Indonesian Society for Science Educators
Journal of Science Learning
journal homepage: ejournal.upi.edu/index.php/jslearning

Web Integrated STEM Learning: Effects on Students' Academic Achievement, Creativity and Metacognitive Awareness

Ayberk Bostan Sarıoğlan[1]*, Özge Şentürk Özkaya[2]

[1]Science Education Department, Education Faculty, Balıkesir University, Balıkesir, Turkey
[2]Ministry of Education, Kocaeli, Turkey

*Corresponding author: abostan@balikesir.edu.tr

ABSTRACT This study examines the effect of teaching with the STEM Cycline of the 'Force and Energy' unit on students' creativity, metacognitive awareness, and academic achievement. The nonequivalent control group design, one of the quasi-experimental models, was used in the study. The study included 54 seventh-grade students studying at a public school in western Turkey, 27 of whom were in the experimental group while 27 were in the control group. The experimental group was taught with the STEM Cycline, whereas the control group took the instruction within the science curriculum framework. The experimental group designed models using Web 2.0 tools related to the given problems and used these models to solve them by printing them from a 3D printer. "Force and Energy Academic Achievement Test", "Scientific Creativity Test" and "Metacognitive Awareness Inventory" were used as data collection tools in the study. SPSS 25.0 package program was used to analyze the data. The results showed that the STEM education in the experimental group increased the academic achievement, creative skills, and metacognitive awareness of the seventh-grade students in the 'Force and Energy' unit. While the students' academic achievement in the control group increased significantly following the instruction, no difference was observed in their creativity and metacognitive awareness. Suggestions were made according to the results obtained from the study.

Keywords STEM, 3D printer, academic achievement, creativity, secondary school students

1. INTRODUCTION

STEM integrates science, mathematics, technology, and engineering disciplines. In recent years, the importance of STEM as an investment in the future has increased, and developed countries, especially the U.S., have focused on this field (Çepni, 2018). Although many existing or continuing studies on STEM exist in the literature, there is no single definition of it (Dugger, 2010; Langdon et al., 2011). One definition emphasizes that STEM is an effort to connect science, mathematics, technology, and engineering disciplines in a course with the connections between these disciplines and real-life problems (Stohlmann et al., 2012). STEM education helps individuals make sense of the world they live in and prepare themselves for the future (Morrison, 2006). STEM is shaped according to the interests and life experiences of teachers and students. It can be defined as teaching special skills and knowledge related to the discipline in the center by integrating it with at least one different STEM discipline (Çorlu et al., 2014). While STEM education provides permanent learning for individuals (Kuenzi, 2008), it also increases success (Alemdar et al., 2018; Chine & Larwin, 2022; Honey et al., 2014; Karaşah-Çakıcı et al., 2021; McDonald, 2016), interest (Koyunlu Ünlü & Dökme, 2020; Mohd Shahali et al., 2019), and motivation (McDonald, 2016; Murphy et al., 2019; Yabas et al., 2022) of students who are faced with real-life problems. In addition, STEM effectively increases students' creativity (Hanif et al., 2019; Hsu & Fang, 2019). Thanks to STEM education, individuals can look at events from a multi-dimensional perspective. At the same time, they can transfer this information to their daily life. Engineering applications and designs made by students form the basis of STEM education and are also effective in students' learning (Guzey et al., 2016). In addition, students who receive STEM education develop positive attitudes toward the engineering discipline, and their interest in the professions of the future increases (Tseng et al., 2013). STEM is a theoretical framework that has the "Authentic Problems of

Received: 29 March 2023
Revised: 30 July 2023
Published: 16 October 2023

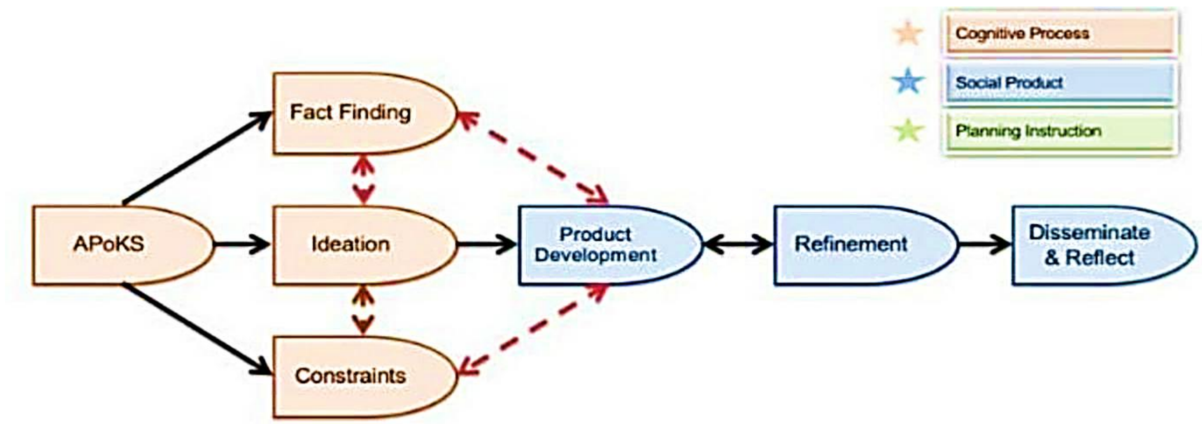

Figure 1 STEM learning cycline (Çorlu & Çallı, 2017)

Knowledge Society" at its center, aiming that teachers should contribute to the transformation of society into an information society, place the learning culture in the school where they work, base their actions on the results of the literature or conduct their research, and create a flexible curriculum specific to the school they are in (Erdogan et al., 2013). Cognitive processes of Integrated Teaching methods should be modeled practically in the classroom in a way that does not impose additional cognitive load on teachers and students. For this purpose, the STEM Cycline (Figure 1), defined as a learning cycle for teachers and students, has been developed.

At the center of the STEM Cycline is the Authentic Problems of Knowledge Society (APKS). These problems are dynamic, complex, and related to daily life. According to the STEM Cycline, the steps of the 5E-5D teaching models can be followed in the solution of APKS, which is taken to the center (Çorlu & Çallı, 2017).

Using Web tools in STEM education improves students' knowledge and skills (Bolatlı & Korucu, 2018). Web 2.0 tools are second-generation Web environments (Chiou, 2011), allowing people to transfer or produce information simultaneously, interactively, in groups, or individually (Hung & Yuen, 2010; McLoughlin & Lee, 2007). Communication via Web 2.0 tools creates opportunities such as information transfer, easy access to information, creating content with a team, storing and sharing content, and evaluating and visualizing information (Ajjan & Hartshorne, 2008). These technologies provide students and teachers with the convenience and educational support they need in the educational environment. Today, students are required to be active participants in the educational environment. Accordingly, Web 2.0 tools allow students to produce, control, and change the content according to their needs and socialize with other students (Palaigeorgiou & Grammatikopoulou, 2016).

For this reason, Web 2.0 tools are essential to support education and should be in educational environments (Hursen, 2021). The biggest reason for using Web 2.0 tools is that they can gather many people together for the same purpose socially and practically rather than reading the information on the screen (O'Reilly, 2007). In addition, it is stated in the studies that Web 2.0 tools are also effective in increasing the academic success of students (Arslan & Coştu, 2021; Arslan & Yıldırım, 2021; Kırıkkaya & Yıldırım, 2021; Uysal & Çaycı, 2022). It is critical to connect technology with integrated STEM learning and investigate how to use technology to support student learning and address the challenges associated (Yang & Baldwin, 2020). Kwon (2017) stated that summer STEM camps using 3D printing and 3D design software positively affect students' overall mathematical and technical skills, motivation, and interest performance. Hsu et al. (2017) stated that the use of augmented reality in STEM education causes an increase in students' participation and motivation in the course. Leonard et al. (2016) used robotics and game design to develop middle school students' computational thinking strategies in STEM education. In studies where web technology is integrated into STEM education, it is seen that while various competencies of students are examined, their development in areas such as creativity and metacognitive awareness is not emphasized.

