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Research Article

The Impact of Reconstructing Historical Scientific Experiments with Secondary School Students on Their Academic Success and Word Association Levels

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Abstract – This study aims to investigate the impact of faithfully reconstructing the experiments in the history of science on the academic success and word association levels of secondary school students. It uses the one-group pretest-posttest weak experimental design, which is one of the mixed experimental designs. It was carried out for six weeks with 13 students in seventh grade in the physics group for the Development of Special Talents in a Science and Art Center located in Istanbul in the 2021-2022 academic year. During the practice, three experiments were performed by the students. Academic Success Test and Word Association Test, formed by the investigators, were applied to the students as a pretest and a posttest. A significant difference was found between the students' pretest and posttest academic success scores, which was in favor of the posttests. It was seen that new relationships were established between the concepts after the practice.

Key words: Academic success, scientific experiments, history of science, word association test.

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Introduction

Science is an attempt to discover facts and the laws binding them through observation and observational reasoning (Russell, 1935). Such laws may be defined as hypotheses with a capacity to explain phenomena, and science, as a method, seeks to verify them (Yıldırım, 2018). Throughout history, scientists have built experiments using their imagination to develop and test hypotheses and revised or negated them in light of the results of such experiments (Kauffman, 1989). Experiments are central to producing new hypotheses and information, particularly in natural sciences (Ho-Ttecke, 2000). However, although experiments are part of the historical schemes, they have also been performed to suggest new studies, reinterpret past or existing research and eliminate any deficiencies. For these purposes, millions of experiments have been conducted since the systematic scientific studies by the Greeks around 400 BC (Harre, 2014). According to Unat (2021), the history of science is the analysis of scientific development periods, contributions of scientists and communities to science, and scientific thought by means of the method of the discipline of history. Considering how experiments are connected to the past, present, and future, scientific experiments in history have improved the understanding of the history of science, allowing us to understand and appreciate the conditions and processes in which scientists have lived (Chang, 2011; Lacin Simsek, 2009).

By nature of science, scientific information is built upon knowledge and is not immutable. Since all scientific ideas are based on experimental and observational verification, all scientific information may change, in principle, as new evidence comes up (National Research Council [NRC], 1996). One of the most favorable means to test ideas in this dynamic course of science is experiment. The history of science, on the other hand, may be regarded as the repository of meaningful experiments which can be reconstructed in classes (Bachtold, 2021). Up to date, scientific experiments and observations have helped eradicate many unclarities and contributed to a number of technological advancements. For instance, one of the foremost academic success of Galileo is that he proved the theorem of “average velocity” and differentiated it from “instantaneous velocity” (Drake, 1978). Studies by Galileo on free-falling and his law of free-fall, in particular, played a key role in the invention of the Atwood machine (Yavuz, 2008). Moreover, Joule (1850) found the mechanical equivalent of heat with his paddle wheel experiment. This experiment became the forerunner of the steam engines used today.

Studying friction force nearly 500 years ago, Leonardo Da Vinci suggested a linear relationship between normal force and friction force. He concluded that as the normal force was doubled, the friction force was also doubled and that the latter was independent of surface area (Pitenis et al., 2014). Today, the link between surface area and friction force is still a question of debate, and studies about such a connection are ongoing (Weber et al., 2018).

To the best of our present knowledge, we know that distilled water boils at 100 0C at sea level and that its temperature remains stable during the boil. We convey this piece of information to our students as a fact and expect them to remember it. However, former studies show that if distilled water reaches "superheat" at sea level, its boiling point can rise to higher temperatures. It indicates that modern science can overlook past information. Chang (2011) emphasized the need to relearn overlooked scientific knowledge through complementary experiments. He referred to his study of reconstructing historical experiments as "complementary experiments" to bring back lost information and generate ideas about controversial issues. Contributions of complementary experiments to science teaching can be defined in four items which are "enriching the fact-based resources of science teaching, helping students understand the nature of science, inviting students to think critically and outside the box, and evoking their curiosity about science".

The body of literature includes studies on the repetition of experiments conducted in the history of science (Becu-Robinault & Tiberghien, 1998; Ho-Ttecke, 2000; Cavicchi, 2008; Heering, 2009; Eggen et al., 2012; Kostur, 2017; Ioannis & Polatoglou; 2019; Guven et al., 2022). Among them is a case study by Ho-Ttecke (2000) in which the experiments of Faraday & Galvani were repeated in that using faithful reconstruction of past scientific experiments as a learning and teaching tool allows for intellectual and emotional experiences. This study proposed such reconstruction as a method for teaching the history of science. Furthermore, in a similar study with two students, Cavicchi (2008) suggested that this method offered a specific capacity to convey the science curriculum and made any experimental activity more thrilling and productive.

Ioannis & Polatoglou (2019) reconstructed the experiments of Galileo with secondary school students and proposed that they made sense of the nature of science and the evolution of scientific thought within the framework of the changeability of scientific knowledge. Heering (2009), on the other hand, examined the role and effects of this method in science teaching with the "Coulomb experiment". His study results showed that the use of historical experiments could enrich the nature of science and epistemological beliefs for science education. However, the same study also suggested that repeating experiments, which are critical for the initial development of a scientific concept, through the concept of "electrostatic" can contribute to the development of students' conceptual understanding. As a result of his study conducted by repeating the first physics experiments in history with high school students and receiving their opinions, Cetiner (2016) stated that he received positive views on science/physics teaching conducted as mentioned. Based on his study, this method makes it possible to give students insight into the nature of science and scientific knowledge and teach them the basic concepts. In their study correlating success at all grades with key scientific experiments in the history of science, Guven et al. (2022) drew attention to the importance of integrating the experiments from the history of science into science education, suggesting conducting experimental studies including such experiments in the classroom environment.

All these studies are based on replication of experiments from the history of science. In their study on the Voltaic Battery, Eggen et al. (2012) emphasized that the reorganization of these experiments creates a much more exciting teaching environment than usual. The body of literature includes experiments repeated with this method, such as the Voltaic battery (Eggen et al., 2012), Coulomb's torsion balance (Heering, 2009), Archimedes' crown of the king (Cetiner, 2016), Faraday's rotation engine (Ho-Ttecke, 2000) and Galileo's inclined plane, free fall and inertia experiments (Ioannis & Polatoglou, 2019). Da Vincin's friction experiment deserves to be repeated 500 years after its time. These studies revealed different results from those of Da Vinci regarding the independence of friction force from the surface area (Pitenis et al., 2014; Weber et al., 2018). It was believed that the discussion arising from the differences between the results of the original experiment and those obtained by today's reconstruction would be nurturing for students in terms of concepts and the nature of science. Ioannis & Polatoglou (2019) focused on the scientific method, the development of which Galileo contributed to, by re-applying Galileo's experiments with their students. The study inquiring about students' knowledge and opinions about this experiment shows that high school students have fallacies related to the concepts and information involved (Temiz & Kızılcık, 2016). In this context, it is critical to teach the concepts and information about the experiment. Since the 1900s, Joule's paddle wheel experiment has been used in the quantitative teaching of the energy concept at the secondary school level (Becu-Robinault & Tiberghien, 1998). The experiment setup was used for the high school students to learn the problems of measuring heat, and it was thought that the experiment should be included in the teaching process (Jindrova, 2018).

