Necatibey Faculty of Education Electronic Journal of Science and Mathematics Education
Vol. 19, Issue 1, June2025, pp. 30-64. ISSN: 1307-6086

Research Article

Influences of Arduino and Algodoo Based Mechanics Teaching on Achievement*

Atakan ÇOBAN[1], Mustafa EROL[2]

[1] Dokuz Eylül University, Buca Faculty of Education, Türkiye (Ludwig-Maximilians-Universität München, Faculty of Physics, Germany), atakan.coban@lmu.de, https://orcid.org/0000-0003-4959-0614

[2] Dokuz Eylül University, Buca Faculty of Education, Türkiye, mustafa.erol@deu.edu.tr, https://orcid.org/0000-0003-1022-4975

Received : 02.10.2024 Accepted : 24.02.2025

Doi: https://doi.org/10.17522/balikesirnef.1559865

Abstract – This work focuses on investigating the influence levels of Arduino and Algodoo based mechanics teaching activities on academic achievement. The research was carried out based on a pre-test post-test quasi-experimental method with two experimental groups totally consisting of 61 pre-service science teachers studying at a state university. Specifically, Arduino based STEM and Algodoo based education materials are carefully developed on the units of vectors, kinematics, dynamics, and work-energy in accordance with teaching objectives. The influences of the teaching materials on achievement are measured by Mechanics Achievement Scale. The findings demonstrate that Arduino based education has improved the achievement by 28.21% and Algodoo based teaching has improved by 28.83%, both influencing significantly. It was also revealed that simplicity of the activities and prior knowledge of the groups related with experimental processes were factors that increased the effectiveness of the applications.

Keywords: Physics education research, Arduino, STEM, Algodoo, mechanics teaching, academic achievement.

Corresponding author: Atakan ÇOBAN, atakan.coban@lmu.de

*This paper is based on the PhD thesis of Atakan Çoban, tittled "Investigation of the Effects of Arduino-Based STEM and Algodoo-Based Simulation on Mechanics Teaching", conducted under the supervision of Mustafa Erol at Dokuz Eylül University in 2023.

Introduction

The teaching of mechanics aims to facilitate the understanding of physical laws, the application of mathematical modeling, and the development of analytical problem-solving skills. This process plays a fundamental role in both engineering and science fields and is critical for students to succeed in advanced courses requiring in-depth technical knowledge (Hopf et al., 2011). However, the abstract nature of concepts, the likelihood of misunderstandings, and the limitations of traditional teaching methods etc. can make mechanics instruction challenging for students at times. For instance, students' failure to accurately utilize free-body diagrams or to account for physical dimensions may lead to fundamental comprehension deficiencies (Papadopoulos et al., 2006).

Innovative methods are of great importance in overcoming these challenges. Technology-enhanced educational tools, interactive digital simulations, and curricula integrated with experiments enable students to gain a deeper understanding of concepts. For example, computer-assisted instruction on Newtonian mechanics has been shown to correct students' misconceptions and foster a more concrete understanding (Hennessy et al., 1995).

One of the fundamental commitments of the Physics Education Research (PER) is to develop novel or alternative teaching materials in order to reduce recognized learning/teaching difficulties (Docktor & Mestre, 2014). The other important issue is to integrate up-to-date technological tools into teaching activities. In this sense, Arduino microprocessors are very convenient tools that can be introduced to teaching processes with almost no cost (Goncalves et al., 2023). Employing simulations can be another up-to-date approach to get rid of certain teaching difficulties and to achieve deeper conceptual understanding. Algodoo, in this sense, is a very handy software that can easily be reached and employed within teaching activities (Gregorcic & Bodin, 2017).

Arduino microprocessors are specifically very valuable due to their ability to measure the instant forces and displacements of a body as a function of time with a time sensitivity of 1 microsecond and displacement sensitivity of 1 micrometer. Accordingly, one can precisely measure the time dependence of the displacements and forces, which can then be employed to obtain various quantities, such as velocity, acceleration, momentum, etc. Therefore, it is very important to introduce Arduino microprocessors in physics teaching in order to provide students with deeper learning levels and 21st-century skills (Bao & Koenig, 2019).

Algodoo simulation program also offers a valued tool for teaching physics in the sense that almost every parameter can be varied to see and measure the effect of the change. Algodoo bridges the gap—crucial for deeper learning—between the unreachable region that is the measurement of the instantaneous displacements or forces and the theoretical formulations of that specific subject (Özdemir & Coramik, 2022).

In previous studies, numerous alternative teaching materials have been developed and reported based specifically on Arduino microprocessors. Specifically, kinematics (Çoban & Erol, 2021a), dynamics (Çoban & Erol, 2022), work-energy theorem (Çoban & Erol, 2021b), Newton's second law (Çoban & Erol, 2020), and impulse-momentum law (Çoban & Erol, 2021c) have been tackled and studied by means of Arduino microprocessors. Algodoo-based teaching material on impulse-momentum has also been developed and reported earlier (Çoban, 2021).

In this work, carefully developed Arduino and Algodoo teaching materials are employed at mechanics unit with pre-service science teachers within the 5E teaching approach, and the effectiveness of the materials is determined. The teaching materials are specifically tested to determine their impact on academic achievement at mechanics.

Previous Research

Mechanics is the most fundamental sub-topic of physics and is experienced countless times every day; however, it is also one of the most problematic topics in physics education. Difficulties in teaching mechanics, to some extent, originate from the lack of verification of mathematical models due to the insufficiency of measuring instantaneous displacements, velocities, and forces. Therefore, introducing novel teaching materials based on technological developments is essential to improve conceptual learning.

Mechanics teaching has been a hot topic in Physics Education Research (PER), addressing numerous teaching difficulties and misconceptions. In this sense, a paradigmatic change concerning mechanics teaching was addressed almost 30 years ago (Schecker, 1992). Misconceptions and difficulties in teaching mechanics among high school and university students were also tackled by Daud et al. (2015). In another work, introductory mechanics was studied in terms of students' learning difficulties (Nguyen & Rebello, 2011).

Vectors, on the other hand, have been one of the trickiest concepts in mechanics, evidently including several conceptual difficulties. Various works have concentrated on teaching vectors. In this sense, student use of vectors in introductory mechanics has been addressed, and some problems have recently been mentioned (Flores et al., 2004). In another study, students' learning difficulties regarding symbolic and graphical representations of vector fields have been handled (Bollen et al., 2017). Similarly, students' difficulties regarding vector representations in the free-body system have also been studied comprehensively (Poluakan & Runtuwene, 2018).

Student learning difficulties and conceptual problems in kinematics have likewise been studied by a number of researchers. To mention some, student difficulties in connecting graphs and kinematics have been addressed, and some important findings were underlined (McDermott et al., 1987). Lichtenberger et al. (2017) reported validation and structural analysis of the kinematics concept test. Assessment of representational competence in kinematics has also been handled by Klein et al. (2017). In another study, the effect of conceptual change texts on physics education students' conceptual understanding in kinematics was studied (Syuhendri, 2021).

Teaching dynamics and related fundamental concepts, namely force and acceleration, have also been studied extensively. For instance, Rosenblatt et al. (2009) have studied modeling students' conceptual understanding of force, velocity, and acceleration. In another study, a systematic study of student understanding of the relationships between the directions of force, velocity, and acceleration in one dimension was tackled (Rosenblatt & Heckler, 2011). Liu and Fang (2016) have recently studied student misconceptions about force and acceleration in physics and engineering education. Force, acceleration, and velocity during trampoline jumps have been examined in terms of a challenging assignment (Pendrill & Ouattara, 2017). Molefe and Khwanda (2020) have recently studied activities to enhance students' understanding of acceleration.

Work and energy concepts have also been tackled by numerous studies. In one study, multiple representations of work–energy processes were examined (Van Heuvelen & Zou, 2001). Tang et al. (2011) addressed students' multimodal construction of the work–energy concept. Gutierres-Berraondo et al. (2019) studied addressing undergraduate students' difficulties in learning the generalized work-energy principle in introductory mechanics. In another study, the analysis of students' difficulties with work and energy was tackled (Rivaldo et al., 2020).

There have been various studies concerning the STEM approach to teaching mechanics. Applying a simple model aiding in understanding the acceleration of a bungee jumper has been studied by Kesonen et al. (2019). Büyükdede and Tanel (2019) studied the effect of

STEM activities related to work-energy topics on academic achievement and prospective teachers' opinions on STEM activities. Arduino-based STEM education materials concerning work-energy theorem, Newton’s second law, and impulse-momentum have been studied by Çoban and Erol (2021a, 2021b, 2020). Erol and Oğur (2023) studied the large-angle pendulum via Arduino-based STEM education material.