Technology used during teaching increases students' creativity (Sumarni & Kadarwati, 2020). Creativity is noticing new and original situations (Runco, 2008). Jaarsveld et al. (2012) defined creativity as presenting an existing image or object differently or taking it further. Although many definitions of creativity exist, common points are innovation, difference, and originality (Acar et al., 2017). If individuals use their creativity to solve a scientific problem with certain limits, this becomes scientific creativity (Liang, 2002). Scientific creativity is using science, mathematics, technology, or science to make a different and innovative product in any field or to have this skill (Rawat, 2010). There should be a process to solve scientific problems and scientific creativity should be used (Hu & Adey, 2002). When searching for a new and different solution to a scientific problem, it should be used in scientific processes together with scientific creativity

(Harlen, 2004; Meador, 2003). Scientific creativity is high-level thinking based on identifying the problem, creating new ideas, and establishing a link between ideas (Lubart et al., 2013). Sometimes, we encounter problems in our daily lives, and these problems reveal the necessity of creative ideas. Scientific creativity aims to mix and use the information storage of an individual, together with scientific dimensions, at all stages, from the scientific determination of the problem to the method determined for the solution (Samuels & Seymour, 2015). Ambruso (2003) associated scientific creativity with individuals' scientific ability and the scientific processes they go through and stated that scientific creativity has a significant role in stages such as defining the problem, forming hypotheses, and conducting experiments, like a scientist.

Metacognition is a term used to express a person's processes to become aware of, monitor, control, and organize their cognitive processes (Veenman et al., 2006). This definition was first used by Flavell (1979) as the organization of cognitive processes to learn most efficiently in understanding one's abilities and mastering and directing their abilities. Metacognition is the upper system at the top of the information processing process, which examines and controls information (Thomas, 2012). Wilson and Bai (2010) defined metacognition as "the awareness that individuals have of their ideas and analyses and the ability to organize them".

STEM is taught with various teaching approaches in science courses. One of these approaches is the STEM cycline. It has also been stated in studies that teaching with STEM cycline has a positive effect on students' academic achievement (Uslu & Boz-Yaman, 2021) and creativity (Genek & Kucuk, 2020; Sarıçam & Yıldırım, 2021). However, studies investigating the effects of the STEM cycline on metacognitive awareness have not been found in the literature.

1.1 Significance of Research

In order to increase the creative thinking and metacognitive awareness of individuals, it is necessary to carry out and develop studies on STEM education (Çorlu, 2014). STEM is an education method that simultaneously integrates the disciplines of science, mathematics, engineering, and technology, as well as the development of students in engineering and technology (Williams, 2011). In this respect, countries must increase their importance to STEM education (Kelley & Knowles, 2016). With the science curriculum updated in 2018, studies in the field of STEM education have started to increase in Turkey. However, although the number of studies has increased, it is considered insufficient (Çavaş et al., 2020). There are studies in the literature that STEM education improves many skills in students (Apriyani et al., 2019; Martín-Páez et al., 2019; Wahono et al., 2020). However, few studies examine the effect of STEM activities in science education on creativity and metacognitive awareness (Hwang et al., 2020). In this study, it is thought that the student's academic achievement, creativity, and metacognitive awareness will increase with the lesson plans designed following the STEM Cycline method and the activities implemented. In addition, it is thought that working as a team will enable students to develop socially and, thus, they will try to produce solutions to the daily life-related problems presented at the beginning of the lesson in cooperation. While producing these solutions, simulations and Web 2.0 tools following today's technology will benefit their technology knowledge and creativity. At the same time, using 3D printers while creating products will be an innovation for secondary school students, and their relationship with technology will increase at an early age. When the literature was examined, no studies were found in which all these activities were carried out together at the secondary school level. In this context, the study will contribute to the literature. In addition, the developed STEM plans are thought to guide science educators who would like to use STEM activities while teaching.

1.2 Purpose of the Research

This study aims to make students active with enriched STEM activities and to increase their creative thinking skills, metacognitive awareness, and academic achievement. With the lesson plans prepared by the steps of the STEM Cycline, the students were confronted with the complex and dynamic problems experienced by the 21st-century information society, and they did group work with an interdisciplinary approach to solve them. While making designs to solve Authentic Problems of Knowledge Society improves creativity, the use of Web 2.0 tools and three-dimensional printers in creating designs will also contribute to developing technology skills by ensuring the inclusion of technology in the process. This study aims to answer the following research questions:

1. What is the effect of teaching with STEM Cycline on the academic achievement of seventh-grade secondary school students in the Force and Energy Unit?
2. How does teaching with the STEM Cycline affect the metacognitive awareness scores of seventh-grade secondary school students?
3. What is the effect of teaching with STEM Cycline on the creativity scores of seventh-grade secondary school students?

2. METHOD

In this study, which investigates the effect of teaching the Force and Energy unit with the STEM Cycline on seventh-grade secondary school students' creativity, metacognitive awareness, and academic achievement, the nonequivalent control group design, one of the quasi-experimental models was preferred as the model of the research.

In this study, pre-tests were applied to both groups before the study. Then, the experimental group was taught

Table 1 Research process

Groups	Pre-test	Instruction	Post-test
Experimental	FEAAT	Web Integrated STEM	FEAAT
	SCT	Cycline	SCT
	MAI	(5 weeks)	MAI
Control	FEAAT	Science Curriculum	FEAAT
	SCT	(5 weeks)	SCT
	MAI		MAI

with the STEM Cycline while the control group was taught within the framework of the MEB science curriculum. At the end of the five-week instruction, post-tests were applied to both groups. The research process is presented in Table 1.

2.1 Study Group

The study group consisted of 54 seventh-grade secondary school students studying in two different classes in a public school in the western part of Turkey. The study's sampling was determined with the convenient sampling method as one of the probabilistic sampling methods. The convenient sampling method saves both time and effort for the implementers to reach the convenient sampling (Patton, 2002). The main reasons for choosing the practice school were that it was the school where the first researcher worked, the sample was easily accessible, and the school was technologically equipped. Twenty-seven students are in the experimental group, while 27 are in the control group. There are 15 male and 12 female students in the experimental group and 14 male and 13 female students in the control group. In choosing the groups, the mean academic scores of the two classes were examined, and the mean scores were found to be quite close.

2.2 Data Collection Tools

Force and Energy Academic Achievement Test (FEAAT), Scientific Creativity Test (SCT), and Metacognitive Awareness Inventory (MAI) were used as data collection tools in the study.

The "FEAAT," developed by Kurt (2020), was used to measure the academic achievement of seventh-grade students in the Force and Energy unit. The test consists of 28 multiple-choice questions. The reliability coefficient of the test was calculated as .85 by the researcher, which shows that the reliability of the test is high (Kılıç, 2016).

The Scientific Creativity Test was initially developed by Hu and Adey (2002). The test consists of seven open-ended questions. The test was prepared following the scientific creativity dimensions. The reliability of the test was calculated as .74. The SCT measures the product (science, technical product, science problem, science phenomenon), process (thinking, imagination), and trait (originality, flexibility, fluency) according to the dimensions of the scientific structure creativity model. The content of the questions in the test is to discover and find the problem in the first and second questions, product development in the 3rd question, scientific imagination in the 4th question, problem-solving in the 5th question, scientific experiment in the 6th question, and product design in the 7th question (Kadayıfçı, 2008). Each question can correspond to more than one dimension. While scoring, the answers were evaluated according to flexibility, originality, and fluency sub-scores. Fluency includes producing more than one idea, flexibility involves producing different ideas with the same stimulus, and originality consists of producing new and original ideas (Torrance & Goff, 1989).