Some of these experiments in the literature can be applied at the secondary school level (Guven et al, 2022); however, there is a lack of conceptual knowledge about most of them (Harrison et al., 1999; Jindrova, 2018; Sukarmin et al., 2018; Tavukcuoglu, 2018). Cetiner (2016), Devons & Hartmann (1970) and Kostur (2017) reported the contribution of repeating experiments from the history of science to learning concepts, scientific facts, and subjects. The accessible body of literature offers no study on the effect of remaking such experiments on academic success.

There are studies showing that students misassociate certain concepts such as mass-weight and velocity-speed and that they have misconceptions about such pairs (Koray & Tatar, 2003; Balbag, 2018; Uyduran 2019).

Some studies suggest that the same applies to the heat-temperature concept pair and that this misconception exists at the high school or even university level (Harrison et al., 1999; Sukarmin et al., 2018; Aydogan & Gunes, 2003). In addition to the misconception, some studies also propose that words similar to each other are used interchangeably. Yurumezoglu et al. (2009) state that it is hard to understand energy-related concepts and that similar concepts can be replaced with the concept of energy. Complementary assessment tools can be used to determine this situation. For example, Tasdere et al. (2014) used Word Association Test (WAT), a complementary assessment and evaluation technique, to determine the cognitive structures of pre-service science teachers towards the nature of science in their study and according to the concept networks drawn, it was determined that the post-test concept network at the end of the course showed a more complex and interrelated structure than the pre-test concept network. Kostova & Radoynovska (2008) also used the word association test to reveal students' scientific conceptual structures regarding cells and biodiversity. In our study, through the word association test, the students' minds a wider knowledge domain and knowledge network was probed for the concepts.

Science and Arts Centers (BİLSEM) are institutions established by the Turkish Republic Ministry of National Education (Milli Egitim Bakanlığı [MEB]) to ensure that students with special talents from pre-schools, primary schools, secondary schools, and high schools become aware of their abilities and develop and use them to the maximum (MEB, 2020). According to Guney (2018), BİLSEM students are expected to transform their potential into performance in fundamental scientific fields by gaining skills in scientific thinking and studying. In this respect, there is a need for differentiated education programs. It is known that using inquiry-based and differentiated teaching in the activities prepared for BİLSEM students has positive effects and that the students are willing to perform different experiments (Ulger & Cepni, 2020). As such, it is believed that the experiments from the history of science should be conducted with BİLSEM students in terms of application and conceptual level.

The study focuses on experiments in the history of science, which include concepts described as misconceptions in the body of literature. In this study, misconceptions are expected between the concepts of "mass and weight" in the Friction Experiment; between the concepts of "speed and velocity", "instantaneous speed and average speed" in the Average Speed Experiment; between the concepts of "heat and temperature" in Joule's Pedal Wheel Experiment. It aims to review students' academic success and word association levels related to experiments that are repeated faithfully.

The research question was formed by considering the importance of reconstructing historical scientific experiments in science education, the scarcity of applications with different experiments in the literature, and the historical and conceptual importance of the selected experiments. As such, the research question is as follows: Does faithful reconstruction of the experiments in the history of science affect the academic success and word association levels of BİLSEM students?

Method

In this study, the Simultaneous Triangulation Design (Concurrent- Triangulation Design) of the Mixed Method (Creswell, 2009) was used. Mixed design is defined by Creswell (2009) as a research approach in which both quantitative and qualitative data are collected and integrated, and results are drawn from these integrated data to understand the research question. In this study one-group pretest-posttest weak experimental design and "word association test" were used simultaneously. The quantitative data of the study were obtained with the academic success test and the qualitative data were obtained with the word association test. Although quantitative data on certain concepts is obtained with existing surveys and scales, it can be said that a broader field of knowledge about the relevant concepts is examined in the minds of students through the word association test. Because students are expected to present the concepts presented through WAT in the numbers they want, without limiting the words and phrases that they evoke in their minds. In addition, WAT provides the opportunity to obtain qualitative data because it reveals the concepts, words, and the relationships between words and conceptual organization put forward by students through concept networks (Tasdere et al., 2014). In this context, a one-group pretest-posttest weak experimental model was used in the study (Buyukozturk et al., 2018). The students participating in the application were determined by convenience sampling method. In the convenience sampling method, data are collected from a sample that the researcher can easily reach, and this accessible sample minimizes the loss of money, time and labor (Buyukozturk et al., 2018).

Conduct of the Study

This study was carried out with 13 students in the seventh grade in the Physics group for the Development of Special Talents (ÖYG) in a Science and Art Center in Istanbul in the 2021-2022 academic year. The practice period lasted for five weeks. Among the noteworthy experiments that scientists performed in the past, three were selected relating to the concepts in science lessons suitable for the students' age group. They are the Friction Experiment, Average Velocity Experiment, and Joule's Paddle Wheel Experiment (Hutchings, 2016; Ford, 2003; Bachtold, 2021). For each experiment, an experiment sheet was prepared by the investigators. Students were given presentations about how the scientists conducted their experiments under particular conditions then, and experiment setups were formed remaining faithful to the original version.

The Academic Success Test, which was prepared by the investigators and consists of skill-based questions, was applied to the students as a pretest and posttest to see how the acquisition of certain concepts worked for them. The relevant science concepts emphasized in the experiments were identified, and the Word Association Test (WAT) including such concepts was presented to the students before and after the application to analyze any word association levels. One of the experiments used in the study is described below as an example.

Conduct of the Friction Experiment

Students were informed about Leonardo da Vinci's life, his work, the historical background of the friction experiment, and why he was interested in friction force and they were shown his drawings (Figure 1).