De Lima et al. (2020) developed Arduino-supported experiments in the fields of thermology and optics, implemented them in two public high schools in Brazil, and identified their positive contributions to students' learning processes. Schnider and Hömöstrei (2024) designed Arduino-based classroom experiments for teaching electromagnetism and observed that these experiments enhanced students' conceptual understanding. Petry et al. (2016) integrated Arduino into physics laboratories to develop project-based teaching methods and reported that students gained interdisciplinary skills. Similarly, Xianfeng et al. (2020) implemented electronics circuit design experiments based on the Arduino platform and noted improvements in students’ practical abilities and problem-solving skills. These studies demonstrate that Arduino is an effective tool in physics education for enhancing student engagement and improving learning outcomes. Algodoo is a well-known simulation platform employed in numerous studies. Gregorcic (2015) studied exploring Kepler’s laws using an interactive whiteboard and Algodoo. Çoban (2021) studied Algodoo for online education concerning impulse and momentum activities. Algodoo has also been used to study the force that makes a car accelerate and what the acceleration depends on (Radnai et al., 2023). Additionally, a study focused on educational experiments with motion simulation programs, questioning whether gamification can be effective in teaching mechanics (Radnai et al., 2019).

Sontay and Karamustafaoğlu (2023) examined the perspectives of physics teachers on Algodoo training and reported that teachers provided positive feedback, indicating that using this software in lessons increased students' motivation and made the topics more comprehensible. Similarly, Cayvaz and Akçay (2018) investigated the effects of using Algodoo in middle school science teaching. The results demonstrated that Algodoo-supported instruction facilitated students’ understanding of scientific concepts and increased their interest in the subject. These studies highlight that Algodoo software is an effective tool in physics education, playing a significant role in enhancing students’ conceptual understanding, motivation, and engagement in lessons.

Theoretical Framework

Physics education efforts, in general, employ various theoretical frameworks to improve student achievements and conceptual learning. Conceptual learning is crucial because it substantially enhances students' cognitive skills, thereby improving their readiness to solve original problems. In this work, resource-based learning has been employed. This theoretical framework develops and provides various resources available to students, including textbooks, educational technologies, and laboratory experiments, and researchers analyze the effectiveness of those resources in facilitating learning. Resource-based learning is a pedagogical approach that actively involves students and teachers in applying a range of resources in the learning process (Brown & Smith, 2013; Turner, 1974). This theoretical framework offers a flexible structure to learning, allowing students to develop their varied interests, experiences, learning styles, needs, and ability levels (Hill et al., 2005; Stewart, 1998). Resource-based learning also focuses on the resources available to the learners and how the learners interact with these resources, which leads to an interest in using technology to support and develop a learning environment. Essential features of resource-based learning can be summarized as follows (Kononets et al., 2020; Rumahlatu et al., 2021).

- A wide variety of resources are prepared in harmony with the proposed gains
- Learning experiences are planned in accordance with instructional objectives
- Teaching strategies and skills are identified and thought with the context of relevant and meaningful components of work
- Adapted to different learning styles and subject areas

In today's world, providing students with a deep and lasting learning experience has become increasingly important. Particularly in application-oriented fields such as physics, methods that offer students opportunities to explore real-world phenomena, conduct observations, and enhance their learning by developing their own projects have gained significant importance. In this context, tools such as experiment kits (e.g., Arduino) and simulation programs (e.g., Algodoo), stand out as valuable resources for enriching the teaching process.

The primary aim of this study is to investigate the impact of innovative teaching approaches utilizing Arduino and Algodoo on students' success in mechanics education. The significance of the study can be addressed from several perspectives. First, the study offers concrete recommendations on how cost-effective experimental tools developed using Arduino can be employed in teaching, along with data on their effectiveness in enhancing learning outcomes, demonstrating the strength of practical applications.

Second, by providing specific insights into how the free Algodoo simulation program can be integrated into lessons and how the effectiveness of this integration can be evaluated, the study addresses the potential to overcome cost and infrastructure challenges, particularly in remote or blended learning models.

Furthermore, another notable aspect of this study is the comparison of hands-on experimental processes conducted with Arduino, whose advantages over traditional methods have been demonstrated in previous studies, and simulations performed using the Algodoo program, in order to identify the similarities and differences between these two approaches. Particularly following the extensive experience with online education during the pandemic, the results obtained from comparing these methods will provide valuable insights into which approaches offer greater added value when planning future mechanics education.

Research Questions

1. What is the influence of Arduino based teaching on achievement regarding mechanics teaching?
2. What is the influence of Algodoo based teaching on achievement regarding mechanics teaching?
3. Is there any significant difference between Arduino based and Algodoo based teaching on Mechanics achievement?

Method

Research Design

The design of the study is pre-test post-test quasi-experimental model with two experimental groups. The research was carried out within the scope of the Physics 1 course in the fall semester of the 2022-2023 academic year. The teaching practices were carried out using two different teaching approaches in two different branches in weekly 180-minute lessons for four weeks. To investigate the impacts of these pedagogical methods on achievement, the measurement tools were applied to the study groups before and after the teaching processes and evaluated carefully.

Participants

The sampling of the research consists of a total number of 61 teacher candidates, between the ages of 18 and 22, studying in two different branches of the Science Education department of a state university. The sampling students were randomly and naturally assembled and divided into branches from the moment they registered to the department. In one of the branches, all courses were carried out experimental activities using Arduino microcontroller (n = 28, 20 females and 8 males), while in the other branch all courses were carried out with the Algodoo simulation program (n = 33, 20 females and 13 males).

Data collection

Mechanics Achievement Scale

The scale employed to measure the success within the scope of the study is the Mechanical Achievement Scale (MAS) developed by the researchers. Validity and reliability studies of the scale were carried out in the fall semester of the 2021-2022 academic year. After the necessary adjustments were made by consulting expert opinions within the scope of validity of the studies, the scale was applied to students who had previously taken Physics 1 courses and the obtained data were evaluated by two different experts. As a result of the evaluations, the compatibility of the results was tested via Kendall analysis and the concordance coefficient between the two rates was determined as 0.990 and it was concluded that the scale was highly reliable. The scale consists of four separate parts namely vectors, kinematics, dynamics, and work-energy units and each one includes 5 true-false, 2 classic and 2 multiple choice questions within the framework of a daily life problem case related to the subject. The maximum score that can be obtained from the scale is 100. In order to give an idea about the content of the scale, the scale section regarding the vectors unit is given as Apendix 1.

Teaching Materials

In this study, teaching materials using Arduino microcontrollers and Algodoo simulation programme were developed and used concerning the units of Vectors, Kinematics, Dynamics and Work-Energy in accordance with undergraduate Physics 1 course. The source book and teaching sequence were identical for both approaches. Before starting the development process of the instructional materials, initially learning gains of the related units were determined based on the source book and those learning gains were taken into consideration in the teaching activities in both groups.

Materials and Teaching Sequence Involving Arduino

In the first step of the preparation of Arduino-based instructional materials, specific mental models of the activities were designed by considering the proposed learning outcomes. The mental models for each activity were converted into three-dimensional instructional materials and the activities were tested through the material. At this point, activities that did not have any problems in their implementation as mentally planned were made ready to be used in the study. The activities that could not be implemented as planned and had problems in their implementation were revised and made suitable for the use. The materials that caused problems despite the revisions, were improved and new applications were developed and tested in the same way.

The developed materials were implemented in the teaching processes in accordance with the 5E pedagogical model. The implementation is managed in the following manner. In the Engage stage of the 5E model, a stimulating question related to the subject was asked to the students to attract their attention and increase their learning motivation by triggering their curiosity. The applications using Arduino are included in the Explore and Explain sections. In these stages, firstly, the working principle, coding and connections of the sensors to be used in the Arduino application planned to be realised in the course were explained to the students. Then, detailed lectures and question solutions were made through the source book, and after these lectures, the whole class was asked to brainstorm on how an experiment could be designed using Arduino and the sensors introduced in this subject by discussing among themselves. At this stage, the researchers ensured that the students are well guided during the brainstorming in the classroom environment. The predetermined material was not shown or explained to the students in any way and the students were enabled to be active in the process as if they were producing a new material from scratch. At this stage, the process carried out in the classroom is very important to increase activity and co-operation. During the process, it is important that the students communicate among themselves about the experimental material that needs to be done and get results. The process of programming the experimental equipment used in the study takes time and there is a high chance of making mistakes at the first attempt. If such studies are carried out in the classroom in addition to the lectures, there may be some problems in terms of time. For this reason, the researchers have prepared planned and tested activities that can be performed for each subject. However, bringing them to the classroom and giving them to the students is not the best way to teach in a way that encourages creativity and co-operation. Considering both situations, the researchers asked the students to identify the materials by talking among themselves and guiding them in this process. As a result of this guidance, the students were able to design and test the materials that the researcher had previously designed and tested. Thus, both the problems that may arise during the development of the material were eliminated and the applications were carried out as planned by ensuring that the students were active. As a result of the brainstorming, three-dimensional material design, electronic connections, code writing and programming applications were carried out within the scope of the studies for the development of the experimental setup for the experimental activity determined by a common decision. The experimental activity was carried out using the experimental setup developed at the end of the Explore and Explain steps and the results were obtained by analysing the collected data. In the Elaborate stage, the subject was summarised and in the Evaluate stage, problem solutions related to the subject were carried out.