The Metacognitive Awareness Inventory was developed by Schraw and Dennison (1994). The measurement tool consists of eight sub-dimensions. These sub-dimensions are declarative knowledge, procedural knowledge, conditional knowledge, planning, comprehension monitoring, evaluation, debugging, and information management strategies. The 5-point Likert-type scale consists of 52 items. The scores given to the items range from one to five points. Therefore, the lowest score on the scale is 52, while the highest score is 260. There is no reverse item in the scale, and high scores indicate a high level of metacognitive awareness.

2.3 Data Analysis

SPSS 25 was used to analyze the FEAAT, SCT, and MAI data. In the study, the normality test was first conducted to examine whether the data showed a normal distribution. The Shapiro-Wilk test, one of the normality tests, was used because the groups in the study were smaller than 50 (N=27).

While SCT was scored, the answers given by the students were considered "raw ideas", then similar ideas were gathered under common ideas as "organized ideas". While giving points, the answers were scored based on the arranged ideas (Kadayıfçı, 2008). The criteria given in Table 2 were considered in scoring the questions.

Table 2 Scoring criteria for the scientific creativity test

Questions	Scoring Criteria
Questions 1, 2, 3, 4	1 point (fluency score) for each generated answer +1 point (flexibility score) for each different suggested application 2 points for each answer found in less than 5% of people, 1 point for 5-10% (originality score)
Question 5	For each answer, 3 points were found in less than 5% of people, 2 points for an answer found in 5% to 10% of people, and 1 point in more than 10% of people (originality).
Question 6	The answer is evaluated in three dimensions: tool, method, and application. In each dimension, the student is evaluated over 3 points (flexibility). Three points for each answer found in less than 5%, 2 points for 5-10%, and 1 point for more than 10% (originality).
Question 7	Three points of flexibility for each given function of the machine. In addition, an originality score of 1 to 5 is based on a comprehensive overall impression.

In scoring the questions, two researchers evaluated by converting the raw ideas into organized ideas, and they decided together by reaching a consensus. A science education specialist analyzed the answers using scoring criteria independent of two researchers. Inter-rater agreement was calculated as .95 (Miles & Huberman, 1994), and answers to other questions were discussed until a consensus was reached.

The data obtained from the FEAAT, SCT, and MAI analysis with the Shapiro-Wilk test are presented in Table 3. In Table 3, when the data obtained from the Shapiro-Wilk test were considered, the p values in all tests were greater than .05, and the skewness and kurtosis coefficients were in the range of (-1.5) to (+1.5). It was determined that the results of the students' FEAAT, SCT, and MAI pre-test/post-test administrations had a normal distribution, and parametric tests were used to analyze the data. Cohen's D values were also calculated in addition to the independent sample t-test to determine whether the method applied influenced the difference between groups.

Table 3 Normality test results of the FEAAT, SCT, and MAI

Shapiro-Wilk	Statistics			p	(skewness)	(kurtosis)
FEAAT	Experimental Group	Pre-test	.948	.192	.698	.671
		Post-test	.941	.128	-.687	-.413
	Control Group	Pre-test	.975	.731	.416	-.359
		Post-test	.925	.058	.827	.118
SCT	Experimental Group	Pre-test	.987	.971	-.041	.245
		Post-test	.949	.198	.636	-.369
	Control Group	Pre-test	.967	.521	.143	-.710
		Post-test	.979	.836	.246	-.421
MAI	Experimental Group	Pre-test	.985	.954	-.157	-.223
		Post-test	.974	.722	-.222	-.565
	Control Group	Pre-test	.965	.478	.450	-.341
		Post-test	.943	.143	.480	-.593

Table 4 Instruction procedure with STEM cycline in experimental group

Lesson Plan	Instruction Procedure
1st Plan (4 class hours)	Students conducted mass and weight issues experiments in the Crocodile Physics simulation program and the pHet Colorado simulation site. They designed equal-arm balances and dynamometers with the Thinkercard Web 2.0 tool and 3D printed these models. They made experiments with the materials they obtained from the 3D printer and discussed the experiment results with the information they wrote in the performance evaluation rubrics.
2nd Plan (2 class hours)	The students designed a model to show that the work is related to the applied force and the path taken, and they printed their models from the 3D printer. They conducted experiments with the printed models and evaluated the results of the experiments with idea development notebooks that they filled in as a group.
3rd Plan (3 class hours)	In order to determine the factors on which kinetic energy depends, students designed a tool in Thinkercad Web 2.0 tool in groups and used these tools in the BTHP solution. They printed the vehicles they designed with a 3D printer. The groups that conducted experiments with the designed tools discussed the information they filled in the research logbooks they filled in throughout the process for process evaluation purposes by sharing with the class.
4th Plan (3 class hours)	In order to determine the factors on which the potential energy depends, the students prepared mechanisms similar to the dynamic compaction method. The students, who designed the materials for their setups with Tinkercad Web 2.0 tools and printed their models from the 3D printer, conducted experiments to measure the factors on which the potential energy depends. At the end of the lesson, the information in the research logbooks filled in throughout the process was shared with the class by the group spokespersons.
5th Plan (2 class hours)	In order to grasp the elastic potential energy, the students designed a spring using the Tinkercard Web 2.0 tool and shot arrows with the bows they printed from the 3D printer. Then, the students visited the pHet Colorado simulation site and did the spring experiment, and the factors on which the elastic potential energy depended were discussed. At the end of the lesson, the groups shared the information in the product development notebooks they filled out during the process with the class.
6th Plan (2 class hours)	The groups performed the experiments on energy conversions available on the pHet Colorado simulation site and designed a poster on energy conservation using the Canva Web 2.0 tool. The students concluded that energy is conserved based on the conversion of kinetic and potential energy types to each other.
7th Plan (4 class hours)	The groups visited the Phet Colorado simulation site and performed the energy skate park experiment on friction force. The groups observed the energy exchange and conservation by changing the friction variable on the energy skate park platform. The groups then designed rockets to reduce friction and explained what additions they made to their models to reduce friction. They 3D printed their models. At the end of the lesson, the groups evaluated the process as a class using the Kahoot Web 2.0 tool.