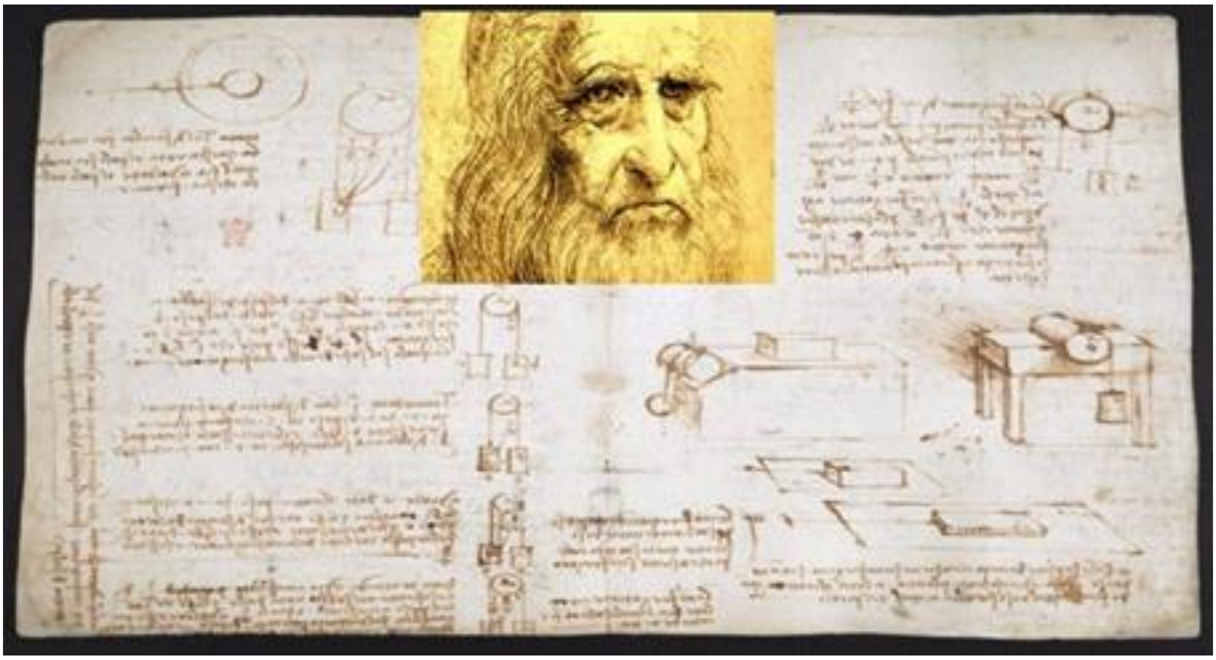

Figure 1 Drawings and portrait of Leonardo da Vinci (Hutchings, 2016)

Students were divided into groups of 3-4 people, given experiment sheets to follow during the experiment, and asked to perform the friction experiment in identical setups designed in line with the original experiment. Students were divided into groups of 3-4 students, given experiment sheets to follow during the experiment and asked to perform the friction experiment in identical setups prepared in accordance with the original experiment. In the friction experiment, it was tried to prove what the friction force changes depending on. For this reason, objects with equal masses, volumes and surface types were needed. These objects were obtained with 200 ml milk cartons of the same brand from supermarkets. In the friction experiment, the object moving horizontally and the object moving vertically were connected to each other with the help of a rope and a fixed pulley. The stage of connecting the rope to the milk carton was carried out with the help of a paper clip and tape. The movement and fall time of the suspended mass, which will fall under the effect of gravity, were observed. Students were expected to do the experiment following the setup in Figure 2 and record the results.

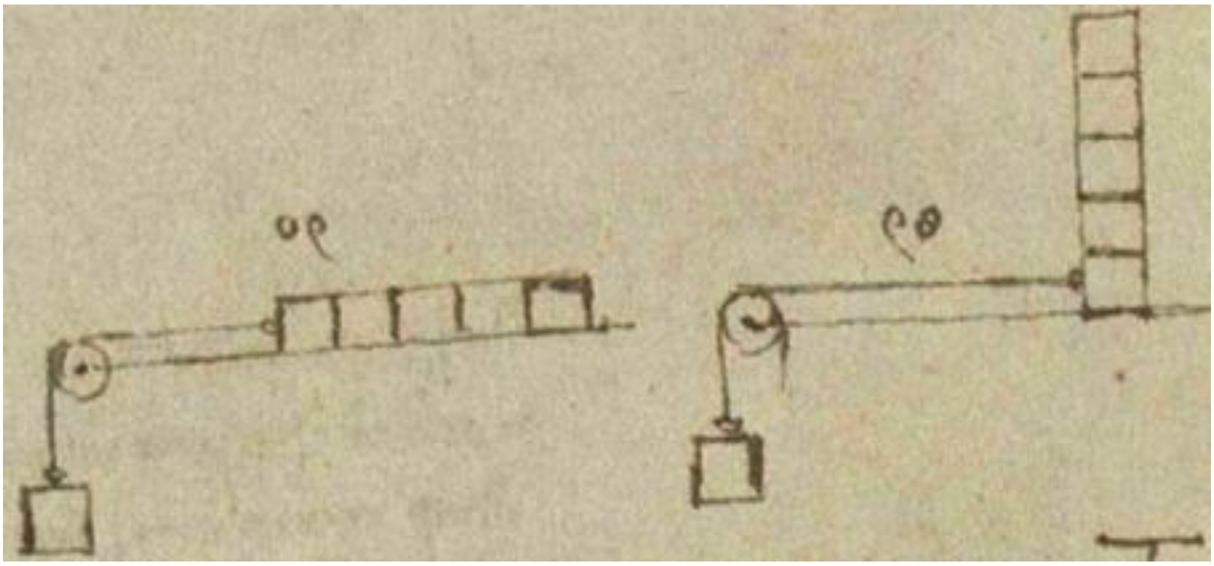

Figure 2 Drawings of Leonardo da Vinci, experimental setup (Pitenis et al., 2014)

In the next stages, the milk masses were increased and this increase was realized by adding another milk box to a milk box with the help of tape. The students were asked to add identical blocks next to the horizontal block as shown in Figure 3 and to observe the change in motion when the number of blocks on the horizontal increased. Then, the blocks were moved to the vertical position and the motion of the suspended mass was observed, the experiment was repeated with different positions of the blocks horizontally and vertically and the observations were recorded.

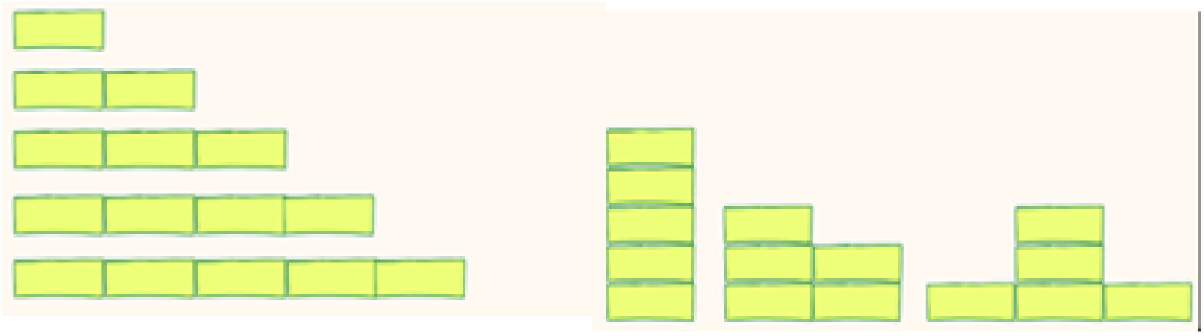

Figure 3 Different positions of the blocks connected to the bobbin

Finally, the experiment was conducted using a single block to observe the effect of the surface on the friction force. First, the suspended mass was observed connected to one block, then the bottom of the block was lubricated with soap, and it was observed again, comparing the motions. At the end of the experiment, the students shared their conclusions with their teachers and friends.

Data collection

In this study, Academic Success Test and Word Association Test prepared by the investigators were used to collect data.

Academic Success Test

Academic Success Test, which is prepared by investigators based on PISA questions and skill-based questions, to measure what students know and what they learn from each experiment and consists of 3 different groups of questions including comprehensive sub-questions for each experiment, was evaluated over the answer key formed in consideration of the "PISA question types and evaluation criteria" defined by Alkan (2013). The academic success test consisted of two open-ended two-stage tests: 1 fill-in-the-blank test from Davincin's friction force experiment, 1 open-ended test each from Galileon's average speed experiment and Joule's pedal wheel experiment A total of three questions were formed in the academic success test, one question for each experiment. Since the number of questions in the academic success test was small, these questions consisted of Pisa-style questions and were supported by open-ended questions, expert opinion was used to determine content validity.

