection, and increased their interest and motivation in lessons. This potential not only facilitates a more nuanced and comprehensive grasp of mechanics but also champions the broader educational imperative of equipping future generations with the critical, creative, and technological fluency necessary for navigating and innovating within the increasingly complex landscapes of the 21st century.

The research group is limited to 32 teacher candidates studying in a state university in Turkey, and the mechanics unit expression is limited to vectors, kinematics, dynamics and work-energy. In addition, the experimental processes carried out in the research are limited to teaching processes that last a total of 6 weeks and 180 minutes per week. Taking these limitations into account, it is very important and necessary to carry out longer-term studies with more diverse working groups, on different subjects, in the future, especially in terms of training key role teachers with the necessary competencies in raising generations with the necessary competencies to be active in the technology race. In addition, it was observed in subsequent trials that the ChatGPT artificial intelligence bot, which had not yet been announced at the time this study was conducted, was a very effective assistant, especially in the coding, connection and data analysis processes, in addition to theoretical knowledge support. In future studies, by showing teacher candidates how they can use ChatGPT as an assistant in these processes, the way for teacher candidates to achieve more active participation in all processes can be paved for more intensive gains, and the results of studies conducted in this way can be very useful for the literature.

Research ethics

Author contributions

A.C.: conceived and designed the study, collected and analysed the data, and wrote the original draft of the manuscript.
M.E.: supervised the entire research process, provided guidance on data interpretation, and contributed to the review and editing of the manuscript.
All authors have read and approved the final version of the manuscript.

Artificial intelligence

No artificial intelligence tools were used during the research process or in the writing of this manuscript.

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Institutional review board statement

This study was reviewed and approved by the Ethical Committee of the Educational Sciences Institute at Dokuz Eylül University, Turkey. All procedures followed national ethical guidelines, and informed consent was obtained from all participants prior to their involvement in the study.

Informed consent statement

Informed consent was obtained from all research participants.

Data availability statement

You can contact the corresponding author for all data.

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Conflicts of Interest

The authors declare no conflicts of interest.

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