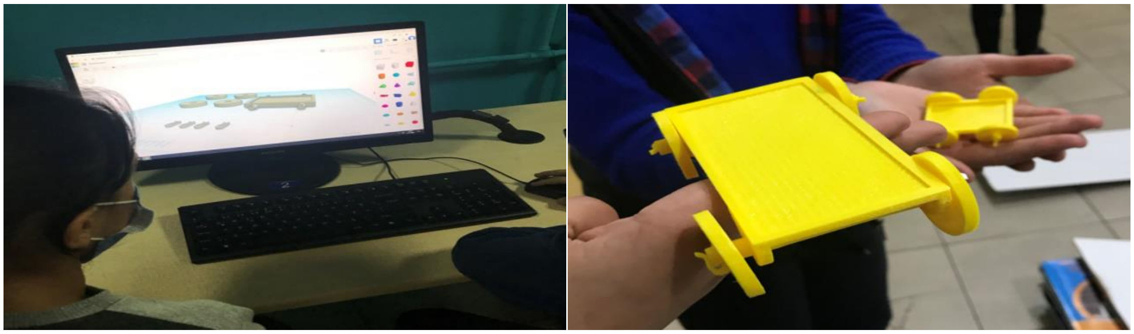

Figure 2 3D printed models designed with Tinkercad Web 2.0 tool

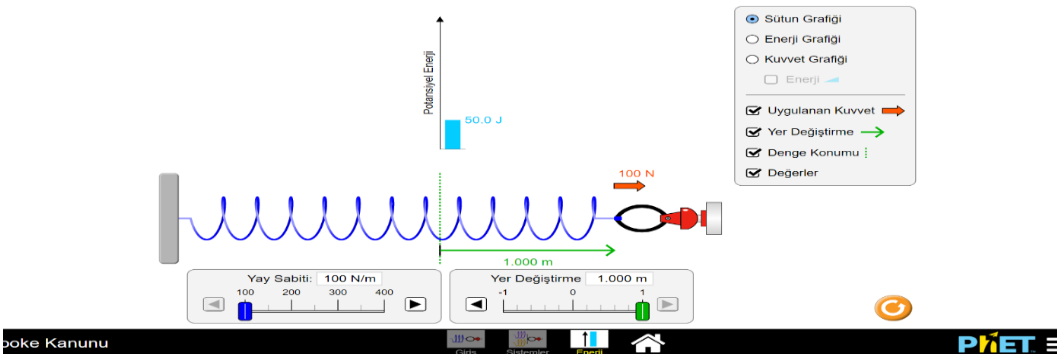

Figure 3 Experiment setup with springs at the Phet colorado simulation site

2.4 Instruction Procedure

During the five weeks (20 class hours), the Force and Energy unit was taught with the STEM education in the experimental group, while it was taught according to the science curriculum in the control group. The experimental group prepared seven lesson plans following the STEM Cycline. The instruction procedure in the experimental group is explained in Table 4.

5D learning model was used in lesson plans, which started with the Authentic Problems of Knowledge Society (APKS), and a possible problem situation they would encounter in daily life was narrated for the relevant outcome. In the introductory step, they are asked what kind of a solution they propose for the solution of APKS, and the students discuss their opinions about the solution to the problem. In the trial phase, students design the models they propose for the APKS solution by conducting experiments using Web 2.0 tools (Canva, Kahoot!, and Tinkercad) and simulation programs in the computer environment, and they print the models they develop from a 3D printer. They test whether these models are effective in solving APKS. Sample images of students who made designs with the Tinkercad Web 2.0 tool in the trial stage of the third lesson plan and how they printed the model they designed with a 3D printer are presented in Figure 2.

In the supporting step, the teacher shares information about the subject outcome and explains the implementation of the models developed by the groups. In the deepening step, students design new applications based on their learning. Examples of the experimental setup that the students made on the pHet Colorado simulation site during the deepening phase of the fifth lesson plan are presented in Figure 3.

Figure 4 Image of Kahoot application in the evaluation step

In the evaluation step, students designed posters, banners, etc., using Web 2.0 tools and kept lesson diaries. The images of the Kahoot application used in the evaluation step of the seventh lesson plan are presented in Figure 4.

3. RESULT AND DISCUSSION

3.1 Results Related to the First Research Question

The findings obtained from the FEAAT pre-test/post-test mean scores of the experimental and control group students are given in Table 5. As seen in Table 5, the post-test mean score ($\bar{X}$=20.03; sd=4.33) of the experimental group for the FEAAT was higher than the pre-test mean score ($\bar{X}$=8.81; sd=2.51). In addition, a statistically significant difference was found between the pre-test and post-test mean scores of the experimental group obtained from FEAAT [$t(26)=14.00$; $p < 0.05$]. The post-test mean score ($\bar{X}$=16.25; sd=4.81) of the control group obtained from FEAAT was higher than the pre-test mean score ($\bar{X}$=9.40; sd=2.43). In addition, a statistically significant difference was found between the pre-test and post-test mean scores of the control group obtained from FEAAT [$t(26) = 7.52$; $p < 0.05$].

The comparison of the FEAAT pre-test and post-test scores of the experimental and control group students is shown in Table 6.

As seen in Table 6, no statistically significant difference was found between the experimental and control groups' mean scores obtained from the FEAAT pre-tests [$t(52)=0.880$; $p > 0.05$]. Considering the pre-test mean scores ($\bar{X}$e=8.81; $\bar{X}$c=9.40), the two groups were quite close. However, the mean of the control group was slightly higher than the experimental group. A statistically significant difference was found between the mean scores of the experimental and control groups from the FEAAT post-tests [$t(52) = 3.02$; $p < 0.05$]. Considering the post-test mean scores ($\bar{X}$e=20.03; $\bar{X}$c=16.25), the FEAAT mean of the experimental group is higher than the control group. When the literature is examined, many studies concluded that STEM education increases academic achievement in parallel with the result obtained in this study (Çevik, 2018; DeWaters & Powers, 2006; Eroğlu & Bektaş, 2022; Gülen & Yaman, 2019; Lamb et al., 2015; Wang et al., 2022). In the study of Özcan and Koca (2019), a significant difference was found between the academic achievement of the experimental group taught with STEM education compared to the control group studying with the curriculum. In another study, Guzey et al. (2016) concluded that STEM activities increased the academic success of seventh-grade students and that the students enjoyed the lessons. Wang et al. (2022) stated in their meta-analysis study that digital game-based STEM education affects students' learning. In a study with sixth- and seventh-grade students, Ricks (2006) concluded that education enriched with STEM activities positively affected students' understanding of science concepts. DeWaters & Powers (2006) observed in their study that the education given with STEM activities increased students' learning abilities regarding STEM lessons. Doppelt et al. (2008) concluded in their study that STEM education increased the learning levels of eighth-grade students. Riskowski et al. (2009) made applications to eighth-grade students by including engineering in the science education process and concluded that the applications effectively increased the students' success. Kurt and Benzer (2020) found that STEM education effectively increases sixth-grade students' academic achievement. In their study, Ali et al. (2021) concluded that the education provided to students with integrated STEM increases students' understanding of scientific concepts/principles and increases student productivity. Unlike the results obtained in this study, some studies conclude that STEM education does not positively affect academic achievement. James (2014) examined the effect of STEM education on students' academic achievement in mathematics and science. STEM education was applied to one of the two groups in the study, and traditional education to the other. The results showed that although there was an increase in the success rates in both groups, there was no significant difference between the results. Judson (2014) concluded in a study that STEM-based schools are insufficient in increasing students' academic success. In another study with seventh graders, the Cohen's-D effect size was calculated as .83, which shows that the effect size of teaching with STEM Cycline is high. Chang et al. (2022) determined in their meta-analysis that STEM education has a small to moderate effect on academic achievement compared to traditional education. This study determined that the effect of teaching in the experimental group on academic achievement was higher than that of the control group.

3.2 Results Related to the Second Research Question

The findings obtained from comparing the MAI pretest-posttest scores of the experimental and control groups are given in Table 7.

As seen in Table 7, the post-test mean score ($\bar{X}$=208.25; sd=24.62) of the experimental group from MAI was higher than their pre-test mean score ($\bar{X}$=177.81; sd=26.80). In addition, a statistically significant difference was found between the pre-test and post-test mean scores of the

Table 5 Paired sample T-test results of FEAAT for experimental and control group

Group	Test	N	$\bar{X}$	sd	df	t	p
Experimental	Pre-test	27	8.81	2.51	26	14.00	.001
	Post-test	27	20.03	4.33			
Control	Pre-test	27	9.40	2.43	26	7.52	.001
	Post-test	27	16.25	4.81			

Table 6 Independent sample T-test results of FEAAT for pre-test and post-test

Test	Groups	N	$\bar{X}$	sd	df	t	p	Cohen's-D
Pre-test	Experimental	27	8.81	2.51	52	.880	.383	
	Control	27	9.40	2.43				
Post-test	Experimental	27	20.03	4.33	52	3.02	.004	.83
	Control	27	16.25	4.81				

Table 7 Paired sample T-test results of MAI for experimental and control group

Group	Test	N	$\bar{X}$	sd	df	t	p
Experimental	Pre-test	27	177.81	26.80	26	9.04	.001
	Post-test	27	208.25	24.62			
Control	Pre-test	27	180.44	24.44	26	.799	.432
	Post-test	27	178.85	22.11			