Word Association Test (WAT)

The vocabulary association test, which is one of the alternative assessment and evaluation tools, is a technique that affects vocabulary learning and recall and gives important clues about how students construct knowledge (Istifci, 2010). In this study, the connections that students established between concepts through experiments and whether the connections established were correct or sufficient were examined. For the Word Association Test used in this study, concepts were defined for each experiment, and students were asked to write down 6 words and a sentence related to each concept within 60 seconds. The concepts of "friction force", "normal force", "weight" and "mass" for Davincin's friction force experiment; "velocity", "average velocity", "acceleration" and "gravity" for Galileo's average velocity experiment; "heat", "temperature", "work", "potential energy", "kinetic energy", and "mechanical energy" for Joule's pedal wheel experiment were used. The concepts used and the general structure of the test were formed in line with the expert opinion.

Data Analysis

Academic Success Test

The test was applied to 13 students as a pretest, and it was evaluated by 4 investigators, who were science teachers and doctoral students. The consistency between the raters was checked and found 90.3%. In order for the inter-rater evaluation results to be considered reliable, the percentage of agreement must be above 75% (Sencan, 2005). The pretest and posttest Academic Success Test data of 13 students, who participated in both tests, were transferred to the SPSS 23.0 program, and statistical analyzes were made.

According to Can (2018), it is unlikely that the data display normal distribution since the sample size is less than 30, and non-parametric tests are used for groups without such distribution. If the group is non-parametric, Wilcoxon Signed Rank Test is used to compare the means of two measurements from a group. In this case, since the number of participants was less than 30 ($n<30$) and the pre and posttest scores of a group were to be compared, the Wilcoxon Signed Rank Test, one of the non-parametric tests, was used in the analysis of the data for the Academic Success Test.

Word Association Test (WAT)

The cutoff point technique was used in the evaluation of the word association test. In this context, 3-5 numbers below the maximum number of answers for the key concept are used as the cutoff point. Then, the answers above this frequency are placed in the first part of the map. In the next stage, the cutoff point is decreased, and new emerging concepts are added to the map. The same procedure is continued until all key concepts are revealed (Kırtak, 2010).

The students' answers were reviewed, and the most common concept cutoff point was identified as 3. Based on these frequency values, cut-off points were set, and concept maps were created.

Results

Results for the Academic Success Test

The data for the Academic Success Test were analyzed with the Wilcoxon Signed Rank Test, one of the non-parametric tests.

Table 1 Academic Success Test - Wilcoxon Signed Rank Test Results

Score	Rank	N	Rank Average	Rank Total	Z	p
Posttest Pretest	Negative Rank	2	3.00	6.00	-2.620	0.009
	Positive Rank	10	7.20	72.00		
	Equivalent Rank	1				

Table 1 shows that there is a significant difference between the posttest-pretest Academic Success Test scores and this significant difference is in favor of the posttests ($p<.05$).

Results for the Word Association Test (WAT)

Students in the study read the concepts in the WAT and noted the words they associated with them. These words were listed and put in an order depending on the frequency of repetition. Concept maps were created by using the words written down by students about each concept before and after the application, and the relationship between the WAT pretest and posttest data was analyzed. The numbers above the arrows in the concept maps signify the frequency of words associated with the concepts. The data for WAT applied before and after the experiment and the concept maps based on these data are as follows.

Results of the Friction Experiment

Below are the results of the concept maps built on the results of the WAT applied as a pretest. The main concepts of the experiment are "friction force", "normal force", "weight" and "mass". The concept map of the pretest word association tests in the Friction Experiment is given in Figure 4.

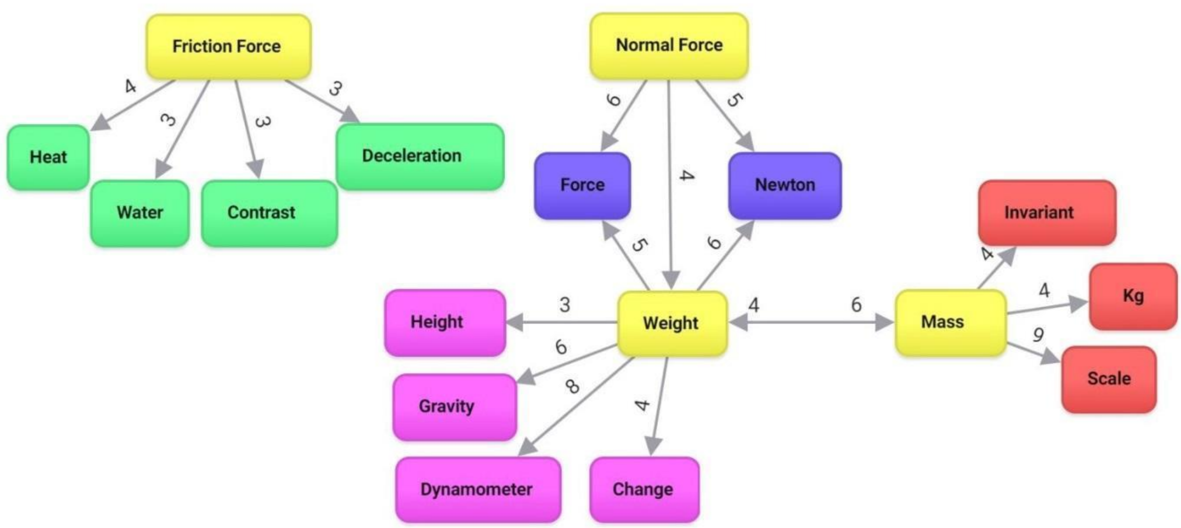

Figure 4 Pretest Concept Map for Friction Force Experiment

Below are the results of the concept maps built on the results of the WAT applied as a posttest. The main concepts of the experiment are "friction force", "normal force", "weight" and "mass". The concept map of the posttest word association tests in the Friction Experiment is given in Figure 5.