Arduino based teaching materials have been developed using Arduino UNO microcontroller and some related sensors for vectors, kinematics, dynamics, and work-energy units. The materials were specifically designed to gradually improve students' coding and electronics skills throughout the course. For this reason, in the vectors unit, which is the first unit where the HC-SR04 distance sensor is used, applications with basic level connections and programming have been carried out. In this application, the position data measured using the HC-SR04 distance sensor with the help of the setup in Figure 1a are tested experimentally and theoretically with the applications in the vector subject. The HC-SR04 distance sensor is an easy-to-use sensor that requires basic skills and is suitable for use in the most basic applications. In the first lesson, students learnt the basic working principles of the distance sensor that will be used 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 students were involved in the robotic coding process without reducing their learning motivation.

In the applications performed in the second unit, the kinematics unit, three different materials were used (Figures 1b,1c, 1d). HC-SR04 distance sensor, which was also used in the first lesson, was used as the sensor in both materials. In this lesson, the connections and programming processes were completed in a shorter time with the students who learned how to use distance sensors in the previous lesson, and the next process, the analysis of the collected data, was carried out in detail, especially emphasising the methods of determining the instantaneous velocity and acceleration magnitudes, which will be carried out in other lessons. The materials used are shown in Figure 1b, Figure 1c and Figure 1d. The data obtained using the system in Figure 1b were copied to Excel where the basic concepts of kinematics and motion graphs were analysed. The system in Figure 1c was developed to analyse the bottom-up throwing motion and the values such as acceleration, velocity, and position during the movement of the wooden block thrown vertically upwards were analysed. At last, for kinematics, with the system shown in Figure 1d, 2D motion was analyzed (Çoban & Erol, 2021a).

In the third unit, the dynamics unit, force, and uniform circular motion analyses were performed. Load-cell force sensor was used in the analyses of the force. The connections and coding processes related to the force sensor to be used both in this unit and in the applications in the other unit, the work-energy unit, were carried out with the students in the classroom and used in force-related applications. After the load-cell force sensor was programmed, the developed material was attached to the wooden block as shown in Figure 1e and Figure 1f. Using the system shown in Figure 1e, detailed force-related information such as force properties, equilibrium, and friction force was analyzed, and by using the system shown in Figure 1f, analyses regarding Newton's 3rd law were made (Çoban & Boyacı, 2020). For the analysis of uniform circular motion, a material with slightly more complex coding and electronic connection processes than the others were developed. The purpose of the current development of this content is to further challenge and develop the creativity of students who have already acquired most of the basic robotic coding skills. The basic concepts were introduced with the help of the system shown in Figure 1g used in the teaching process about uniform circular motion. Unlike the others, this system used a tracking sensor, a motor driver, and a potentiometer. Since it may take a long time to code it from the beginning, it was thought that it would be more effective to prepare this material before the lesson and to introduce the coding in writing and this method was followed.

In the applications carried out in the last unit, both the applications related to the friction force and Newton's fundamental law within the scope of the force unit explained in the previous lesson and the applications including analyses related to the concepts in the work-energy unit were made. Within the scope of these analyses, two applications were carried out and the sensors used in these applications are like those used in previous lessons. With the help of the system in Figure 1h, the analyses of the basic law of dynamics and the relationship between work and energy were performed (Çoban & Erol, 2020, 2021b). During these analyses, a Bluetooth sensor was used to transfer data from the force sensor and distance sensor to the computer. With the help of the same system (Figure 1c), as the application was carried out within the scope of the kinematics unit, analyses on energy conservation were conducted (Çoban et al., 2023). The last teaching practice of the energy subject, and therefore the last teaching practice of the study, was carried out using the material shown in Figure 1i, which includes experimental processes for the concepts of elastic potential energy, reactive force, and spring constant (Çoban & Çoban, 2020).

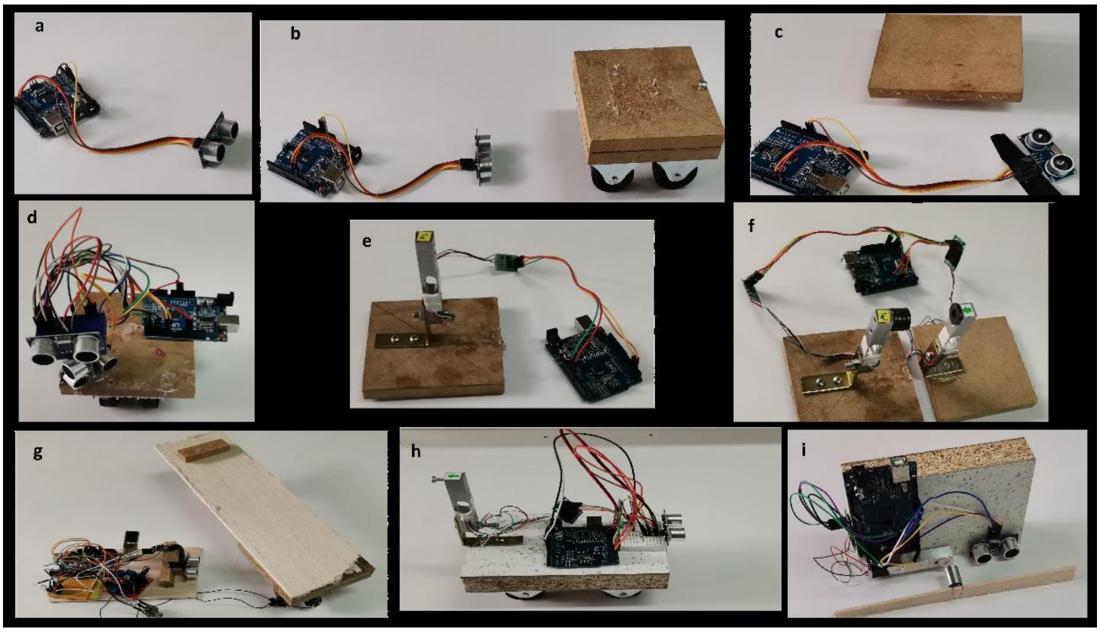


Figure 1 Experimental Setup Used for; **a** Vectors, **b** 1st Application of Accelerated Motion in One Dimension, **c** 2nd Application of Accelerated Motion in One Dimension and Experimental Setup Used in Conservation of Energy, **d** Accelerated Motion in Two-dimension, **e** Force Concept and Friction Force **f** Newton's 3rd Law, **g** Uniform Circular Motion, **h** Work-energy and Newton's 2nd Law, and **i** Elasticity Potential Energy.

Materials and Teaching Sequence Involving Algodoo

Concerning the second experimental group, educational activities were carried out by using the Algodoo physics-based simulation program regarding the Vectors, Kinematics, Dynamics, and Work-Energy units. In the process of designing the activities, firstly a mental model was developed for the proposed activity considering the course objectives and then a simulation activity was designed based on this mental model. It was then analyzed whether the designed simulation functioned as intended, and adjustments were made when necessary. The simulations were accordingly finalized and included in the teaching materials. While determining these simulations, it was also aimed to use the content of the Algodoo programme in the most efficient way during the lectures and the most frequently used features were vector representation, adding external forces to the objects, adjusting the masses of the objects, adjusting the frictions, information window with information about velocity, acceleration and position, and a wide variety of graphical representation namely, acceleration-time, velocity-time, position-time, total energy, kinetic energy, potential energy-time graphs. In addition to the main objective of teaching the subject matter in the course content in the best way, a secondary objective was to improve the Algodoo usage skills of the prospective teachers. Screenshots of some of the simulations used during the lectures are shown in Figure 2.

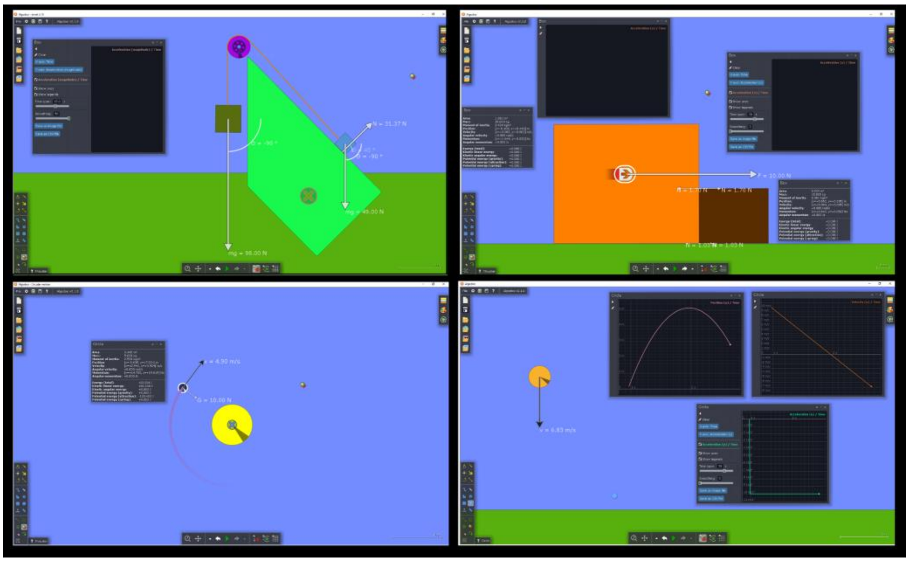


Figure 2 Screenshots of Algodoo Simulations Used During Lectures in the Algodoo Group.