Table 8 Independent sample T-test results of MAI for pre-test and post-test

Test	Group	N	$\bar{X}$	sd	df	t	p	Cohen-d
Pre-test	Experimental	27	177.81	26.80	52	.377	.708	
	Control	27	180.44	24.44				
Post-Test	Experimental	27	208.25	24.62	52	4.61	.0001	1.25
	Control	27	178.85	22.11				

Table 9 Paired sample T-test results of SCT for experimental and control groups

Group	Test	N	$\bar{X}$	sd	df	t	p
Experimental	Pre-test	27	19.29	8.20	26	3.98	.001
	Post-test	27	26.29	8.12			
Control	Pre-Test	27	16.96	6.45	26	.778	.444
	Post-Test	27	16.11	5.01			

Table 10 Independent sample T-test results in the SCT for pre-test and post-test

Test	Group	N	$\bar{X}$	sd	df	t	p	Cohen's-D
Pre-Test	Experimental	27	19.29	8.20	52	1.16	.251	
	Control	27	16.96	6.45				
Post-Test	Experimental	27	26.29	8.12	52	5.54	.0001	1.51
	Control	27	16.11	5.01				

experimental group obtained from the MAI [$t(26) = 9.04$; $p < 0.05$]. The post-test mean score ($\bar{X}$=178.85; sd=22.11) of the control group obtained from the MAI was close to their pre-test mean score ($\bar{X}$=180.44; sd=24.44). However, no statistically significant difference was found between the pre-test and post-test mean scores of the control group obtained from MAI [$t(26)=0.799$; $p > 0.05$].

The findings obtained from comparing the MAI pre and post-test scores of the experimental and control groups are given in Table 8.

As seen in Table 8, no statistically significant difference was found between the mean scores of the experimental and control groups from the MAI pre-test [$t(52)=0.377$; $p > 0.05$]. Considering the pre-test mean scores ($\bar{X}e$=177.81; $\bar{X}c$=180.44), the two groups were quite close. However, the mean of the control group was slightly higher than the experimental group. A statistically significant difference was found between the mean scores of the experimental and control groups from the MAI post-tests [$t(52) = 4.61$; $p < 0.05$]. Considering the post-test mean scores ($\bar{X}e$=208.25; $\bar{X}c$=178.85), the MAI mean score of the experimental group was higher than that of the control group. In addition, Cohen's effect size value was calculated as 1.25, which shows that STEM education in the experimental group had a much higher effect on students' metacognitive awareness than teaching in the control group.

Parallel to the result obtained in this study, studies are concluding that STEM education increases metacognitive awareness (Franklin et al., 2018; Santangelo et al., 2021; Wangguway et al., 2020). In their study, Wangguway et al. (2020) concluded that STEM-based learning improved students' metacognitive skills. In another study, Wilis et al. (2023) found that STEM activities caused an increase in secondary school students' metacognitive awareness levels. Similarly, Contente and Galvão (2022), in a study with secondary school students, concluded that problem-based STEM practices positively affected students' metacognitive abilities. Unlike this result, Anwari et al. (2015) observed that education with STEM activities did not significantly increase metacognitive awareness in eighth-grade students.

3.3 Results Related to the Third Research Question

The findings obtained from comparing the SCT pretest-posttest scores of the experimental and control groups are presented in Table 9.

As seen in Table 9, the post-test mean score ($\bar{X}$=26.29; sd=8.12) of the experimental group from SCT was higher than their pre-test mean score (X=19.29; sd=8.20). In addition, a statistically significant difference was found between the pre-test and post-test mean scores of the experimental group obtained from SCT [$t(26)=3.98$; $p < 0.05$]. The post-test mean score ($\bar{X}$=16.11; sd=5.01) of the control group from SCT was close to their pre-test mean score ($\bar{X}$= 6.96; sd=6.45). However, no statistically significant difference was found between the pre-test and post-test mean scores obtained from the SCT [$t(26)=0.778$; $p > 0.05$].

The findings obtained from comparing the SCT pre-test and post-test scores of the experimental and control groups are given in Table 10.

As understood in Table 10, no statistically significant difference was found between the mean scores of the experimental and control groups from the SCT pre-tests [$t(52)=1.16$; $p > 0.05$]. Considering the pre-test mean scores ($\bar{X}e=19.29$; $\bar{X}c=16.96$), the two groups were very close. However, the mean of the experimental group was slightly higher than the control group. A statistically significant difference was found between the mean scores of the experimental and control groups from the SCT post-tests [$t(52)=5.54$; $p < 0.05$]. Considering the post-test mean scores ($\bar{X}e=26.29$; $\bar{X}c=16.11$), the experimental group's SCT mean score was higher than the control group. In addition, Cohen's effect size value was calculated as 1.51, which shows that the STEM education in the experimental group had a much higher effect on the student's creativity than that of the control group.

When the literature is examined, there is more than one study that concluded that STEM education increases scientific creativity in parallel with the result obtained in this study (Charyton, 2015; Eroğlu & Bektaş, 2022; Hanif et al., 2019; Hebebci & Usta, 2022; Kim et al., 2014; Larkin, 2015; Lee & Lee, 2013; Putri et al., 2019; Tunkham et al., 2016) and a study with eighth graders, Sutaphan and Yuenyong (2023) observed that STEM education increased creativity. Bozkurt Altan and Tan (2021) and Ugras (2018) concluded that STEM activities developed following the STEM approach increased the scientific creativity of secondary school students. In their study, Lee and Lee (2013) concluded that scientific creativity increased in students when science lessons were carried out with activities by STEM education. Kim et al. (2014), in their study with sixth graders, concluded that students' scientific creativity increased significantly due to the education provided with STEM-integrated activities. Genek and Kucuk (2020) found that STEM education positively affected the scientific creativity of primary school students.

4. CONCLUSION

This study examined the effect of STEM education of the Force and Energy unit on seventh-grade students' academic achievement, creativity, and metacognitive awareness. There was no statistically significant difference between the mean scores of the experimental and control groups from the FEAAT pre-tests, and it was concluded that the prior knowledge levels were equal. On the other hand, a statistically significant difference was found between the mean scores of the experimental and control groups from the FEAAT post-tests, and it was observed that this difference was in favor of the experimental group. At the same time, when the pre-and post-tests of the groups were examined separately, it was concluded that both groups had increased academic achievement. However, the increase in academic achievement observed in the experimental group was higher than in the control group. The difference between the experimental and control group FEAAT post-test scores can be considered significant considering the effect value.

There was no statistically significant difference between the mean scores of the experimental and control groups from the MAI pre-tests, and it was concluded that the metacognitive awareness levels were the same in both groups before the instruction. However, a statistically significant difference was found between the mean scores of the experimental and control groups from the MAI post-tests. When the post-test means were examined, it was observed that the post-test mean scores of the experimental group were found to be higher. According to the effect size between the MAI post-test scores, it was determined that STEM education had a very high effect on increasing students' metacognitive awareness.

There was no statistically significant difference between the mean scores of the experimental and control groups obtained from the SCT pre-tests, and it was concluded that the scientific creativity levels of both groups were close before the instruction. However, a statistically significant difference was found between the mean scores of the experimental and control groups from the SCT post-test, and it was observed that the mean score of the experimental group from the SCT post-test was higher. The SCT post-test effect size of the experimental and control groups shows that STEM education significantly increased scientific creativity.

Education in the control group was effective in increasing academic achievement. However, it was ineffective in changing the metacognitive awareness and creativity levels. In the experimental group taught with the STEM cycline, metacognitive awareness, and creativity levels increased significantly in addition to academic success. While both instructions used in this study increased the students' academic achievement, only the STEM cycline effectively increased the students' metacognitive awareness and creativity. The significant increase in the students' metacognitive awareness and creativity levels in the experimental group, unlike those in the control group, may be because they try to solve the given problem situations. Experimental group students had the opportunity to print the models they designed through Web 2.0 tools on a 3D printer and discussed using these models in solving problem situations.