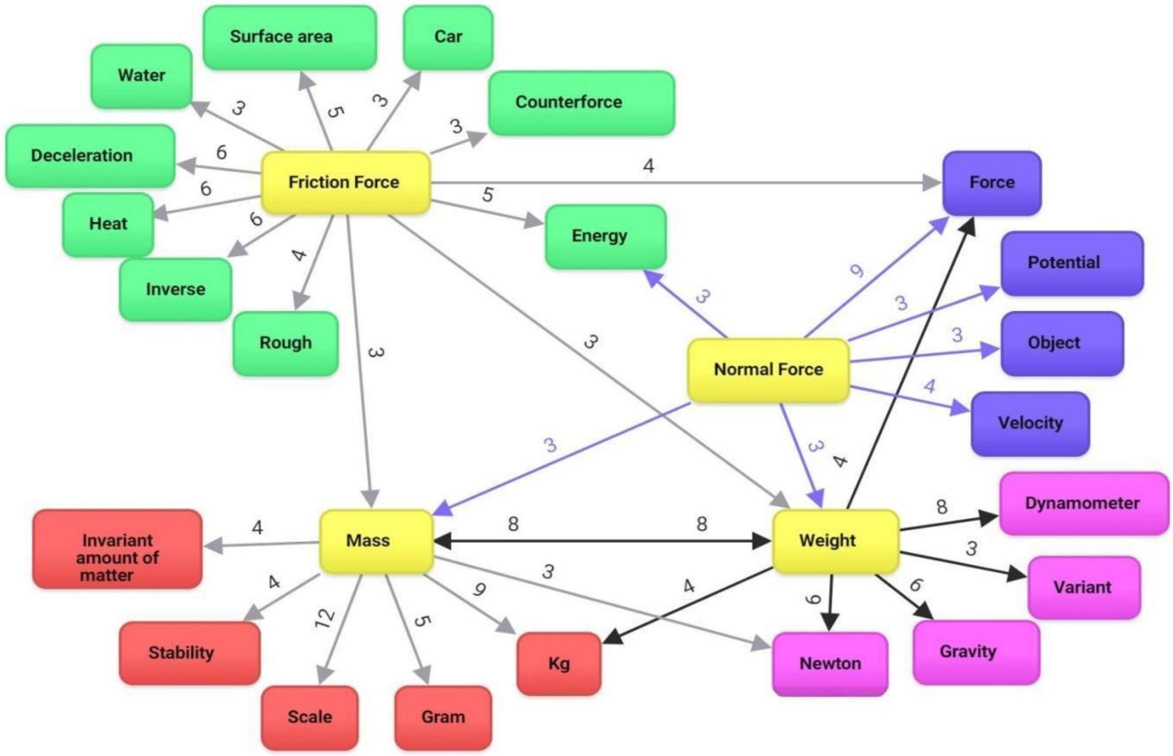

Figure 5 Posttest Concept Map for Friction Force Experiment

In the pretest, heat (f=4), water (f=3), contrast (3), and velocity reduction (f=3) were specified for friction force; force (f=6) and newton (f=5) for normal force; dynamometer (f=8), mass (f=6), gravity (f=6), change (f=4), and height (f=3) for weight; and scale (f=9), kg (f=4), invariant (f=4), and weight (f=4) for mass. On the other hand, in the posttest, deceleration (f=6), inverse (f=6), heat (f=6), energy (f=5), surface area (f=5), rough (f=4), and counterforce (f=3) were indicated for friction force; force (f=9), and velocity (f=4) for normal force; mass (f=8), dynamometer (f=8), and newton (f=6) for weight; and scale (f=12), kg (f=9), and weight (f=8) for mass.

- Pretest data show that the students were not able to associate the friction force with weight and mass, other main concepts; however, they could establish this relationship in the posttest.

- While the frequency of the associated words for each concept increased, new words were added. These new associations included "friction force - rough", "friction force - surface area", "friction force - counterforce", "normal force - velocity", and "friction force - energy".

Examples of sentences built by students about friction force and normal force according to the pretest WAT results are given below.

> *"The car was rubbing against the road", "Friction force does not always run counter to movement",* and *"Friction force is the counter force acting on the object"*; and, for normal force, *"It is a form of force", "Every object has a normal force"* and *"It does not slow down or speed up the object".*

Examples of sentences built by students about "friction force" and "normal force" according to the posttest WAT results are given below.

> *"Oil is used on the hinges to reduce friction", "It makes it more difficult to move" and "If it combines with kinetic energy, heat energy emerges".*

- The concepts of mass and weight were associated in both the pretest and the posttest.

Examples of sentences built by students about "weight" and "mass" according to the pretest WAT results are given below.

> *"It is the variant force of man", "Weight is a form of force" and "Weight may vary with planets"; and, for mass, "Mass is the invariant quantity of matter", "The mass of my car is 2000 kg" and "It does not vary depending on our position in the world".*

Examples of sentences built by students about weight and mass according to the posttest WAT results are given below.

> *"It is measured with a dynamometer", "The weight of matter is proportional to gravity" and "It is the gravitational force that varies with the location of the matter or object", and, for mass, "It is the quantity of matter that does not vary based on the location of the matter or object", "It is measured with an equal-arm scale" and "Its unit is kilogram."*

Results of the Average Velocity Experiment

Below are the results of the concept maps built on the results of the WAT applied as a pretest. The main concepts of the Average Velocity Experiment are "velocity", "average velocity", "acceleration" and "gravity". The concept map of the pretest word association tests in the Average Velocity Experiment is given in Figure 6.

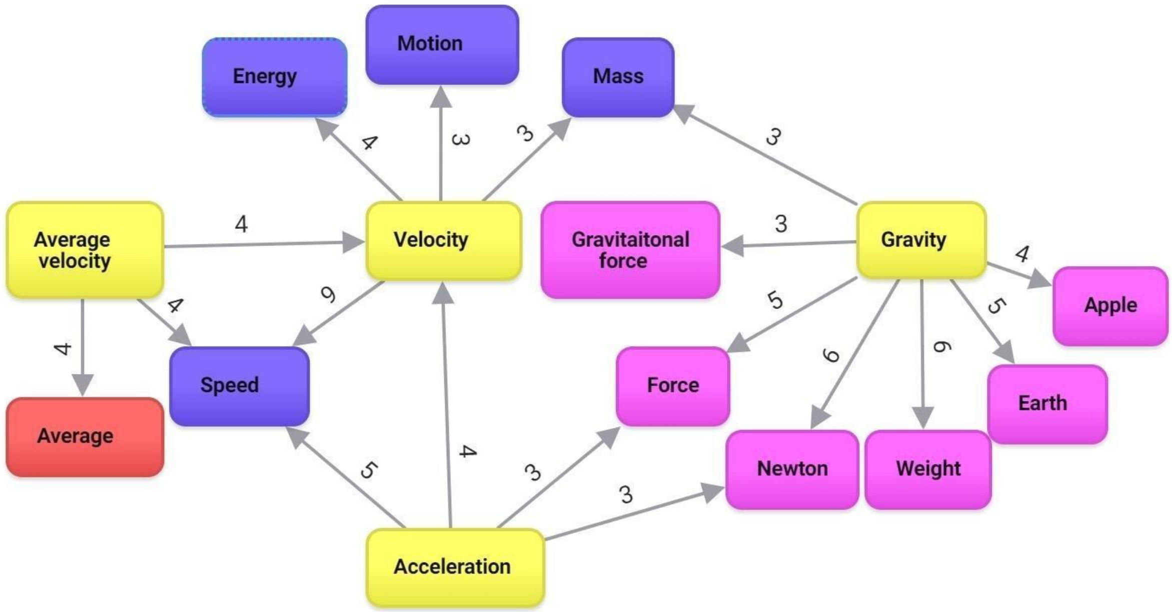

Figure 6 Pretest Concept Map for Average Velocity Experiment

Below are the results of the concept maps built on the results of the WAT applied as a posttest. The main concepts of the Average Velocity Experiment are "velocity", "average velocity", "acceleration" and "gravity". The concept map of the posttest word association tests in the Average Velocity Experiment is given in Figure 7.

