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RESEARCH ARTICLE

Teaching Environmental Sustainability Topics with Flipped Learning Model Enriched with STEM Activities*

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ABSTRACT

This study aims to reveal the effect of the flipped learning model enriched with STEM activities on students' cognitive structures related to environmental sustainability concepts and to present the design, implementation, and evaluation processes of these activities. The study group consisted of 28 female students in the eighth-grade of secondary school. Word Association Test was used as a data collection tool. In the analysis of the word association tests, the cut-off points were determined by creating a frequency table of the number of words written by the students about the concepts in the word association tests. It was determined that there was a difference between the students' answers to the key concepts given in the word association test (waste, garbage, recycling, reuse, recovery, environmental pollution, sustainability) in the pre-test (f= 611) and post-test (f= 1943) and that they frequently included various concepts in the post-test that they did not include in the pre-test. In addition, it was revealed that the key concepts were meaningfully associated with the activity topics of the research in the post-test. In line with the findings obtained, it was concluded that the students' previously existing weak cognitive structures towards the concepts related to environmental sustainability improved after the activities.

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1. Introduction

Sustainability is a highly topical issue today. Climate change, the rapid depletion of natural resources, social inequalities, increasing eco-friendly consumer demands, international agreements, and technological developments have made this issue a current trend and a fundamental necessity of today's world. By itself, sustainability means "to continue". However, when it is used with other concepts, it gains a meaning that embodies today and tomorrow and expresses the continuation of development for the benefit of future generations (Morelli, 2011; Yılmaz & Yücel, 2022). It has found a wide place in the world through the concept of "sustainable development" by using it with the concept of development. Sustainable development aims to meet the basic needs and the expectation of a better life for all humanity (Presidency of the Republic of Türkiye Strategy and Budget Directorate, 2024). Sustainability is generally considered to have three components: environmental, social, and economic sustainability. The development of these three areas is not separate but intertwined. Sustainability is considered a paradigm for thinking about a future in which environmental, social, and economic considerations are balanced in pursuing

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development and improved quality of life (McKeown et al., 2002).

Environmental sustainability, one of the components of sustainability, is defined in the Our Common Future report as "meeting the resource and service needs of present and future generations without compromising the health of the ecosystems that provide them" (World Commission on Environment and Development [WCED], 1987). In short, it can be expressed as ensuring the continuity of natural resources. Environmental sustainability covers issues such as protection of biodiversity, reduction of environmental pollution, combating climate change, waste management, protection of natural resources and order, and efficient use of resources.

There are many important activities and initiatives related to sustainability in the world. The "UN Conference on Environment and Development" was held in Rio in 1992. The "World Summit on Sustainable Development" was held in 2002; the UN Conference on Sustainable Development, also known as Rio+20, was held in 2012, and the Paris Agreement adopted in 2016 can be considered as milestones that have been effective in shaping today's understanding of the concept of sustainability. Another important aspect of these dates is their increasing international recognition of education as a key enabler for sustainable development (UNESCO, 2017). The "Decade of Education for Sustainable Development, 2005-2014" is a global initiative by the United Nations that aims to integrate sustainable development principles, values, and practices into all aspects of education. This education is a vision to promote behavioral changes that will create a more sustainable future for present and future generations in environmental integrity, economic viability, and a just society (UNESCO, 2005). The goals adopted in 2015 as "Agenda 2030: UN Sustainable Development Goals (SDGs)" and prepared within the scope of the "United Nations Development Program" have established 15-year targets for the ongoing environmental, social, and economic problems in the world (United Nations, 2015). With these goals, a new global development framework was drawn, and environmental issues such as sustainable cities, climate change, combating drought, and protecting biodiversity were included in the sustainable development agenda (Republic of Türkiye Ministry of Foreign Affairs, 2022). The emphasis on education for sustainability continued with the fourth goal, "quality education". In addition, with the 'European Green Deal' announced in 2019, the European Commission has identified learning for environmental sustainability as a priority area by providing quality and inclusive education on climate change, biodiversity, and sustainability to students of all ages (Ministry of National Education [MoNE] Workshop Report, 2023)].