Applications using Algodoo were implemented using the 5E pedagogical model similar to the first experimental group. In the Engage stage, students were asked an interesting question about the subject to attract their attention to the lesson and to increase their learning motivation. The questions asked in this section are the same as the questions in the STEM group. In the Explore phase, an example simulation was developed and necessary explanations were made to show the students the use of the Algodoo program through an example and to increase their desire to use the Algodoo. In the Explain phase, subject explanations were managed. Simulations were used in three different ways, summarized below, during the lecturing. First, a theoretical explanation was given on the subject, then a volunteer was selected from the students, and they were asked to design a simple case study on the subject of simulation, guided by the results reached by other students by brainstorming. In this way, the scope of the subject was learned by discovering its equivalency in daily life and the students were also enabled to go through creative thinking processes.

At the other method, initially, a sample problem from the source book was solved with the class after the lesson. Then, a simulation of this problem case was developed and the simulation was started through which the problem was analysed by the students. The information learned was reinforced by testing the accuracy of the result obtained through theoretical calculationIn another approach, lectures were delivered directly using the Algodoo program. In Algodoo, firstly, the situation related to the subject was shown and questions were asked to make the students wonder and think about the subject. Then, the lesson was conducted with theoretical explanations on the situation, and the simulation was taken back and analyzed again with theoretical calculations. For example, the simulation was started until the object under the influence of a force made a certain displacement and stopped after a certain period. The steps to be followed and the equations to be used to determine the speed of the object at the point it reaches are explained. Then, by opening the vector representation of the velocity, it is shown that the calculated value is consistent with the value in the simulation.

Although the activities designed considering the achievements and what can be done with Algodoo correspond to most of the targeted achievements regarding mechanics, they cannot meet all the achievements. These achievements that cannot be met are explained with the traditional method. After these, a summary of the subject was made at the 'Elaborate' stage. Lastly, during the 'Evaluate' process, problem solutions related to the subject were carried out.

Data Analysis

In the study, with 28 pre-service teachers in the Arduino group and 33 pre-service teachers in the Algodoo group, subject lectures related to the Mechanics unit were carried out using Arduino and Algodoo for 4 weeks and data collection tools were applied to the experimental groups both before and after the application. Table 1 below shows the experimental design of the study.

Table 1 Experimental Design of the Study

Group	Pre-application	Experimental procedures	Post-application
Arduino (n=28)	MAS	Arduino supported physics education (4 weeks)	MAS
Algodoo (n=33)	MAS	Algodoo supported physics education (4 weeks)	MAS

During the study, the MAS was applied to the experimental groups as pre-test and post-test before and after the study. SPSS 23 statistics program was used to analyze the data obtained. During statistical analyses, the pre-test post-test scores of the same groups, the pre-test scores between two groups and the post-test scores between two groups were compared and it was checked whether the difference was statistically significant. Considering the characteristics of the research questions, normal distribution analysis was first performed on all test results, and parametric tests (dependent sample t-test for comparisons of same groups and independent sample t-test for comparisons between two groups) were used to compare normally distributed scores, while non-parametric tests (Wilcoxon signed rank test for comparisons of same group and Mann-Whitney U test for comparisons between two groups) were used to compare scores that did not show normal distribution.

Results and Discussions

In this section, the results obtained after the comparison of the pre-test and post-test scores obtained from MAS both within and between groups and the discussion based on these results are presented.

Before comparing the scores, normal distribution analysis was performed on the findings obtained in both pre and post-tests and it was concluded that the scores were normally distributed. Based on this result, the dependent sample t test and independent sample t test, which are parametric tests, were employed for comparisons. The results obtained and the discussion about them are given below.

Results

Change in Achievement for the Arduino Group

In this section, findings acquired as a result of the comparison of the scores obtained from the MAS applied to the study groups as pre-test and post-test in order to analyse the effects of Arduino-based teaching on the achievement are presented. Since the scores obtained from the both tests showed normal distribution, these scores were compared using the parametric test. The dependent sample t test and the results are presented in Table 2.

Table 2 Results of the Dependent Sample t-test Analysis Comparing the MAS Pre-test and Post-test Scores of the Arduino Group Students.

Test	N	$\bar{X}$	sd	t	p	Cohen's d
MAS pre	28	18.61	7.95	-11.24	0.00*	2.33
MAS post	28	46.82	15.47			

maximum score: 100

When table 2 is examined, it is seen that the difference between the two mean scores is statistically significant ($p<0.05$) in favour of the post-test. This result shows that the teaching using Arduino has an increasing effect on the achievement. It is also seen that the mean scores of the pre-service teachers in the Arduino group increased more than two times (% 28.21) after the instructions and the Cohen's d coefficient was 2.33. It can be said that the educational practices based on the experimental activities using Arduino had a significant effect on the achievement.

MAS consists of 4 separate sections including questions on vectors, kinematics, dynamics and work-energy. Each section has an equal score of 25. Throughout the statistical analyses, the changes occurring in these 4 sections were examined in detail. Since the scores of the pre-service teachers in the Arduino group on vectors, kinematics and work-energy were not normally distributed, the analyses were performed with Wilcoxon signed-rank test and the results are presented in Table 3. On the other hand, since the scores obtained from the dynamics subject showed normal distribution, the analyses were performed with the dependent sample t test and the findings are presented in the Table 4.

Table 3 Wilcoxon Signed-rank Test Analysis Results Comparing the Pre-test and Post-test Scores of Arduino Group Students in MAS Vectors, Kinematics and Work-energy Subjects

Subject	Post-test-Pre-test	N	Mean rank	Sum of rank	Z	p	Cohen's d
Vectors	Negative ranks	0	0	0	-4.623	0.00*	1.69
	Positive ranks	28	14.50	406.00			
	Ties	0					
Kinematics	Negative ranks	2	4.25	8.50	-4.34	0.00*	1.50
	Positive Rranks	25	14.78	369.50			
	Ties	1					
Work-energy	Negative ranks	2	2.50	5	-4.51	0.00*	2.03
	Positive ranks	26	15.42	401.00			
	Ties	0					

** difference is significant (p<.05), maximum score:25*

Table 4 Dependent Sample T-test Analysis Results Comparing MAS Dynamic Pre-test and Post-test Scores of Arduino Group Students

Test	N	$\bar{X}$	ss	sd	t	p	Cohen's d
MAS dynamics pre	28	2.61	1.72	27	-6.31	0.00*	1.56
MAS dynamics post	28	9.92	6.54				

**difference is significant (p<.05), maximum score:25*

When the Tables 3 and 4 are examined, it is revealed that the teaching via Arduino increased the achievement level of each subject at a statistically significant level. When the effect level of the teaching is examined, it is seen that the Cohen's d effect coefficient ranking is in the order of work-energy, vectors, dynamics and kinematics.

Before addressing this difference, it would be useful to mention the effects of cognitive load on learning during training. Many studies on cognitive load and learning reveal that an increase in extraneous cognitive load, which is not related to the main topic, has a detrimental effect on learning, whereas an increase in germane cognitive load, which is related to the subject content, has an enhancing effect on learning (Sweller et al., 2019).While analysing the difference between subtopics, evaluations will be made relating these two cases.

When the Arduino application in the work-energy topic, which is the highest, is analysed, it is seen that the distance sensor used in the previous lessons and similar data analysis processes carried out in the previous lessons were covered. Since the students who are more familiar with these electronic devices and the data analysis process have already learnt the force sensor and distance sensor, they have not gone through an extra cognitive process to understand the features of these devices such as connection and coding, and therefore, by reducing the extraneous cognitive load and increasing the germane cognitive, it may lead to a higher level of understanding of the subject in the course content. In the teaching of the vectors subject, where Arduino applications were the second most effective subject, a very simple material was preferred as an introduction to Arduino programming and a very basic level activity was carried out. Therefore, it can be easily said that the extraneous cognitive load in this process is less compared to kinematics and dynamics topics. The reason why the effect in the dynamics unit was higher than the effect in the kinematics unit may be that the materials of the kinematics topic contain more complex electronic connections and data analyses compared to the vectors unit. The students encountered these processes for the first time during the teaching of the kinematics unit, and the data analyses performed similarly in the dynamics unit may have caused less extraneous cognitive load than in the kinematics unit.