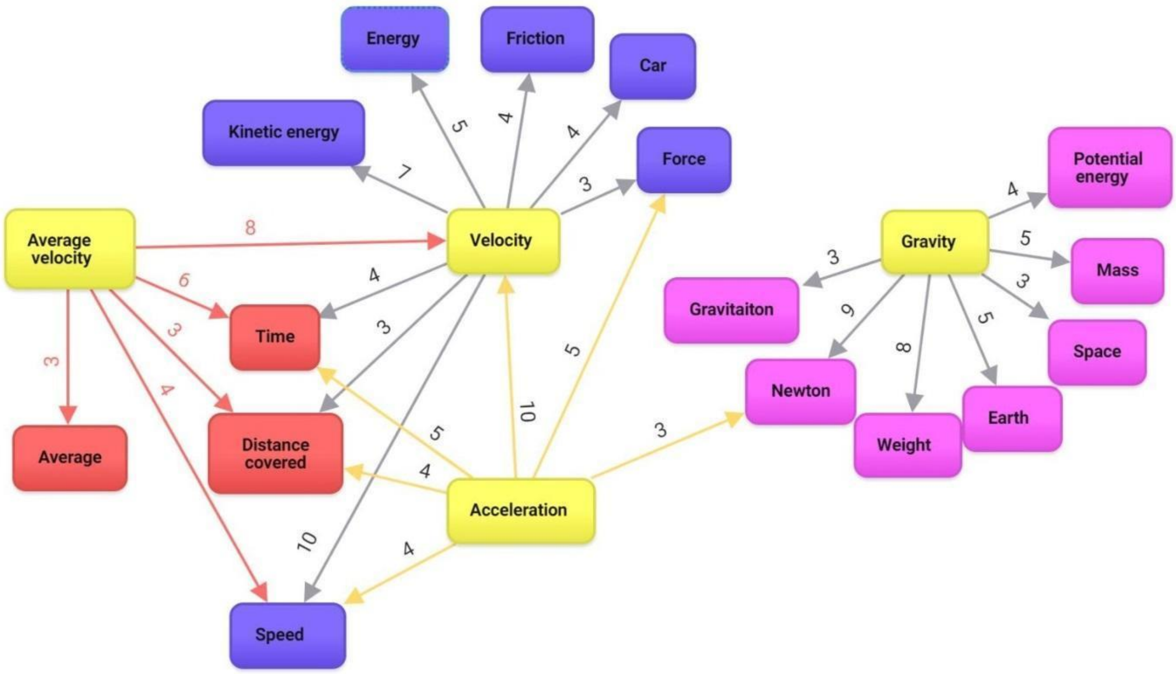

Figure 7 Posttest Concept Map for Average Velocity Experiment

In the pretest, speed (f=4), velocity (f=4), and average (f=4) were specified for average velocity; speed (f=10), energy (f=7), motion (f=3), and mass (f=3) for velocity; newton (f=6), weight (f=6), earth (f=5), and force (f=5) for gravity; and speed (f=5), kg (f=4), and velocity (f=4) for acceleration. On the other hand, in the posttest, velocity (f=8), time (f=6) and speed (f=4), and distance covered (f=3) were indicated for average velocity; speed (f=10), kinetic energy (f=7), energy (f=5), and friction (f=4) for velocity; newton (f=9), weight (f=8), and potential energy (f=4) for gravity; and velocity (f=10), force (f=5), and time (f=5) for acceleration.

WAT results show that the concept of kinetic energy was not mentioned in the pretests; however, in the posttests, half of the students associated the concepts of "speed" and "kinetic energy”.

- The concepts of “distance covered” and “time”, which were not included in the pretest, were associated with the concepts of “average velocity”, “velocity” and “acceleration” in the posttest.

Examples of sentences built by students about average velocity and velocity according to the pretest WAT results are given below.

> For average velocity, *"A car that exceeds the average velocity can crash", "It is dependent on the mass"* and *"Average velocity is a type of velocity";* for velocity, *"Vehicles crossing the speed limit are fined", "Velocity= distance x time"* and *"The speed of sound is less than the speed of light";* and for gravity, *"If there was no gravity we would fly",* and *"It is different everywhere".*

Examples of sentences built by students about average velocity and velocity according to the posttest WAT results are given below.

> For *average* velocity, *"It is the average of velocity", "If we add the velocities of two or more cars and divide it by the number of cars, we can find the average velocity"* and *"An object traveling on a straight road has an average velocity";* and for velocity *"The kinetic energy of an object depends on its velocity and mass".*

- Examples of new associations added to the posttest include the pairs of "gravity-potential energy", "velocity-kinetic energy", and "velocity-friction".

Examples of sentences built by students about gravity according to the pretest WAT results are given below.

> "*Gravity is towards the center of the Earth";* and for acceleration, *"It depends on velocity per unit of time", "The acceleration of the object A is 20"* and *"One of Newton's laws is the law of acceleration".*

Results of Joule's Paddle Wheel Experiment

Below are the results of the concept maps built on the results of the WAT applied as a pretest. The main concepts of Joule's Paddle Wheel Experiment are "heat", "temperature", "work", "potential energy", "kinetic energy", and "mechanical energy". The pretest concept map of Joule's Paddle Wheel Experiment is given in Figure 8.

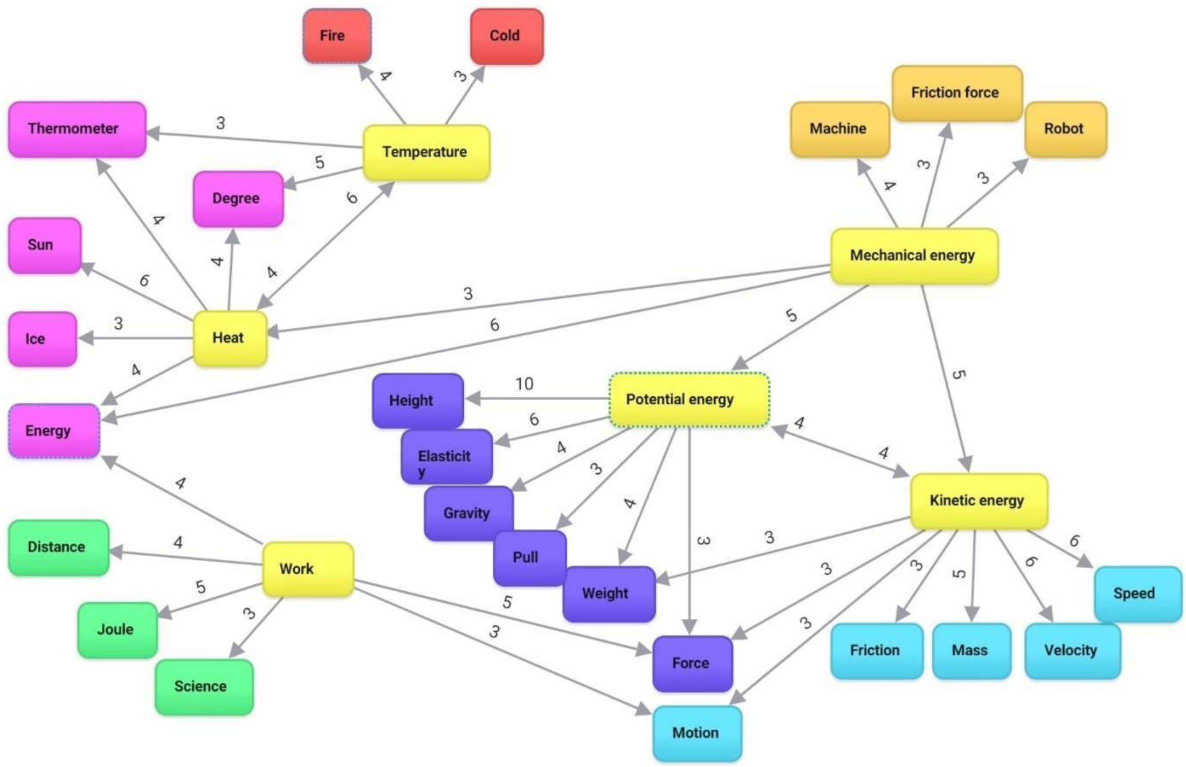

Figure 8 Pretest Concept Map of Joule's Paddle Wheel Experiment

Below are the results of the concept maps built on the results of the WAT applied as a posttest. The main concepts of Joule's Paddle Wheel Experiment are "heat", "temperature", "work", "potential energy", "kinetic energy", and "mechanical energy". The posttest concept map of Joule's Paddle Wheel Experiment is given in Figure 9.