Türkiye, on the one hand, follows and becomes a party to international activities related to sustainability, and on the other hand, conducts various studies on education for sustainability in this process. Some of these efforts include the inclusion of sustainable development outcomes in curricula (MoNE, 2013, 2018, 2024), updating the "Environmental Education" course as "Environmental Education and Climate Change" course, in-service trainings on climate change, digital content prepared for the EBA platform, and training programs on climate change within the framework of lifelong learning (MoNE, 2023). The most recent curriculum, the Turkish Maarif Model Curriculum, adopts a science teaching approach based on sustainability. The content determined in the program aims to make students think about sustainability and gain life skills related to sustainability (MoNE, 2024). Sustainability awareness, it aims aware of local and global environmental problems and take action to solve them. In short, the critical role of education in developing sustainability awareness has been recognized internationally and nationally.

Education is a fundamental tool for building a sustainable future. Education for sustainability demands an action-oriented and transformative pedagogy that supports self-directed learning, participation and collaboration, problem-orientation, inter- and transdisciplinarity, and the linking of formal and non-formal learning. Only such pedagogical approaches make it possible to develop the core competencies needed to promote sustainable development (UNESCO, 2017). STEM education is an approach that provides these characteristics. Teachers are expected to make the necessary adaptations in realizing the programs' objectives and outcomes (MoNE, 2018). In this study, flipped learning model enriched with STEM activities were preferred for teaching topics related to environmental sustainability. The fact that we are faced with a generation born in the age of technology motivated to learn when it comes to what they can see, do and understand, and more accustomed to discovering through their own experiences than previous generations (Ramírez & Macías, 2013) has made the use of technology in education a necessity. This need supports using technology more in STEM applications (Bybee, 2010). One of the most appropriate ways to combine STEM and technology is to combine STEM with flipped learning. Due to its structure, flipped learning can be combined with many different teaching approaches.

In flipped learning, according to Abeysekera and Dawson (2015), through the use of computer technology and the internet (e.g., online or in a recorded video lecture), the information-transfer component of a traditional lecture is taken out of class time and replaced with a series of interactive activities designed to provide active learning. Flipped learning puts the learner at the center, ensures that students come to class prepared, encourages students to take responsibility for learning, allows students to move at their own pace, increases the effective use of class time for active learning and student engagement, and enhances the learning environment by combining the advantages of face-to-face and online learning (Bergmann & Sams, 2014; Bishop & Verleger, 2013; Cueva & Inga, 2022; Fautch, 2015; Johnson, 2013; Kara, 2016; Kardaş &

Yeşilyaprak, 2015; McCallum et al., 2015; Moraros et al., 2015; Stöhr et al., 2020; Yangari & Inga, 2021).

In this study, combining flipped learning and STEM aimed to increase the quality and efficiency of students' learning by having the subject content outside the classroom and the applications in the classroom to capture the advantage of both types of learning by combining students' self-paced learning and group collaborative learning; to increase students' interactions with each other and the teacher in the classroom; to benefit from one-to-one time in the classroom that allows the teacher to deal with each student individually; to enable students to learn how to learn; to encourage and enable students to take responsibility for their own learning and to become lifelong learners; to stimulate intellectual curiosity about the field of engineering; to provide insight into the current issue of environmental sustainability, to raise awareness of the need for everyone to do something about it and to demonstrate through practice that something can be done.