Change in Achievement for the Algodoo Group

In this section, the results of the dependent sample t-test obtained by comparing the MAS pre-test and post-test scores in order to analyse the effects of Algodoo-based training on the achievement levels in mechanics are presented. The results are shown in Table 5.

Table 5 Results of the Dependent Sample T-test Analysis Comparing the MAS Pre-test and Post-test Scores of Algodoo Group Students.

T-Test	N	$\bar{X}$	sd	t	p	Cohen's d
MAS pre	33	18.88	6.04	-13.88	0.00*	3.02
MAS post	33	47.71	12.31			

maximum score: 100

When Table 5 is examined, it is understood that the difference between MAS pre-test and post-test mean scores is statistically significant (%28.83) and in favour of the post-test (p<0,05). Cohen's d coefficient also shows that there is a highly significant difference between the scores of the group before and after the application. Such a high effect can be clearly seen when the difference between the post-test mean scores and the pre-test mean scores is taken into consideration. This result shows that the teaching activities using Algodoo have a significant effect on academic success.

Similar to the analyses performed for Arduino applications in the previous section, statistical analyses were performed to test the effectiveness of Algodoo applications in vectors, kinematics, dynamics and work-energy topics. The scores of vectors, dynamics and is-energy topics, which do not show a normal distribution, were tested using the Wilcoxon signed-rank test and are presented in Table 6. Since the scores obtained from the kinematics section were normally distributed, they were analysed by using the dependent sample t-test and the findings are given in Table 7.

Table 6 Wilcoxon Signed-rank Test Analysis Results Comparing the Pre-test and Post-test Scores of the Algodoo Group Students in MAS Vectors, Dynamics and Work-Energy Subjects

Subject	Post-test-Pre-test	N	Mean rank	Sum of rank	Z	P	Cohen's d
Vectors	Negative ranks	0	0	0	-5.01	0.00*	1.96
	Positive ranks	33	17.00	561.00			
	Ties	0	-	-			
Dynamics	Negative ranks	1	9.00	9.00	-4.85	0.00*	1.86
	Positive ranks	32	17.25	552.00			
	Ties	0	-	-			
Work-energy	Negative ranks	2	3.75	7.50	-4.88	0.00*	1.67
	Positive ranks	31	17.85	553.50			
	Ties	0	-	-			

**difference is significant (p<.05), maximum score:25*

Table 7 Dependent Sample T-test Analysis Results Comparing MAS Dynamic Pre-test and Post-test Scores of Arduino Group Students

Test	N	$\bar{X}$	ss	sd	t	p	Cohen's d
MAS kinematics pre	33	5.98	2.10	32	-8.95	0.00*	2.16
MAS kinematics post	33	12.86	4.07				

**difference is significant (p<.05), maximum score:25*

When Tables 6 and 7 are analysed, it is perceived that the achievement in each subject has increased statistically significantly. Among the effects causing these increases, the order from the highest Cohen's d effect level to the lowest is kinematics, vectors, dynamics and work-energy.

In the teaching process of work-energy, relatively higher-level graphical analyses such as force-position, kinetic energy-time, potential energy-time and total energy-time graphs have been carried out and simulations with more complex content have been used. The results show that although such complex applications have the effect of increasing the success, they fall behind other, somewhat simpler level lecture contents in terms of Cohen's d effect coefficient. The main reason for this may be the high level of extraneous cognitive load similar to the situation discussed in Arduino applications. In kinematics, visualisation of motion graphs and detailed examination of the graphs simultaneously with the motion were carried out thanks to Algodoo. Compared to the energy topic, it contains fewer types of graphs and also the graphs in these applications are the graphs that are mostly taught at high school level. Such convenience and prior knowledge seem to have an effect on the effectiveness of the Algodoo programme. The simulations used in the subject of vectors are simulations that are very simple and complex at the lowest level, and it is seen that such simulations also have a high effect. It is thought that the reason why the applications on dynamics are ranked 3rd in the ranking is that they contain relatively more complex simulation contents compared to the others.

Comparison of the Achievement Levels of the Groups

In this section, the MAS scores of the Arduino group and Algodoo group before and after the application were compared. Since all of the MAS scores of the groups showed normal distribution, an independent sample t test was used in the comparisons between the groups. The results obtained are as shown in Table 8.

Table 8 Independent Sample T-test Analysis Results Comparing the MAS Pre-test Scores of Arduino Group and Algodoo Group Students

Test	Group	N	$\bar{X}$	sd	t	p
MAS pre	Arduino	28	18.61	7.95	-0.146	0.88
	Algodoo	33	18.88	6.04		
MAS post	Arduino	28	46.82	15.48	-0.25	0.80
	Algodoo	33	47.71	12.31		

maximum score: 100

It is clearly detected from table 8 that there was no statistically significant difference ($p>0.05$) between the MAS scores of Arduino group and Algodoo group both before and after the application. In both groups, both pre-test and post-test scores were quite close to each other and it was seen in the previous sections that both methods had similar effects on achievement. It is, based on the resolutions, concluded that there is no significant difference between the two groups in terms of mechanics achievement both before and after the application. Additionally, comparisons of each sub-score were made for both pre-test and post-test, but no statistically significant difference was found for any of the sub-scores, and the tables of these findings are not included in the article to avoid too much data overload.

These results are not surprising based on the outcomes of the previous sections which showed that both methods have an effect on increasing success. Although there is no statistically significant difference between the two methods, there is a difference in terms of Cohens' d coefficients and this difference is in favour of the Algodoo group. In the previous sections, it is understood that the effect coefficient of Arduino applications is 2.33 and Algodoo applications is 3.02. Although this difference is not a very big difference, it shows that the applications using Algodoo have a higher effect on the success of the mechanics subject compared to those using Arduino. In terms of sub-subjects, Algodoo supported training has a higher effect on vectors, kinematics and dynamics, while Arduino has a higher effect on only work-energy. In general, it is seen that the effect of Algodoo supported training is higher both in terms of the effect on total scores and in 3 out of 4 subjects. Among the reasons why Algodoo applications have a higher impact level in general may be that the applications carried out with Algodoo programme contain much less detail than the applications using Arduino and the cognitive load is less. While there are extra processes such as the working principle of the sensors, electrical connections, data collection and data analysis in the lessons carried out with Arduino, in the applications carried out with Algodoo, only the tools in the programme were used in the process of designing the relevant simulation. In addition, the people in the classes in which the lessons were conducted were people who received distance education for 2 years between the years of 2020-2022, and this may have created a higher learning disposition towards virtual learning environments.

Conclusions and Suggestions

Under the illuminations of the results presented, it can generally be concluded that Arduino-based and Algodoo-based teaching efforts have both positive effects on achievement. The importance of adapting experimental and up-to-date activities to courses such as physics is obvious. Therefore, it is essential to maintain this need via experimental activities using microcontrollers such as Arduino, which would motivate the students by increasing the sense of curiosity compared to the usual ordinary content. Teaching sequences including very important skills such as technological literacy, coding, programming, and data analysis can be very inclusive and beneficial for the students in addition to very high achievements. Such experimental activities, which have serious advantages in terms of cost, have the potential to replace very high-cost experimental equipment and serve equal opportunities in education. There are many studies on the development of experimental activities using Arduino in physics education (Çoban & Erol, 2020; Erol & Oğur, 2023; Sarı & Kırındı, 2019). However, the number of empirical studies investigating the effects of these materials on students is relatively less. Therefore, the conclusion reached in this study that experimental applications using Arduino increases student achievement, is important.

The result that the courses using Arduino increase the success is in harmony with the results obtained in similar studies. Yıldırım (2020), concluded in his study that Arduino robotic coding-based STEM training increased the academic achievement of pre-service science teachers. Karim et al. (2015), stated that the use of robotic coding-based STEM training in science and mathematics courses has many positive effects on students, including success. Sarı et al. (2022), observed an increase in the problem-solving skills and entrepreneurship of pre-service teachers in their study in which they discovered that the integration of experimental activities using Arduino into STEM education has positive results. Ramadhan et al. (2023), concluded in their study that physics experiment-based learning blended with LabVIEW and Arduino was better than traditional teaching in improving students' critical thinking skills and academic achievement. Similar to these studies, in this study, it was underlined that teaching activities involving experimental applications using Arduino microcontroller have increased the achievement of pre-service science teachers in Physics 1 course. In addition to this result, it was observed that the pre-service teachers' motivation towards learning was high throughout the applications, and they had an attitude of learning by having fun in the lessons.