This study is limited to the seventh-grade level Force and Energy unit. Researchers can also investigate different levels and units at the secondary school level. Another limitation of the study is that it lasted for five weeks. However, future researchers may examine the effect of STEM education by extending it to a semester or an academic year to cover more than one unit. This research has two study groups: experimental and control groups. In future studies, studies can be carried out with more than one experimental group in which STEM education is integrated with different approaches.

ABBREVIATIONS

STEM, Science, Technology, Engineering Mathematics
FEAAT, Force and Energy Academic Achievement Test
SCT, Scientific Creativity Test
MAI, Metacognitive Awareness Inventory

REFERENCES

Acar, S., Burnett, C., & Cabra, J. F. (2017). Ingredients of creativity: Originality and more. *Creativity Research Journal*, *29*(2), 133–144. https://doi.org/10.1080/10400419.2017.1302776

Ajjan, H., & Hartshorne, R. (2008). Investigating faculty decisions to adopt Web 2.0 technologies: Theory and empirical tests. *The Internet and Higher Education*, *11*(2), 71-80.

Alemdar, M., Moore, R.A., Lingle, J. A., Rosen, J, Gale, J., & Usselman, M. C. (2018). The impact of a middle school engineering course on students' academic achievement and noncognitive skills. *International Journal of Education in Mathematics, Science and Technology*, *6*(4), 363-380. DOI: 10.18404/ijemst.440339

Ali, R., Bhadra, J., Siby, N., Ahmad, Z., & Al-Thani, N. J. (2021). A STEM model to engage students in sustainable science education through sports: A case study in Qatar. *Sustainability*, *13*(6), 3483.

Ambruso, M. D. (2003). Challenging students with experiments. *Science Teacher*, *70*(1), 41-43.

Anwari, I., Yamada, S., Unno, M., Saito, T., Suwarma, I., Mutakinati, L., & Kumano, Y. (2015). Implementation of authentic learning and assessment through STEM education approach to improve students' metacognitive skills. *K-12 STEM Education*, *1*(3), 123-136. The Institute for the Promotion of Teaching Science and Technology (IPST). Retrieved March 21, 2023 from https://www.learntechlib.org/p/209546/.

Apriyani, R., Ramalis, T. R., & Suwarma, I. R. (2019). Analyzing students' problem-solving abilities of direct current electricity in STEM-based learning. *Journal of Science Learning*, *2*(3), 85-91.

Arslan, K., & Costu, F. (2021). Web 2.0 applications in the teaching process: A swot analysis. *Shanlax International Journal of Education*, *9*(4), 460-479.

Arslan, K., & Yıldırım, M. (2021). Effect of online science course supported with Web 2.0 tools on the academic achievement of fifth-grade students and student opinions. *Science Education International*, *32*(4), 311-322. https://doi.org/10.33828/sei.v32.i4.6

Bolatlı, Z., & Korucu, A. T. (2018). Secondary school students' feedback on course processing and collaborative learning with web 2.0 tools-supported STEM activities. *Bartın University Journal of Faculty of Education*, *7*(2), 456-478.

Bozkurt Altan, E., & Tan, S. (2021). Concepts of creativity in design-based learning in STEM education. *International Journal of Technology and Design Education*, *31*(3), 503-529. https://doi.org/10.1007/s10798-020-09569-y

Chang, S. H., Yang, L. J., Chen, C. H., Shih, C. C., Shu, Y., & Chen, Y. T. (2022). STEM education in academic achievement: A meta-analysis of its moderating effects. *Interactive Learning Environments*, 1-23. https://doi.org/10.1080/10494820.2022.2147956

Charyton, C. (2015). Creative engineering design: The meaning of creativity and innovation in engineering. Christine Charyton (Ed.), *Creativity and innovation among science and art içinde* (s. 135-152). London: Springer-Verlag.

Chine, D. R., & Larwin, K. H. (2022). Using HLM to determine a STEM program's impact on middle school academic achievement. *International Journal of Research in Education and Science*, *8*(1), 1-17. https://doi.org/10.46328/ijres.2607

Chiou, Y. (2011). *Perceived usefulness, perceive ease of use, computer attitude, and using experience of Web 2.0 applications as predictors of intent to use Web 2.0 by pre- service teachers for teaching* [Unpublished Doctoral Dissertation]. Ohio University, Ohio.

Contente, J., & Galvão, C. (2022). STEM education and problem-solving in space science: A case study with CanSat. *Education Sciences*, *12*, 251. https://doi.org/10.3390/ educsci12040251

Çavaş, P., Ayar, A., Bula Turuplu, S., & Gürcan, G. (2020). A study on the status of STEM education research in Turkey. *YYU Journal of Education Faculty*, *17*(1), 823-854. doi: 10.33711/yyuefd.751853

Çepni, S. (2018). *Kuramdan Uygulamaya STEM Eğitimi. (4. Ed)* [STEM Education from Theory to Practice. (4th Ed)]. Ankara: Pegem Akademi Yayınları.

Çevik, M. (2018). Impacts of the project-based (PBL) science, technology, engineering, and mathematics (STEM) education on academic achievement and career interests of vocational high school students. *Pegem Journal of Education and Instruction*, *8*(2), 281-306. http://dx.doi.org/10.14527/pegegog.2018.012

Çorlu, M. S. (2014). Call for manuscripts on STEM education. *Turkish Journal of Education*, *3*(1), 4–10.

Çorlu, M. S., Capraro, R. M., & Capraro, M. M. (2014). Introducing STEM education: Implications for educating our teachers for the age of innovation. *Education and Science*, *39*(171), 74-85.

Çorlu, M. S., & Çallı, E. (2017). *STEM kuram ve uygulamalarıyla fen, teknoloji, mühendislik ve matematik eğitimi* [Science, technology, engineering and mathematics education with STEM theories and applications]. İstanbul: Pusula Yayıncılık.

DeWaters, J., & Powers, S. E. (2006). Improving science and energy literacy through project-based K-12 outreach efforts that use energy and environmental themes. *Proceedings of the 113th Annual ASEE Conference and Exposition* (pp. 11-738). Chicago, IL.

Doppelt, Y., Mehalik, M. M., Schunn, C. D., Silk, E., & Krysinski, D. (2008). Engagement and achievements: A case study of design-based learning in a science context. *Journal of Technology Education*, *19*(2), 22-39.

Dugger, E. W. (2010). *Evolution of STEM in the United States*. Australia: Biennial International Conference on Technology Education Research. Australia.

Erdogan, N., Corlu, M. S., & Capraro, R. M. (2013). Defining innovation literacy: Do robotics programs help students develop innovation literacy skills?. *International Online Journal of Educational Sciences*, *5*(1), 1-9.

Eroğlu, S., & Bektaş, O. (2022). The effect of 5E-based STEM education on academic achievement, scientific creativity, and views on the nature of science. *Learning and Individual Differences*, *98*, 1-11. https://doi.org/10.1016/j.lindif.2022.102181

Flavell, J. H. (1979). Metacognitive and cognitive monitoring: A new area of cognitive-developmental inquiry. *American Psychologist*, *34*(10), 906-911.

Franklin, S. V., Hane, E., Kustusch, M. B., Ptak, C., & Sayre, E. C. (2018). Improving retention Through metacognition. *Journal of College Science Teaching*, *48*(2), 21-27.

Genek, E. S., & Kucuk, D. Z. (2020). Investigation of scientific creativity levels of elementary school students who enrolled in a STEM program. *Elementary Education Online*, *19*(3), 1715-1728. doi:10.17051/ilkonline.2020.734849

Guzey, S.S., Moore, T.J., Harwell, M., & Moreno, M. (2016). STEM integration in middle school life science: Student learning and attitudes. *Journal of Science Education and Technology*, *25*, 550–560. https://doi.org/10.1007/s10956-016-9612-x

Gülen, S., & Yaman, S. (2019). The effect of integration of STEM disciplines into Toulmin's argumentation model on students' academic achievement, reflective thinking, and psychomotor skills. *Journal of Turkish Science Education*, *16*(2), 216-230.