In addition, in some studies in the literature (Baran et al., 2016; Karakaya et al., 2019; Kaplan & Yılmaz, 2021), students and researchers stated that time was insufficient in the implementation of STEM activities. Similarly, teachers stated that there were time problems in the applications and that students did not have enough knowledge about the subject (Eroğlu & Bektaş, 2016). Siew et al. (2015) recommended that some of the studies should be planned to be carried out outside of class time in order to eliminate the time problem experienced while implementing STEM activities. In order to eliminate these problems and to realize the STEM implementation steps in the most appropriate way, classrooms should be designed to include technology in the process (Karakaya et al., 2019). With flipped learning, students will be able to allocate time outside of school to learn the content and there will be enough time at school for hands-on activities in which students will actively participate in learning (Fulton, 2012; Lafee, 2013; Milman, 2012). In addition, in order for STEM education to achieve its purpose, more time should be allocated to inquiry-based activities to reveal students' information needs and encourage their learning (Baran et al., 2016). With flipped learning activities enriched with STEM activities, students will be able to learn the learning content in out-of-school times and the STEM steps to be done in the face-to-face lessons time in the classroom can be realized without time problems.

Cognition is the processes of mental understanding (Oxford Dictionary, 2024). On the other hand, cognitive structure can be defined as the mental schema and framework that organizes and forms the parts that constitute knowledge in any learning process (Goldenson, 1884; as cited in Uçak & Güzeldere, 2006). Cognitive structure is the basis of mental activities, such as how an individual processes, learns, remembers, perceives, and problem solves information. It has an important place in how individuals perceive and make sense of the stimuli coming from their environment in the learning process, how they direct them with their past experiences and how they associate new knowledge with existing knowledge. It is quite difficult to reveal the cognitive structures of individuals, but determining and analyzing their thoughts about the related concepts can provide important data in this direction (Gilbert et al., 1998; Kurt & Ekici, 2013). At this point, it is possible to reveal students' cognitive structures, that is, the connections and associations that exist in their minds, with the word association test (WAT). WATs are an alternative measurement and evaluation tool that is effective in determining the concepts in students' cognitive structures and whether the connection between these concepts is correct (Bahar et al., 1999). In this context, WAT was used in this study to reveal students' cognitive structures about some key concepts related to environmental sustainability issues.

Considering the need to actively involve students in learning through research and inquiry, digital-based activities suitable for the century we are in (Bybee, 2011), the fact that there is a significant lack and uncertainty in our country about which skills can be gained through sustainability education, especially from an early age (Uslu & Özdemir, 2023), and the need to develop appropriate teaching materials for sustainability (MoNE, 2022), teaching in this study was carried out with flipped learning enriched with STEM activities.

In this study, the answer to the following question was sought:

"How do eighth-grade students' cognitive structures towards environmental sustainability concepts change during flipped learning enriched with STEM activities?"

2. Method

Ethical approval was provided by the Gazi University Ethics Committee with the decision number 2024-1126 on 09.07.2024.

2.1. Research Model

The study was conducted using a one-group pretest-posttest quasi-experimental design. The quasi-experimental method refers to the method used when the experimental study is conducted with spontaneously formed groups (such as classes and institutions) and individuals are not randomly assigned to groups (Creswell, 2017). The independent variable of the study is teaching with flipped learning model enriched with STEM activities, and the dependent variable is the development of students' cognitive structures.

2.2. Study Group

The study was conducted with 28 volunteer eighth-grade female students attending a public secondary school in Kahramanmaraş in the 2024-2025 academic year. The study group was selected using the convenience sampling method. The implementation lasted for six weeks, and a total of four activities were conducted within the scope of the study, except for the pilot study.

2.3. Data Collection Tool

The data of this study were collected with a word association test. The researchers prepared the word association test in line with expert opinions. Key concepts thought to be related to environmental sustainability were selected. Accordingly, the concepts of "recycling", "waste", "garbage", "recovery", "reuse", "environmental pollution," and "sustainability" were determined as key concepts in the study. The keywords were written one under the other and spaces were provided for students to write the words and word groups they associated with them. For each concept, students were asked to write the words they associated with the key concepts within one minute. The word association test was applied twice, pre-test and post-test, before and after the learning process was carried out within the scope of the study. An example key concept with an excerpt from the word association test is given in Figure 1.