When the effects of the experimental activities using Arduino on mechanics subjects are analysed in detail, it is revealed that the simplicity of the activity and the awareness of the experimental processes in the activity increase the effects of the activities on success. The highest level of effect was observed in the work-energy unit, which was the last unit of the applications, and this situation shows that the increase in the awareness of the pre-service teachers towards extra processes such as programming and electronic connection increased the effect on success. Because these experimental processes carried out in this unit are almost the same as the ones carried out in the previous 3 units and therefore it is obvious that the study group's knowledge level towards these processes has improved. Another important factor, the simplicity of the activity, also comes to mind in view of the high impact result obtained in the vector topic. In the vectors unit, applications involving basic level data analyses were carried out with a single sensor and a very short code. These results are in parallel with the results obtained in previous studies that low cognitive load has positive effects on learning (Sweller et al., 2019). Therefore, in training supported by experimental activities using Arduino, it is important to equip the study group with basic electronics and software knowledge skills before the activities or to use activities at a basic level with simple content in order to have a higher impact on success. It will be useful to pay attention to these two factors in similar studies to be carried out in the future.

Algodoo physics simulation programme, which was used in the lessons carried out with the other experimental group, meets the need for experimental activities in physics education and at the same time directly serves the equality of opportunity in education, both because it is completely developed by considering the laws of physics and because it is completely free to download and use. In addition, the fact that it has an interface that can be easily used on smart boards and personal computers makes Algodoo programme very important in terms of physics courses, especially regarding the distance education, as well as ease of use in the classroom. In this study, it has been established that Algodoo-enhanced education increases the success in mechanics and this result is similar to the results obtained in previous studies in this direction in the literature. Çelik et al. (2015), found that the lessons carried out with high school 10th grade students using Algodoo increased academic achievement in physics courses and students presented original solutions to problems. Hırça and Bayrak (2013), in their study conducted with gifted students, mentioned that thanks to the features of Algodoo, it is motivating that users can create customised designs, make fun drawings based on physics and provide an interactive learning environment. Özer and Bilici (2021), revealed that the use of Algodoo-based activities in the force and motion subject of 6th grade students had an effect on increasing students' engineering skills and conceptual understanding.

When the effect differences observed for the units were analysed, it was observed that the effect coefficient decreased as the complexity level of the tools included in Algodoo simulations increased, while the effect coefficient increased when simple simulations were used. In addition to this, it was also observed that the effect on achievement was increased when the simulations had content related to the basic knowledge and skills that the students already had. Both results are in line with previous studies showing that an increase in extraneous cognitive load has a negative effect on learning, while an increase in germane cognitive load has a positive effect on learning (Sweller et al., 2019). The large number of different contents of the simulations increases the extraneous cognitive load and this may be the main reason for the lower success effect in units such as dynamics and work-energy. In vectors, where the content is very simple, the effect level can be considered high, and here too the effect of low extraneous cognitive load is likely to be a factor. When the teaching practices carried out during the kinematics unit, in which the greatest effect was observed, are analyzed, it is seen that the content is very similar to the information at the high school level and from this point of view, it can be said that it increases the germane cognitive load. Therefore, it is important that the Algodoo applications have simple content and that they are connected with the students' prior learning in order to carry out more effective teaching processes on success.

Although there is no direct comparison of the two methods in the literature, there are studies showing that the two methods are superior to the traditional methods in previous studies. From this point of view, it can be assumed that the two methods show similar effects and that there is no difference between them in terms of success, which is consistent with the results in the literature. This result is important in terms of being a result comparing the two methods. In addition to these results, determining whether the fact that students were away from physical experiments in the distance education they received during the pandemic and that simulations were frequently used during distance education had any effect on their learning in their educational life after the pandemic is another situation examined in this study conducted with face-to-face education after the pandemic. It is important that the two different methods, whose superiorities over the traditional teaching method have been revealed in the studies, are basically separated from each other in terms of teaching lessons with experimental applications in the virtual environment and physical environment, and in this way, it is important to compare the two methods among themselves. This result is in line with other results showing that there is no difference between the learning status of students before the pandemic (Burkholder & Wieman, 2022; Nemeth et al., 2023; Zohbi et al., 2023).

When the effect coefficients are compared, it is seen that the effect level of the teaching activities using Algodoo is higher than those using Arduino. Algodoo applications have a higher effect level both in total scores and in sub-scores except for the energy unit. One of the two possible reasons for this situation is thought to be that Arduino applications involve more complex experimental processes and therefore more extraneous cognitive load. The other reason can be considered as the fact that the study group, which has been involved in distance learning for 2 years, has a higher ability to learn in a digital environment. In addition to these, the fact that the change in the scores of the study group in the Arduino group in the energy unit was higher than the Algodoo group shows that although the teaching using Algodoo was found to be more effective, Arduino experimental applications carried out in study groups equipped with the necessary prior knowledge have the potential to be more effective than Algodoo simulations.

As a result, in the study, it was seen that two different teaching practices, which were carried out by using experimental activities in physics education and had significant advantages in terms of cost, time and gaining different skills, were effective in increasing the achievement of pre-service science teachers in mechanics. Additionally, it was determined that there was no difference between the two methods in terms of the effect on achievement and therefore, virtual experiments and physical experiments did not have different effects on pre-service teachers in the subject of mechanics. Innovative experimental processes carried out in teaching practices are critical in terms of training teachers with 21st century skills, ensuring equality of opportunity in education and eliminating the lack of activities encountered in physics education in possible distance education. Therefore, this study showing that these methods have an effect on increasing success is important. It was also observed that the simplicity of the applications and the fact that the study group had the necessary prior learning were factors that increased the effect on success, and this result is also important for future studies.

Compliance with Ethical Standards

Disclosure of potential conflicts of interest

The author declares that there are no conflicts of interest, financial or otherwise, directly or indirectly related to the work submitted for publication.

Funding

This research received no funding.

CRediT author statement

Atakan Çoban: conceived and designed the study, collected and analysed the data, and wrote the original draft of the manuscript.

Mustafa Erol: 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.

Research involving Human Participants and/or Animals

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

Arduino ve Algodoo Tabanlı Mekanik Öğretiminin Başarı Üzerindeki Etkileri

Özet:

Bu çalışma, Arduino ve Algodoo tabanlı mekanik öğretim etkinliklerinin akademik başarı üzerindeki etki düzeylerini araştırmaya odaklanmaktadır. Araştırma, bir devlet üniversitesinde öğrenim gören toplam 61 fen bilgisi öğretmen adayından oluşan iki deney grubuyla ön test-son test yarı deneysel yönteme dayalı olarak gerçekleştirilmiştir. Özellikle, vektörler, kinematik, dinamik ve iş-enerji üniteleri üzerine öğretim hedeflerine uygun olarak Arduino tabanlı ve Algodoo tabanlı eğitim materyalleri titizlikle geliştirilmiştir. Öğretim materyallerinin başarı üzerindeki etkileri Mekanik Başarı Ölçeği ile ölçülmüştür. Bulgular, Arduino tabanlı eğitimin başarıyı %28.21 oranında ve Algodoo tabanlı öğretimin başarıyı %28.83 oranında önemli ölçüde artırdığını göstermektedir. Ayrıca, etkinliklerin basitliği ve grupların deneysel süreçlerle ilgili ön bilgileri, uygulamaların etkililiğini artıran faktörler olarak ortaya çıkmıştır.

Anahtar kelimeler: Fizik eğitimi, Arduino, STEM, Algodoo, mekanik öğretimi, akademik başarı.

References

Bao, L., & Koenig, K. (2019). Physics education research for 21st century learning. *Disciplinary and Interdisciplinary Science Education Research, 1*(1), 2. https://doi.org/10.1186/s43031-019-0007-8

Bollen, L., van Kampen, P., Baily, C., Kelly, M., & De Cock, M. (2017). Student difficulties regarding symbolic and graphical representations of vector fields. *Physical Review Physics Education Research, 13*, Article 020109. https://doi.org/10.1103/PhysRevPhysEducRes.13.020109

Brown, S., & Smith, B. (2013). *Resource based learning*. Routledge.