Hanif, S., Wijaya, A. F. C., & Winardo, N. (2019). Enhancing students' creativity through STEM project-based learning. *Journal of Science Learning*, *2*(2), 50-57.

Harlen, W. (2004). Evaluating inquiry-based science developments: A paper commissioned by the National Research Council in preparation for a meeting on the status of evaluation of inquiry-based science education. *Cambridge: National Academy of Sciences Education*, *26*(1), 14-17.

Hebebci, M. T., & Usta, E. (2022). The effects of integrated STEM education practices on problem-solving skills, scientific creativity, and critical thinking dispositions. *Participatory Educational Research*, *9*(6), 358-379. https://doi.org/10.17275/per.22.143.9.6

Honey, M., Pearson, G., & Schweingruber, H. (2014). *National Academy of Engineering*. Washington D. C.: Committee on Integrated STEM Education.

Hsu, Y. S., & Fang, S. C. (2019). Opportunities and challenges of STEM education. *Asia-Pacific STEM teaching practices: From theoretical frameworks to practices*, 1-16. https://doi.org/10.1007/978-981-15-0768-7_1

Hsu, Y. S., Lin, Y. H., & Yang, B. (2017). Impact of augmented reality lessons on students' STEM interest. *Research and Practice in Technology Enhanced Learning*, *12*(1), 2. DOI 10.1186/s41039-016-0039-z

Hu, W., & Adey, P. (2002). A scientific creativity test for secondary school students. *International Journal of Science Education*, *24*(4), 389-403.

Hung, H., & Yuen, S. (2010). Educational use of social networking technology in higher education. *Teaching in Higher Education*, *15*(6), 703-714.

Hursen, C. (2021). The effect of problem-based learning method supported by Web 2.0 tools on academic achievement and critical thinking skills in teacher education. *Technology, Knowledge and Learning*, *26*, 515–533. https://doi.org/10.1007/s10758-020-09458-2

Hwang, G. J., Li, K. C., & Lai, C. L. (2020). Trends and strategies for conducting effective STEM research and applications: A mobile and ubiquitous learning perspective. *International Journal of Mobile Learning and Organisation*, *14*(2), 161-183.

Jaarsveld, S., Lachmann, T., & van Leeuwen, C. (2012). Creative reasoning across developmental levels: Convergence and divergence in problem creation. *Intelligence*, *40*(2), 172-188.

James, J. S. (2014). *Science, technology, engineering, and mathematics (STEM) curriculum and seventh grade mathematics and science achievement* [Doctoral dissertation, Grand Canyon University]. Grand Canyon University, Chicago.

Judson, E. (2014). Effects of transferring to STEM-focused charter and magnet schools on student achievement. *The Journal of Educational Research*, *107*(4), 255-266.

Kadayıfçı, H. (2008). *The effect of an instructional model based on creative thinking on students' conceptual understanding of separation of matter subject and their scientific creativity* [Doctoral dissertation, Gazi University]. Gazi University, Ankara.

Karaşah-Çakıcı, Ş., Kol, Ö., & Yaman, S. (2021). The effects of STEM education on academic achievement in science courses: A meta-analysis. *Journal of Theoretical Educational Science*, *14*(2), 264-290.

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, *3*, 1-11. https://doi.org/10.1186/s40594-016-0046-z

Kilic, S. (2016). Cronbach's alpha reliability coefficient. *Psychiatry and Behavioral Sciences*, *6*(1), 47.

Kim, D., Ko, D., Han, M., & Hong, S. (2014). The effects of science lessons applying STEAM education program on the creativity and interest levels of elementary students. *Journal of the Korean Association for Science Education*, *34*(1), 43-54.

Kırıkkaya, E. B., & Yıldırım, İ. (2021). Investigating the effect of using Web 2.0 tools on 7th-grade students' academic achievements in science and self-directed learning with technology. *Journal of Turkish Science Education*, *18*(3), 439-460. DOI no: 10.36681/tused.2021.83

Kwon, H. (2017). Effects of 3D printing and design software on student's interests, motivation, mathematical and technical skills. *Journal of STEM Education*, *18*(4) 37-42.

Koyunlu Ünlü, Z., & Dökme, İ. (2020). Multivariate assessment of middle school students' interest in STEM career: A profile from Turkey. *Research in Science Education*, *50*, 1217-1231. https://doi.org/10.1007/s11165-018-9729-4

Kuenzi, J. J. (2008). *Science, technology, engineering, and mathematics (STEM) education: Background, federal policy, and legislative action*. Nebraska: Digital Commons, University of Nebraska. Retrieved February 27, 2023 from http://www.fas.org/sgp/crs/misc/RL33434.pdf

Kurt, U. (2020). *Comparison of the effects of different active learning methods on the teaching of "Cell and division" and "Force and energy" units* [Doctoral dissertation, Atatürk University]. Atatürk University, Erzurum.

Kurt, M., & Benzer, S. (2020). An investigation on the effect of STEM practices on sixth grade students' academic achievement, problem solving skills, and attitudes towards STEM. *Journal of Science Learning*, *3*(2), 79-88.

Lamb, R., Akmal, T., & Petriei, K. (2015). Development of a cognition priming model of STEM learning. *Journal of Research in Science Teaching*, *52*(3), 410-437.

Langdon, D., McKittrick, G., Beede, D., Khan, B., & Dom, M. (2011). STEM: Good jobs now and for the future. *U.S. Department of Commerce Economics and Statistics Administration*, *3*(11), 2.

Larkin, T. L. (2015). Creativity in STEM education: Reshaping the creative project. *International Conference on Interactive Collaborative Learning (ICL)* (pp. 1184-1189). Florence, Italy.

Lee, S., & Lee, H. (2013). The effects of science lesson applying STEAM education on the creativity and science related attitudes of elementary school students. *Journal of Korean Elementary Science Education*, *32*(1), 60-70.

Leonard, J., Buss, A., Gamboa, R., Mitchell, M., Fashola, O. S., Hubert, T., & Almughyirah, S. (2016). Using robotics and game design to enhance children's self-efficacy, STEM attitudes, and computational thinking skills. *Journal of Science Education and Technology*, *25*(6), 860-876. DOI 10.1007/s10956-016-9628-2

Liang, J. C. (2002). *Exploring scientific creativity of eleventh grade students in Taiwan* [Unpublished PhD Thesis]. The University of Texas, Austin.

Lubart, T., Zenasni, F., & Barbot, B. (2013). Creative potential and its measurement. *International Journal for Talent Development and Creativity*, *1*(2), 41-51.

Martín-Páez, T., Aguilera, D., Perales-Palacios, F. J., & Vílchez-González, J. M. (2019). What are we talking about when we talk about STEM education? A review of literature. *Science Education*, *103*(4), 799-822. https://doi.org/10.1002/sce.21522

McLoughlin, C., & Lee, M. (2007). Social software and participatory learning: Pedagogical choices with technology affordances in the Web 2.0 era. In *ICT: Providing choices for learners and learning. Proceedings ascilite Singapore 2007* (pp. 664-675). Centre for Educational Development, Nanyang Techn.…

McDonald, C. V. (2016). STEM education: A review of the contribution of the disciplines of science, technology, engineering and mathematics. *Science Education International*, *27*(4), 530-569.

Meador, K. S. (2003). Thinking creatively about science suggestions for primary teachers. *Gifted Child Today*, *26*(1), 25-29.

Miles, M.B. & Huberman, A.M. (1994). *Qualitative data analysis: An expanded sourcebook. (2nd Ed.).* Calif.: SAGE Publications.