Key concept: Recycling
recycling…………………………
recycling…………………………
recycling…………………………
recycling………………………...

Figure 1. A sample excerpt for the word association test.

2.4. Design and Implementation Stages of the Activities

For flipped learning model enriched with STEM activities, four different activities including environmental sustainability topics were prepared by the researchers. After the activities were designed, opinions were exchanged with field experts. The activities were finalized by making the necessary arrangements in line with the feedback received.

2.4.1. Designing the activities

It was aimed that the students learn the subject content by learning the video lessons and contents prepared at online lessons and in the face-to-face lessons to be held at the school and STEM activities and applications in which students are active were carried out. It was presented in the introduction that the STEM activities in the literature were not completed in the time allocated at school and that the last steps of STEM were passed cursorily. For this reason, in order to make the face-to-face lessons at school more efficient, the activity was designed so that part of the STEM application would be done at home. In the STEM application added to the flipped learning model to enrich learning, the engineering steps prepared by Moore et al. (2013) were used. This cycle has six steps. The steps of the cycle adapted for this study are given in Figure 2.

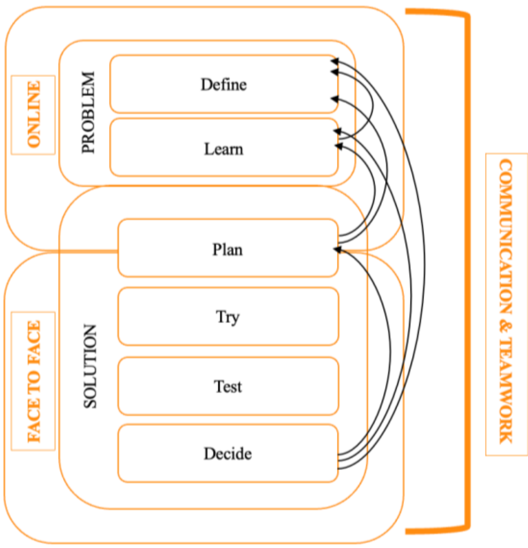

Figure 2. STEM steps of the flipped learning model enriched with STEM activities.

In order for students to follow the lesson easily throughout the activity, an activity notebook was prepared in which the mentioned engineering steps were added and spread throughout the process. The online lessons of this activity notebook was designed to be completed outside the school, while the face-to-face lessons was designed to be completed at school. The content of the activity book is given in Table 1.

In Table 2, brief information about the video lessons and activities of the applications are given.

Table 1. Contents of the activity notebook.

	The first section of the activity notebook	The second section of the activity notebook
	Online Lessons	Face-to-Face Lessons
Contents of the activity notebook	* A space for students to write whether they followed the content prepared by the teacher and how many times they watched the video lesson * A space to write down the information they are curious about, research, learn and have difficulty understanding * Scenario text of the problem * Define (Defining the Problem) * Learn (What should we learn about the problem?) * Plan (The part of the "Plan" step that needs to be completed individually)	* Plan (The part of the "Plan" step to be completed as a group) * Try (Creating the Model) * Test (Testing the Solution) * Decide (Decision Making) * Self-evaluation (the part where the students should evaluate themselves)

Table 2. Information on online lessons and face to face lessons.