Burkholder, E. W., & Wieman, C. E. (2022). Absence of a COVID-induced academic drop in high-school physics learning. *Physical Review Physics Education Research*, *18*, 023102. https://doi.org/10.1103/PhysRevPhysEducRes.18.023102

Büyükdede, M., & Tanel, R. (2019). Effect of the STEM activities related to work-energy topics on academic achievement and prospective teachers' opinions on STEM activities. *Journal of Baltic Science Education, 18*(4), 507-518. https://doi.org/10.33225/jbse/19.18.507

Cayvaz, A., & Akcay, H. (2018). The effects of using Algodoo in science teaching at middle school. *The Eurasia Proceedings of Educational and Social Sciences*, *9*, 151-156. https://dergipark.org.tr/en/pub/epess/issue/38900/457934

Çelik, H., Sarı, U., & Harwanto, U. N. (2015). Developing and evaluating physics teaching material with Algodoo (Phun) in virtual environment: Archimedes' Principle. *The Eurasia Proceedings of Educational and Social Sciences, 1*, 178-183. https://dergipark.org.tr/en/pub/epess/issue/30314/333374

Çoban, A. (2021). Algodoo for online education: impulse and momentum activities. *Physics Education*, *56*(2), 025017. https://doi.org/10.1088/1361-6552/abd1e9

Çoban, A., & Boyacı, S. (2020). The calculation of kinetic and static friction coefficient and friction graph analysis using Arduino. *Physics Education, 56*(1), Article 013003. https://doi.org/10.1088/1361-6552/abc07c

Çoban, A., & Çoban, N. (2020). Determining of the spring constant using Arduino. *Physics Education*, *55*(6), Article 065028. https://doi.org/10.1088/1361-6552/abb58b

Çoban, A., & Erol, M. (2020). Validation of Newton's second law using Arduino: STEM teaching material. *Physics Education, 56*(1), Article 013004. https://doi.org/10.1088/1361-6552/abc639

Çoban, A., & Erol, M. (2021a). Teaching kinematics via Arduino based STEM education material. *Physics Education, 57*(1), Article 015010. https://doi.org/10.1088/1361-6552/ac342d

Çoban, A., & Erol, M. (2021b). Arduino-based STEM education material: Work-energy theorem. *Physics Education, 56*(2), Article 023008. https://doi.org/10.1088/1361-6552/abd991

Çoban, A., & Erol, M. (2021c). Teaching impulse-momentum law by Arduino based STEM education material. *The Physics Educator*, *3*(2), Article 2150006. https://doi.org/10.1142/S2661339521500062

Çoban, A., & Erol, M. (2022). STEM education of kinematics and dynamics using Arduino. *The Physics Teacher*, 60, 289-291. https://doi.org/10.1119/10.0009994

Çoban, A., Çoban, N., & Çoban, E. (2023). Energy conservation analysis using Arduino. *The Physics Teacher*, 61, 295-297. https://doi.org/10.1119/5.0067534

Daud, N. S. N., Karim, M. M. A., Hassan, S. W. N. W., & Rahman, N. A. (2015). Misconception and difficulties in introductory physics among high school and university students: An overview in mechanics. *Educatum Journal of Science, Mathematics and Technology, 2*(1), 34-47. https://ejournal.upsi.edu.my/index.php/EJSMT/article/view/26/19

de Lima, Í. M., de Souza, E. V., & de Araújo, F. D. (2020). *The use of Arduino as a methodological tool for teaching physics in high school*. arXiv. https://doi.org/10.48550/arXiv.2003.10594

Docktor, J. L., & Mestre, J. P. (2014). Synthesis of discipline-based education research in physics. *Physical Review Special Topics Physics Education Research*, 10, Article 020119. https://doi.org/10.1103/PhysRevSTPER.10.020119

Erol, M., & Oğur, M. (2023). Teaching large angle pendulum via Arduino based STEM education material. *Physics Education, 58*(4), Article 045001. https://doi.org/10.1088/1361-6552/accef4

Flores, S., Kanim, S. E., & Kautz, C. H. (2004). Student use of vectors in introductory mechanics. *American Journal of Physics*, 72, 460-468. https://doi.org/10.1119/1.1648686

Goncalves, A. M. B., Freitas, W. P. S., & Calheiro, L. B. (2023). Resources on physics education using Arduino. *Physics Education*, *58*(3), Article 033002. https://doi.org/10.1088/1361-6552/acb8a2

Gregorcic, B. (2015). Exploring Kepler's laws using an interactive whiteboard and Algodoo. *Physics Education, 50*(5), 511-515. https://doi.org/10.1088/0031-9120/50/5/511

Gregorcic, B., & Bodin, M. (2017). Algodoo: A tool for encouraging creativity in physics teaching and learning. *The Physics Teacher*, 55, 25-28. https://doi.org/10.1119/1.4972493

Gutierres-Berraondo, J., Guisasola, J., & Zuza, K. (2019, August). Addressing undergraduate students' difficulty in learning the generalized work-energy principle in introductory mechanics. *Journal of Physics: Conference Series, 1287*, Article 012024. https://doi.org/10.1088/1742-6596/1287/1/012024

Hennessy, S., Twigger, D., Driver, R., O'shea, T., O'Malley, C. E., Byard, M., Draper, S., Hartley, R., Mohamed, R., & Scanlon, E. (1995). A classroom intervention using a computer-augmented curriculum for mechanics. *International Journal of Science Education*, *17*(2), 189-206. https://doi.org/10.1080/0950069950170204

Hırça, N., & Bayrak, N. (2013). Sanal fizik laboratuarı ile üstün yeteneklilerin eğitimi: Kaldırma kuvveti konusu. *Journal for the Education of Gifted Young Scientists*, *1*(1), 16-20. https://dergipark.org.tr/en/pub/jegys/issue/37126/427767

Hill, J. R., Hannafin, M. J., & Domizi, D. P. (2005). Resource-based learning and informal learning environments: Prospects and challenges. In L. Tan Wee Hin & R. Subramaniam (Eds.), *E-Learning and Virtual Science Centers* (pp. 110-126). https://doi.org/10.4018/978-1-59140-591-7.ch006

Hopf, M., Wilhelm, T., Tobias, V., Waltner, C., & Wiesner, H. (2011). Promoting students' understanding of Newtonian mechanics through an alternative content structure–Results from an empirical study. *ESERA Conference Lyon*, 1-5. https://www.thomas-wilhelm.net/veroeffentlichung/Esera_Lyon.pdf

Karim, M. E., Lemaignan, S., & Mondada, F. (2015). A review: Can robots reshape K-12 STEM education? *2015 IEEE International Workshop on Advanced Robotics and its Social Impacts (ARSO)*, 1-8. https://doi.org/10.1109/ARSO.2015.7428217

Kesonen, M. H., Leinonen, R., & Asikainen, M. A. (2019). Applying a simple model aiding in understanding the acceleration of a bungee jumper. *Physics Education*, *54*(4), Article 045012. https://doi.org/10.1088/1361-6552/ab1ae8

Klein, P., Müller, A., & Kuhn, J. (2017). Assessment of representational competence in kinematics. *Physical Review Physics Education Research*, 13, Article 010132. https://doi.org/10.1103/PhysRevPhysEducRes.13.010132

Kononets, N., Ilchenko, O., & Mokliak, V. (2020). Future teachers resource-based learning system: experience of higher education institutions in Poltava city, Ukraine. *Turkish Online Journal of Distance Education*, *21*(3), 199-220. https://doi.org/10.17718/tojde.762054

Lichtenberger, A., Wagner, C., Hofer, S. I., Stern, E., & Vaterlaus, A. (2017). Validation and structural analysis of the kinematics concept test. *Physical Review Physics Education Research*, 13, Article 010115. https://doi.org/10.1103/PhysRevPhysEducRes.13.010115

Liu, G., & Fang, N. (2016). Student misconceptions about force and acceleration in physics and engineering mechanics education. *International Journal of Engineering Education*, *32*(1), 19-29. https://spada.uns.ac.id/pluginfile.php/232092/mod_resource/content/1/03_ijee3131ns_2016.pdf

McDermott, L. C., Rosenquist, M. L., & Van Zee, E. H. (1987). Student difficulties in connecting graphs and physics: Examples from kinematics. *American Journal of Physics, 55*(6), 503-513. https://doi.org/10.1119/1.15104

Molefe, P., & Khwanda, M. N. (2020). Activities to enhance students' understanding of acceleration: Part B. *Journal of Physics: Conference Series*, *1512*, Article 012018. https://doi.org/10.1088/1742-6596/1512/1/012018

Nguyen, D. H., & Rebello, N. S. (2011). Students' difficulties with multiple representations in introductory mechanics. *US-China Education Review*, *8*(5), 559-569. https://eric.ed.gov/?id=ED520690

Nemeth, A., Wheatley, C., & Stewart, J. (2023). Comparing introductory undergraduate physics learning and behavior before and after the COVID-19 pandemic. *Physical Review Physics Education Research*, 19, 013103. https://doi.org/10.1103/PhysRevPhysEducRes.19.013103

Özdemir, E., & Coramik, M. (2022). Development of a virtual teaching environment with Algodoo: 'eye' and 'cactus type light source' models. *Physics Education, 57*(4), 045022. https://doi.org/10.1088/1361-6552/ac60b0

Özer, İ., & Canbazoğlu Bilici, S. E. D. E. F. (2021). The effect of engineering design-based Algodoo activities on students' design skills and academic. *Hacettepe University Journal of Education*, *36*(2), 301-316. https://doi.org/10.16986/huje.2020062006

Papadopoulos, C., Rahman, A., & Bostwick, J. (2006). Assessing critical thinking in mechanics in engineering education. *2006 Annual Conference & Exposition,* 11-235. https://peer.asee.org/assessing-critical-thinking-in-mechanics-in-engineering-education.pdf

Pendrill, A. M., & Ouattara, L. (2017). Force, acceleration and velocity during trampoline jumps—a challenging assignment. *Physics Education*, *52*(6), Article 065021. https://doi.org/10.1088/1361-6552/aa89cb