Mohd Shahali, E. H., Halim, L., Rasul, M. S., Osman, K., & Mohamad Arsad, N. (2019). Students' interest towards STEM: a longitudinal study. *Research in Science & Technological Education*, *37*(1), 71-89.

Morrison, J. (2006). *TIES STEM education monograph series, attributes of STEM education*. Baltimore, MD: TIES.

Murphy, S., MacDonald, A., Wang, C. A., & Danaia, L. (2019). Towards an understanding of STEM engagement: A review of the literature on motivation and academic emotions. *Canadian Journal of Science, Mathematics and Technology Education*, *19*, 304-320.

O'Reilly, T. (2007). What is Web 2.0: Design patterns and business models for the next generation of software. *Communications and Strategies*, *1*(3), 17-37.

Özcan, H., & Koca, E. (2009). The impact of teaching the subject "pressure" with STEM approach on the academic achievements of the secondary school 7th grade students and their attitudes towards *STEM. Education and Science*, *44*(198), 201-227. DOI: 10.15390/EB.2019.7902

Palaigeorgiou, G., & Grammatikopoulou, A. (2016). Benefits, barriers and prerequisites for Web 2.0 learning activities in the classroom: The view of Greek pioneer teachers. *Interactive Technology and Smart Education*, *13*(1), 2-18. DOI 10.1108/ITSE-09-2015-0028

Patton, M. (2002). *Qualitative evaluation and research methods*. Beverly Hills, CA: SAGE.

Putri, N., Rusdiana, D., & Suwarma, I. R. (2019). The comparison of student creative thinking skill using CBL implemented in STEM education and combined with PSL worksheet in Indonesian school. *Journal of Science Learning*, *3*(1), 7-11.

Rawat, T. C. (2010). A study to examine the fluency component of scientific, creative talent of elementary stage students of Himachal Pradesh with respect to area, type of school, and gender. *International Transactions in Humanities and Social Sciences*, *2*(2), 152-161.

Ricks, M. M. (2006). *A study of the impact of an informal science education program on middle school students' science knowledge, science attitude, STEM high school and college course selections, and career decisions* [Doctoral dissertation, The University of Texas]. The University of Texas at Austin.

Riskowski, J. L., Todd, C. D., Wee, B., Dark, M. & Harbor, J. (2009). Exploring the effectiveness of an interdisciplinary water resources engineering module in an eighth-grade science course. *International Journal of Engineering Education*, *25*(1), 181-195.

Runco, M. A. (2008). Creativity and education. *New Horizons in Education*, *56*(1), n1.

Samuels, K., & Seymour, R. (2015). The middle school curriculum: Engineering, anyone?. *Technology and Engineering Teacher*, *74*(6), 8-12.

Santangelo, J., Cadieux, M., & Zapata, S. (2021). Developing student metacognitive skills using active learning with embedded metacognition instruction. *Journal of STEM Education*, *22*(2), 75–87.

Sarıçam, U., & Yıldırım, M. (2021). The effects of digital game-based stem activities on students' interests in stem fields and scientific creativity: Minecraft case. *International Journal of Technology in Education and Science*, *5*(2), 166-192. https://doi.org/10.46328/ijtes.136

Schraw, G., & Dennison, S. R. (1994). Assessing metacognitive awareness. *Contemporary Educational Psychology*, *19*, 460-470.

Stohlmann, M., Moore, T., & Roehrig, G. (2012). Considerations for teaching integrated STEM education. *Journal of Pre-College Engineering Education Research*, *2*(1), 28–34.

Sumarni, W., & Kadarwati, S. (2020). Ethno-STEM project-based learning: Its impact to critical and creative thinking skills. *Jurnal Pendidikan IPA Indonesia*, *9*(1), 11-21.

Sutaphan, S., & Yuenyong, C. (2023). Enhancing grade eight students' creative thinking in the water stem education learning unit. *Jurnal Cakrawala Pendidikan*, *42*(1), 120-135. https://doi.org/10.21831/cp.v42i1.36621

Thomas, G. P. (2012). Metacognition in science education: Past, present and future considerations. *Second International Handbook of Science Education*, 131-144.

Tseng, K. H., Chang, C. C., Lou, S. J., & Chen, W. P. (2013). Attitudes towards science, technology, engineering and mathematics (STEM) in a project-based learning (PjBL) environment. *International Journal of Technology and Design Education*, *23*(1), 87-102.

Torrance, E. P., & Goff, K. (1989). A quiet revolution. *Journal of Creative Behavior*, *23*(2), 136-145.

Tunkham, P., Donpudsa, S., & Dornbundit, P. (2016). Development of STEM activities in chemistry on "protein" to enhance 21 st century learning skills for senior high school students. *Humanities, Arts and Social Sciences Studies*, *16*(3), 217-234.

Ugras, M. (2018). The effect of STEM activities on stem attitudes, scientific creativity, and motivation beliefs of the students and their views on STEM education. *International Online Journal of Educational Sciences*, *10*(5), 165-182.

Uslu, S., & Boz Yaman, B. (2021). Reflections from the application of STEM-based environmental siphon activity. *Pamukkale University Journal of Education*, *53*, 457-494. doi: 10.9779/pauefd.787908

Uysal, M. Z., & Çaycı, B. (2022). The effect of using Web 2.0 tools in the primary school 4th-grade science course on various variables. *Participatory Educational Research*, *9*(1), 137-149. http://dx.doi.org/10.17275/per.22.8.9.1

Veenman, M. V., van Hout-Wolters, B. H., & Afflerbach, P. (2006). Metacognition and learning: Conceptual and methodological considerations. *Metacognition and learning*, *1*, 3-14. DOI 10.1007/s11409-006-6893-0

Wahono, B., Lin, P. L. & Chang, C. Y. (2020). Evidence of STEM enactment effectiveness in Asian student learning outcomes. *International Journal of STEM Education*, *7*(36), 1-18. https://doi.org/10.1186/s40594-020-00236-1

Wang, L. H., Chen, B., Hwang, G. J., Guan, J. Q., & Wang, Y. Q. (2022). Effects of digital game-based STEM education on students' learning achievement: a meta-analysis. *International Journal of STEM Education*, *9*(26), 1-13. https://doi.org/10.1186/s40594-022-00344-0

Wangguway, Y., Kurniawati, S., Maylisa, I. N., Al Jabbar, Z. L., & Sulistiyono, B. (2020, June). The analysis of STEM-PjBL implementation and its effect on students' metacognition skills in resolving social arithmetic problems. In *Journal of Physics: Conference Series* (Vol. 1563, No. 1, p. 012048). IOP Publishing.

Wilis, R., Prayitno, B.A., Sunarno, W., & Anjirawaroj, S. (2023). Improving students' metacognitive abilities and creative thinking skills through STEM-based in online learning. *Jurnal Pendidikan Biologi Indonesia*, *9*(1), 90-102. https://doi.org/10.22219/jpbi.v9i1.22994

Williams, P. J. (2011). STEM Education: Proceed with caution. *Design and Technology Education*, *16*(1), 26-35.

Wilson, N. S., & Bai, H. (2010). The relationships and impact of teachers' metacognitive knowledge and pedagogical understandings of metacognition. *Metacognition and Learning*, *5*, 269-288. DOI 10.1007/s11409-010-9062-4

Yabas, D., Kurutaş, B. S., & Corlu, M. S. (2022). Empowering girls in STEM: Impact of girls meets project. *School Science and Mathematics*, *122*(5), 247-258. https://doi.org/10.1111/ssm.12540

Yang, D., & Baldwin, S. J. (2020). Using technology to support student learning in an integrated STEM learning environment. *International Journal of Technology in Education and Science*, *4*(1), 1-11. https://doi.org/10.46328/ijtes.v4i1.22