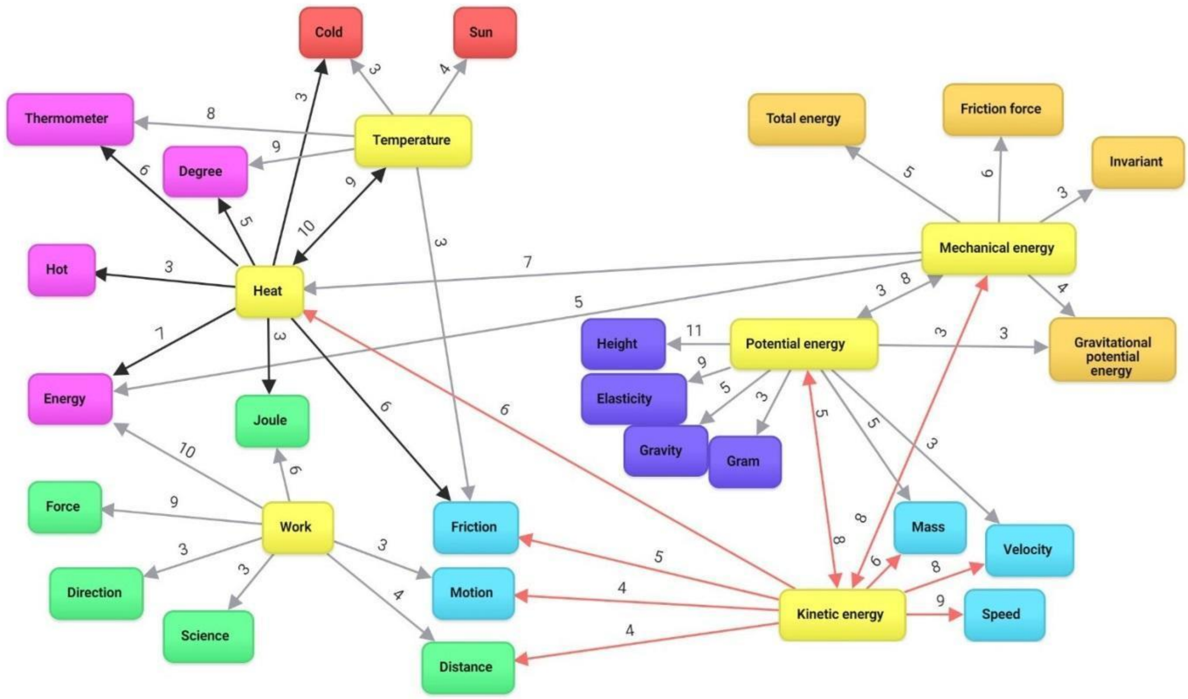

Figure 9 Posttest Concept Map of Joule's Paddle Wheel Experiment

In the pretest, temperature (f=6), sun (f=6), degree (f=4), energy (f=4), and thermometer (f=3) were specified for heat; degree (f=5), and heat (f=4) for temperature; joule (f=5), force (f=5), distance (f=4), energy (f=4), science (f=3), and motion (f=3) for work. On the other hand, height (f=10), elasticity (f=6), gravity (f=4), weight (f=4), force (f=3), and kinetic energy (f=4) were indicated for potential energy; speed (f=6), mass (f=5), potential energy (f=4), friction (f=3), motion (f=3), force (f=3), and weight (f=3) for kinetic energy; and energy (f=6), kinetic energy (f=5), potential energy (f=5), machine (f=4), friction force (f=3), robot (f=3), and heat (f=3) for mechanical energy.

In the posttest, temperature (f=9), thermometer (f=8), degree (f=5), hot (f=3), friction (f=5), and energy (f=1) were specified for heat; heat (f=10), degree (f=9), thermometer (f=8), and friction (f=3) for temperature; energy (f=5), force (f=9), joule (f=6), distance (f=4), motion (f=3), direction (f=3), and time (f=3) for work. On the other hand, height (f=11), elasticity (f=9), mechanical energy (f=8), gravity (f=5), gram (f=3), and gravitational potential energy (f=34) were indicated for potential energy; speed (f=9), velocity (f=8), mass (f=6), heat (f=6), motion (f=4), and distance (f=4) for kinetic energy; and potential energy (f=8), heat (f=7), friction force (f=6), gravitational potential energy (f=4), total energy (f=3), and invariant (f=3) for mechanical energy.

- According to the WAT results, links between the concepts increased and energy-related concepts were associated with others.

- While the concept of "friction" was not associated with "heat" and "temperature" in the pretests, relations were established between "friction and heat" and "friction and temperature" were established in the posttests.

- The students associated the concept of friction with heat and temperature in the posttest.

Examples of sentences built by students about heat and temperature according to the pretest WAT results are given below.

> For heat, *"the weather right now is 30 degrees Fahrenheit", "the heat the in room drops", "the Sun radiates heat and temperature"*; and for temperature, *"fire radiates temperature", "some materials can degrade if not kept at room temperature", "I measured the temperature with a thermometer".*

Examples of sentences built by students about heat and temperature according to the posttest WAT results are given below.

> For heat, "heat energy is generated as a result of friction", "heat and temperature are *different* concepts", "it is an energy"; and for temperature, "it is not an energy", "it is measure with thermometer", "as the temperature rises, some materials may be damaged".

- Examples of sentences built by students about work, potential energy, kinetic energy, and mechanical energy according to the pretest WAT results are given below.

> For *work*, *"in science, work and normal work are different things", "having no work is a pain in the neck", "the distance covered multiplied by the force applied equals to the work"*; for potential energy, *"it is the energy inside every living thing", "kinetic energy can be converted to potential energy", "it depends on height and mass"*; for kinetic energy, *"mechanical energy is calculated by adding kinetic energy and other energies together",* "*it is the energy of moving objects*", *"kinetic energy is also motion energy";* for mechanical energy, *"mechanical energy is the sum of kinetic and potential energy", "mechanical energy is the energy of a mechanism",* and *"machines can have mechanical energy".*

- Examples of sentences built by students about work, potential energy, kinetic energy, and mechanical energy according to the posttest WAT results are given below.