Activity no	Subject content of video lessons	STEM scenario focus	STEM activities
1	wastes and waste types, garbage, household wastes and recycling, recyclable and non-recyclable wastes, upcycling, the difference between upcycling and recycling	The scenario prepared for this activity focuses on various wastes, especially plastic wastes, with which human beings pollute the environment.	In the STEM activity carried out in the context of this scenario, students prepared a bag consisting of waste textile products, using a mathematical pattern, large and strong enough to carry a 3 kg load. The face-to-face part of this activity lasted 4 class hours.
2	the importance of recycling in terms of effective use of resources, waste management, characteristics of environmentally friendly people, waste oil, waste batteries, wastewater treatment	The scenario prepared for this activity is about the pollution of usable fresh water by domestic waste.	In the STEM activity carried out in the context of this scenario, students designed filters to treat wastewater with materials that are easily available and used in daily life. The filter designs were prepared by considering the criteria that the wastewater should not contain soap, detergent, and oil residues, that the wastewater can flow quickly through the device and that the device can be used repeatedly. The face-to-face part of this activity lasted 4 class hours.
3	e-waste, economical use of resources, renewable and non-renewable energy, sustainable development, zero waste project, waste management hierarchy	The scenario prepared for this activity focuses on soil loss due to erosion, desertification, soil pollution, salinization, and the decrease in the presence of organic matter and microorganisms in the soil.	In the STEM activity carried out in the context of this scenario, students created compost and designed compost containers. In the designs prepared, the criteria of appropriate composting rates, easy mixing and heat insulation of the container used in composting were taken into consideration and the compost content was prepared with domestic organic wastes and materials found in nature. The face-to-face part of this activity lasted 5 class hours.
4	ecological footprint, sustainable development, sustainability, suggestions for sustainability	The scenario prepared for this activity is based on a real-life example of distributing rainwater tanks to combat drought.	In the STEM activity carried out in the context of this scenario, students designed a water tank that collects more water in a short time, uses the collected rainwater for irrigation, prevents any living creatures from entering, does not create a bad appearance and does not take up much space. The face-to-face part of this activity lasted 5 class hours.

2.4.2. Implementation of activities

2.4.2.1. online lessons

The video lesson prepared by the researchers was shared with the students with a link from Google Drive. Students watched the video lesson on environmental sustainability in an environment outside the school. The activity notebook was distributed to the students before the video lesson was followed by the students during and after the video lesson. In order for students to reinforce the video lesson and to determine whether they had watched the video lesson, students were sent an exercise with a link shared via Google Forms. Immediately after the video lesson, students were asked to access this exercise link and do the exercise. Each student did the exercise after watching the video lesson. In addition, the online lessons in the activity notebook was filled in individually by the students to record the number of times they watched the video lesson, the topics they learned, and the topics they had difficulty in understanding. In order to help students to realize their learning, the questions in the activity notebook about the video content were answered in detail by the students individually. In this way, students came to school by reading the problem scenario, identifying what the problem was, determining what was needed to solve the problem and working on planning for the solution without coming to the face-to-face lessons.

2.4.2.2. face-to-face lessons

Students formed groups of five-six, and group members worked together throughout the process. A total of six groups were formed. At the beginning of the lesson, how the students identified the problem situation and the topics and concepts they did not understand were emphasized. The questions in the video content and in the activity notebook, which were answered by the students at home, were answered once again in the school environment to correct missing or incorrect learning.

Afterward, students shared the individual solutions they created for the problem situation with their groupmates in the plan step in the online lessons. The advantages and disadvantages of the solution suggestions in the individual plans were determined and noted in the section in the activity notebook.

Each group examined the list of materials and materials prepared by the teacher and discussed within the group how they could prepare a solution proposal with these materials. While creating a solution proposal, the criteria and limitations in the plan section were reviewed again. Students wrote or drew their solution proposals in the space provided in the notebook.

In the try part (model creation), each group took the necessary materials from the teacher and created the model.

In the test the solution step**,** each group recorded the hypothesis they wanted to test in the relevant field in the activity notebook. Student groups followed the observation table in the activity notebook to test the models they prepared. Afterward, the groups followed the observation questions in the notebook to observe the model they created and recorded the observation results in the chart.

In the decide step (decision-making), all of the groups evaluated the designs they made in the solution testing phase within the group. Each group made a presentation to the other groups with the models and presentation posters they prepared at the decision-making stage. In the light of the data and observation results collected through both in-group and inter-group discussions, the students decided whether or not to use the model in solving the problem by evaluating it according to the evaluation criteria in the activity notebook. The table was filled in by evaluating each group's model.