Petry, C. A., Pacheco, F. S., Lohmann, D., Correa, G. A., & Moura, P. (2016). Project teaching beyond Physics: Integrating Arduino to the laboratory. *2016 Technologies Applied to Electronics Teaching,*1-6. https://doi.org/10.1109/TAEE.2016.7528376

Poluakan, C., & Runtuwene, J. (2018). Students' difficulties regarding vector representations in the free-body system. *Journal of Physics: Conference Series*, *1120*, Article 012062. https://doi.org/10.1088/1742-6596/1120/1/012062

Radnai, T., Juhász, T. T., Juhász, A., & Jenei, P. (2019). Educational experiments with motion simulation programs: Can gamification be effective in teaching mechanics?. *Journal of Physics: Conference Series*, *1223*, Article 012006. https://doi.org/10.1088/1742-6596/1223/1/012006

Radnai, T., Juhász, T. T., Juhász, A., & Jenei, P. (2023). A simulation experiment using Algodoo: What force makes a car accelerate, and what does the acceleration depend on? *The Physics Teacher, 61*(4), 271-275. https://doi.org/10.1119/5.0059836

Ramadhan, M. F., Mundilarto, M., Ariswan, A., Irwanto, I., Bahtiar, B., & Gummah, S. U. (2023). The effect of interface instrumentation experiments-supported blended learning on students' critical thinking skills and academic achievement. *International Journal of Interacive Mobile Technologies*, *17*(14), 101-125. https://doi.org/10.3991/ijim.v17i14.38611

Rivaldo, L., Taqwa, M. R. A., Zainuddin, A., & Faizah, R. (2020). Analysis of students' difficulties about work and energy. *Journal of Physics: Conference Series*, *1567*, Article 032088. https://doi.org/10.1088/1742-6596/1567/3/032088

Rosenblatt, R., & Heckler, A. F. (2011). Systematic study of student understanding of the relationships between the directions of force, velocity, and acceleration in one dimension. *Physical Review Special Topics Physics Education Research*, 7, Article 020112. https://doi.org/10.1103/PhysRevSTPER.7.020112

Rosenblatt, R., Sayre, E. C., & Heckler, A. F. (2009). Modeling students' conceptual understanding of force, velocity, and acceleration. *AIP Conference Proceedings, 1179*, 245-248. https://doi.org/10.1063/1.3266727

Rumahlatu, D., Sangur, K., Berhitu, M. M., Kainama, S. Y., Kakisina, V. V., & Latupeirissa, C. (2021). Resource based learning design thinking (RBLDT): A model to improve students' creative thinking skills, concept gaining, and digital literacy. *Cypriot Journal of Educational Sciences*, *16*(1), 288-302. https://doi.org/10.18844/cjes.v16i1.5528

Sarı, U., & Kırındı, T. (2019). Using Arduino in physics teaching: Arduino-based physics experiment to study temperature dependence of electrical resistance. *Journal of Computer and Education Research, 7*(14), 698-710. https://doi.org/10.18009/jcer.579362

Sarı, U., Çelik, H., Pektaş, H. M., & Yalçın, S. (2022). Effects of STEM-focused Arduino practical activities on problem-solving and entrepreneurship skills. *Australasian Journal of Educational* Technology, *38*(3), 140-154. https://doi.org/10.14742/ajet.7293

Schecker, H. P. (1992). The paradigmatic change in mechanics: Implications of historical processes for physics education. *Science & Education*, *1*, 71-76. https://link.springer.com/article/10.1007/BF00430210

Schnider, D., & Hömöstrei, M. (2024). Classroom experimentation – Arduino projects to teach electromagnetism. *Journal of Physics: Conference Series, 2693*, Article 012015. https://doi.org/10.1088/1742-6596/2693/1/012015

Sontay, G., & Karamustafaoglu, O. (2023). Physics teachers' opinions on Algodoo training. *Journal of Science Learning*, *6*(1), 117-124. https://doi.org/10.17509/jsl.v6i1.49285

Stewart, M. (1998). Promoting resource-based learning in HE physics: Tales from the resource centre. *Physics Education*, *33*(6), 385. https://doi.org/10.1088/0031-9120/33/6/021

Sweller, J., van Merriënboer, J. J., & Paas, F. (2019). Cognitive architecture and instructional design: 20 years later. *Educational Psychology Review*, 31, 261-292. https://doi.org/10.1007/s10648-019-09465-5

Syuhendri, S. (2021). Effect of conceptual change texts on physics education students' conceptual understanding in kinematics. *Journal of Physics: Conference Series*, 1876, Article 012090. https://doi.org/10.1088/1742-6596/1876/1/012090

Tang, K. S., Tan, S. C., & Yeo, J. (2011). Students' multimodal construction of the work–energy concept. *International Journal of Science Education, 33*(13), 1775-1804. https://doi.org/10.1080/09500693.2010.508899

Turner, P. (1974). A resource based learning system for practical work in science. *Physics Education, 9*(4), 228-230. https://doi.org/10.1088/0031-9120/9/4/001

Van Heuvelen, A., & Zou, X. (2001). Multiple representations of work–energy processes. *American Journal of Physics, 69*(2), 184-194. https://doi.org/10.1119/1.1286662

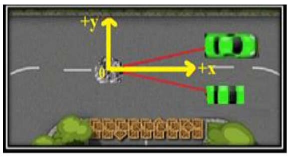
Xianfeng, Y. E., Xihua, L. I., & Hongjun, S. H. I. (2020). Experiment teaching practice of electronic circuit design based on Arduino platform. *Experiment Science and Technology, 18*(2), 68-72. https://doi.org/10.12179/1672-4550.20180475

Yıldırım, M. T. (2020). *The effects of STEM based Arduino robotic activities on the academic achievement and engineering design process in teaching of the nervous* *system*. (Publication No. 641677) [Master's thesis, Muğla Sıtkı Koçman University]. Council of Higher Education Thesis Center.

Zohbi, G., Pilotti, M. A., Barghout, K., Elmoussa, O., & Abdelsalam, H. (2023). Lesson learned from the pandemic for learning physics. *Journal of Computer Assisted Learning, 39*(2), 591-602. https://doi.org/10.1111/jcal.12768

Appendix 1. Vector unit part of Mechanic Achievement Scale

MECHANIC ACHIEVEMENT SCALE



While Ahmet is driving, he sees that there is a huge rock on the road and tries to pull the rock using the rope in his car. However, Ahmet's car alone is not enough to pull this big stone. Thereupon, another vehicle passing by comes to help Ahmet. Initially the two cars try to move the rock by positioning the two vehicles far away from each other consequently they cannot move the rock again. Then, Ahmet as a good physicist says that they need to bring the vehicles much closer to each other and finally they could pull the stone to a safe place.

Answer the following questions by considering the problem situation and information given.

***1.** Express the following statements as true or false. Explain why you have identified it as incorrect. (5 points)*

i. If the angles of the cars and ropes with respect to +x axis were identical, the tension forces on the ropes would be equal.

ii. As the angle between the vectors is increased, the magnitude of the resultant vector decreases.

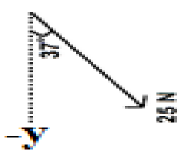
iii. Polar coordinates of the small car's position at the moment seen in the figure can be (+10, 30°).

iv. Cartesian coordinates of the big car shown in the figure can be (+10, +10).

v. If the coordinates of the position of the big car at the initial moment are (+10, +5), its position in unit vectors can be given as $\vec{r} = 5\vec{i} - 10\vec{j}$ in unit vectors.

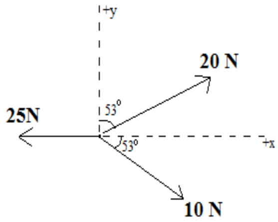
***2.** Consider that Cartesian coordinates of the stone's position are (0, 0) before the vehicles start pulling the rock. The Cartesian coordinates of the rock are (+9, +12) after pulling Calculate the polar coordinates of the final position of the stone and show it by drawing a figure. (5 points)*

***3.** Answer the following multiple choice questions. (2x2.5 points)*



i. Let the polar coordinates of the tension force on the rope attached to the small car be as shown in the figure. Accordingly, in which option are the Cartesian coordinates of the rope given correctly? (cos37=0.8; sin 37=0.6)

a) (20,15) b) (15,-20) c) (-15,-20) d) (-20, 15) e) (20, -15)



ii. If the forces acting on the stone as a result of the tensions and friction in the ropes were as in the figure, what would be the resultant force in Newton? (cos 53=0.6; sin 53=0.8)

a) 5 *b) 6* *c) 10* *d)* $6\sqrt{3}$ *e)* $10\sqrt{2}$

4. *As soon as the vehicles start to apply force on the ropes, the tension force on the rope connected to the small vehicle is 15 N and the polar coordinates of the location of the small vehicle* (R_s, 307^0 *). The tension force in the rope attached to the large vehicle is 20 N and the polar coordinates of the location of the large vehicle are* (R_b, 37^0*). Determine the magnitude and direction of the resultant force acting on the stone at that instant. (10 points)*