> For work, *"energy is the ability to do things" "the unit of work is Joule"* and *"if the object moves in the same direction as the force, it produces work"*; for potential energy, *"it is divided into two as gravitational potential and elastic potential" "it depends on mass and height"*; for kinetic energy *"it depends on the mass and speed of an object and is directly proportional to them", "when kinetic energy and friction force are combined, heat energy is produced", "the sum of kinetic energy and potential energy is mechanical energy"*; and for *mechanical* energy *"it is lost in case of friction force", "in case of no frictional force, it does not change",* and *"it is a form of energy".*

Conclusions and Suggestions

This study analyzes how the faithful reconstruction of experiments in the history of science affects academic success and word association levels. In conclusion, such reconstruction has a positive impact on academic success and word association levels. Comparing the pretest and posttest maps, which were created based on the results from all applications, it is seen that the concepts are produced similarly; however, the number of relationships established after the application increased, and learning took place by building new relationships.

Conclusion and Discussion for the Academic Success Test

The literature also shows that reconducting scientific studies from the history of science in science teaching contributes to learning many subjects, concepts, and scientific facts (Devons & Hartmann, 1970; Kostur, 2017). On the other hand, teachers think that using experiments in science teaching is a waste of time, especially for grades preparing for national exams (Gunes et al., 2013). According to Chang (2011), if sufficient motivation is ensured in learning science, extra learning can occur in addition to obtaining the information required by the curricula and exams. Students can gain motivation to learn science by performing experiments made in the history of science (Chang, 2011; Ho-Ttecke, 2000; Kortam et al., 2021).

Conclusion and Discussion for Word Association Levels

In the friction experiment, it is stated that the friction of the objects does not depend on the surface area, and the normal force increases with the weight of the object (Pitenis, et al., 2014). The most significant difference between the posttest concept map data and the pretest data is that students associate the concept of friction with surface area and weight. Students' misconceptions about associating friction force with surface area bring to mind the different results Weber et al. (2018) obtained from Da Vinci on the independence of friction force from the surface area.

In the friction experiment example, the "weight-kilogram" relationship in the posttest suggested that the students who established such a relationship had misconceptions about the units of weight and mass. Similarly, the presence of a relationship between “mass and Newton” supports the conclusion of Koray and Tatar (2003) that primary school students had many misconceptions regarding mass and weight. The results of the study show that students confuse not only the concepts of weight and mass but also the units of these concepts.

For the average velocity experiment, the associations of "velocity-kinetic energy" and "potential energy-gravity" are not included in the pretest but in the posttest. Uyduran (2019) stated that students associated kinetic energy with “velocity” and potential energy with “gravity” and indicated the variables on which kinetic and potential energy depend. The relevant study supports the results we obtained in our practice.

The posttest data indicate an association between the words "distance covered" and "time", and the concepts of "velocity", "average velocity" and "acceleration". Drake (1978) suggests that Galileo's objects falling with constant acceleration begin to fall slowly and that a gradual increase in their speed is proportional to the time spent. The data obtained from the study are in line with this statement. However, the frequency of associating the concepts of velocity and speed is high in the pretest and posttest, which suggests that the students confuse them (Balbag, 2018).

The fact that students associate the concepts of "thermometer" and "degree" with "heat", as well as "temperature" in the pretest and posttest, shows that they have a misconception about heat-temperature. The body of literature supports that misconceptions about heat and temperature are among the most common and continue even at the high school level (Harrison et al., 1999; Sukarmin et al., 2018). Aydoğan and Guneş (2003) found that such misconceptions were still present not only at the high school level but also at the university level. In his study, Harrison et al., (1999) emphasizes that these concepts are resistant to change and that conceptual progress should be supported by laboratory practices. According to the data obtained at the end of the application, it was seen that the heat-temperature misconception could not be eliminated in the experiment. This result, which supports the studies in the literature, shows that longer periods are required to eliminate the misconception about heat and temperature and to ensure word associations. On the other hand, the students did not establish the heat-joule relationship in the pretest but in the posttest, which may indicate that the students learned the unit of heat after the practice.

According to the WAT results, the words "machine" and "robot" were used in the pretest and "invariant" and "total energy" in the posttest for mechanical energy. It shows that the students were informed about mechanical energy at the end of the application. In addition, students associated all forms of energy with each other in the pretests and posttests. Yurumezoglu et al. (2009) suggest that since it is hard to perceive energy-related concepts, it leads to the interchangeable use of similar ones. However, it is also important for students to associate the concepts of temperature, heat, and friction after the experiment. Joule (1850) demonstrated the relationship between mechanical energy and heat in his experiment. It is believed that repeating this experiment enabled students to establish the relationship between temperature, heat, and friction.

Suggestions for Practitioners on Experiments

Investigator's Experience of the Friction Experiment

Different materials with the same mass and volume can be used instead of milk cartons, such as juice boxes or wooden blocks.

It is recommended to use a durable adhesive in the gluing process to attach the masses to each other.

Investigator's Experience of the Average Velocity

It is recommended that the length and width of the material used for the inclined plane should be chosen as large as possible in order to easily measure the time to complete the movement of the object released from the inclined plane. Because the time to complete the movement of an object released from a short inclined plane will be less, there will be difficulties in measuring the time. In a narrow inclined plane, the probability of deviations in the motion of the released object will increase and the object may not complete its motion by leaving the path of the inclined plane.

Investigator's Experience of the Joule's Paddle Wheel Experiment

It is recommended that the water-filled system should not be too large. Because the temperature increase that will occur in very large systems is much smaller and this temperature increase may be difficult to observe.

Compliance with Ethical Standards

Disclosure of potential conflicts of interest

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CRediT author statement

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Research involving Human Participants and/or Animals

The study involves human participants. Ethics committee permission was obtained from Marmara University, Institute of Educational Sciences Research Ethics Committee.

Tarihi Bilimsel Deneylerin Ortaokul Öğrencileri ile Yeniden Yapılmasının Öğrencilerin Akademik Başarılarına ve Kelime İlişkilendirme Düzeylerine Etkisi

Özet:

Bu çalışma, bilim tarihindeki deneylerin aslına sadık kalınarak yeniden yapılmasının ortaokul öğrencilerinin akademik başarılarına ve kelime ilişkilendirme düzeylerine etkisini araştırmayı amaçlamaktadır. Çalışmada karma deneysel desenlerden biri olan tek gruplu ön test-son test zayıf deneysel desen kullanılmıştır. Uygulama, 2021-2022 Eğitim-Öğretim yılında İstanbul'da bulunan bir Bilim Sanat Merkezi'nde Özel Yetenekleri Geliştirme Fizik grubunda yer alan yedinci sınıf seviyesindeki 13 öğrenciyle altı hafta boyunca gerçekleştirilmiştir. Uygulama sırasında üç deney öğrenciler tarafından yapılmıştır. Araştırmacılar tarafından oluşturulan Akademik Başarı Testi ve Kelime İlişkilendirme Testi öğrencilere ön test ve son test olarak uygulanmıştır. Öğrencilerin ön test ve son test akademik başarı puanları arasında son test lehine anlamlı bir fark bulunmuştur. Uygulama sonrasında kavramlar arasında yeni ilişkilerin kurulduğu görülmüştür.

Anahtar kelimeler: Akademik başarı, bilimsel deneyler, bilim tarihi, kelime ilişkilendirme testi.

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