At the decide step, the students also wrote in the activity notebook how the prepared model could be improved based on the feedback received in class and what changes they would add if they recreated the design.

After completing the decide step phase as a group, the students filled in the self-evaluation form in the activity notebook with answers expressing themselves.

Figure 3 below shows the implementation steps of flipped learning model enriched with STEM activities.

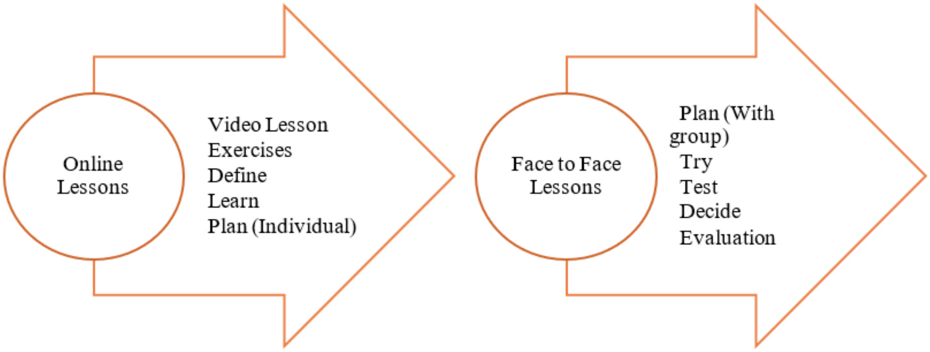

Figure 3. Implementation steps of flipped learning model enriched with STEM activities.

2.5. Data Analysis

Before analyzing the data, the answer words given by the students for each key concept were examined and entered into Microsoft Excel to evaluate the results of the pre-and post-test. Some similar expressions given by the students were combined under a common answer word. Frequencies were calculated to determine the repetition frequency of the words. Tables containing the obtained words and their frequencies were created. Afterward, concept network maps containing the words and word groups that the students associated with the key concepts were created, and the cognitive structures of the students related to these concepts were revealed. While creating the maps, the Cut-off Point technique proposed by Bahar et al. (1999) was used. According to this technique, for any key concept in the word association test, 3-5 numbers below the most frequent answer in the frequency table is considered as the cut-off point, and the answers above this answer frequency are written in the first part of the map. Then the cut-off point is lowered at certain intervals, and the process continues until all key concepts appear on the map.

In this study, the first cut-off point was set at 19 and above. After the first cut-off point, the cut-off point was reduced to intervals of 5, and this process continued until all key concepts and answer words appeared on the map. Similarly, concept network maps were created as a result of the analysis steps in the post-test of the WATs. The analysis of the data obtained from the WATs was carried out by both researchers and the multi-researcher method was utilized. In order to ensure the reliability of the research, the answer words given by the students in the pre- and post-test were transferred to Microsoft Excel without making any changes to them, and the researchers combined similar concepts under a common answer.

3. Results

The WAT was applied to the students at the beginning and at the end of the study within the scope of the research question "How do eighth-grade students' cognitive structures change towards environmental sustainability concepts during flipped learning enriched with STEM activities?". As a result of the application, the number of answer words produced in the pre- and post-test for each key concept is given in Table 3.

Table 3. Frequency of word responses to keywords.

Word Count			
Key Concepts	**Pre-Test**	**Post-Test**	**Difference**
Waste	93	347	254
Garbage	86	199	113
Recycling	155	371	216
Reuse	91	169	78
Recovery	33	140	107
Environmental Pollution	107	324	217
Sustainability	46	393	347
Total	611	1943	1332

When Table 3 is examined, it is seen that the total number of answer words was 611 in the pre-test before the flipped learning model enriched with STEM activities, and 1943 in the post-test. As seen in Table 3, there is an increase in the number of answer words associated with all key concepts after the study. Table 4 shows the first three most repeated answer words that eighth-grade students evoked in their minds about each key concept.

Table 4. The three words associated with the key concepts given as the most common answer.

Key Concepts	**Words given in response to key concepts**					
	1		**2**		**3**	
	pre-test	**post-test**	**pre- test**	**post- test**	**pre- test**	**post- test**
Waste	Garbage, Paper (13)	Paper, Organic waste, Glass (27)	Glass (11)	Plastic (26)	Plastic (10)	Textile (24)
Garbage	Kitchen waste (16)	Single disposable plastics (30)	Pollution (11)	Baby diaper (25)	Garbage box (7)	Ash (23)
Recycling	Plastic (20)	Zero waste, Glass, Raw material (26)	Glass (19)	Paper (23)	Paper (18)	Collection box (22)
Reuse	Goods again using (24)	Clothes to someone to give, Bag (22)	Clothes again using (16)	Goods transform, pencil case (17)	Recycling (9)	Gray Water (15)
Recovery	Recycling, Reuse (4)	Organic from waste biogas (23)	Waste again using (3)	Economic efficiency (22)	Sun energy (2)	Compost (19)
Environmental Pollution	Garbage (14)	Greenhouse gases (30)	Waste (11)	Fossil fuels (28)	Air pollution (7)	Water pollution (26)
Sustainability	Energy (9)	Renewable energy (24)	Sun energy (7)	Waste management, Heat insulation (23)	Water sources (7)	Economic sustainability, Turning off excess lights (22)

In Table 4, it is seen that the students frequently expressed the concepts that they did not include in the pre-test in the post-test regarding the key concepts given in the WAT. While they associated the key concept of "waste" with garbage, paper, glass, and plastic in the pre-test, they associated it with paper, glass, plastic, organic waste and textiles in the post-test. This means that students were able to give examples of different types of waste.

In the pre-test, students associated the key concept of "garbage" with kitchen waste, pollution, and trash, while in the post-test they associated it with disposable plastics, diapers and ash. It is noteworthy that students wrote the wastes that should be disposed of in accordance with the definition of the concept of garbage as answers in the post-test.

In the pre-test, students associated the key concept of "recycling" with plastic, glass and paper, while in the post-test they associated it with zero waste, glass, raw material, paper and collection box. Especially during the implementation, it was seen that the content emphasized about the definition of the key concept of recycling was expressed with answer words such as zero waste, collection box, raw material.

In the pre-test, students associated the key concept of "reuse" with reusing items, reusing clothes and recycling, while in the post-test they associated it with giving clothes away, bags, recycling items, pencil cases and gray water. Here, the words coded as bag and pencil holder were formed by abbreviating student expressions such as making bags and pencil holders from various waste textile products, jars or boxes. In other words, the students developed the answers they gave before the study in a scientifically correct manner and formed their final application answers with different and correct expressions. In addition, students briefly used the gray water answer to express the reuse of usable waste water expressed by gray water for different purposes.

In the pre-test, students associated the key concept of "recovery" with recycling, reuse, waste reuse and solar energy. In the post-test phase, biogas from organic wastes, economic efficiency, and compost were the most frequently used expressions. It is seen that students' knowledge about the concept of recycling improved throughout the study and in the post-test, examples appropriate to the nature of recycling were given.

While students associated the key concept of "environmental pollution" with garbage, waste and air pollution in the pre-test, they associated it with greenhouse gases, fossil fuels and water pollution in the post-test. The answers given by the students in the post-test revealed that students made associations with the situations that affect environmental pollution the most.

In the pre-test, students associated the key concept of "sustainability" with energy, solar energy and water resources, while in the post-test, they associated it with renewable energy, waste management, thermal insulation, economic sustainability and turning off excess lights. The answers given to sustainability in the pre-test show that students' knowledge structure on this subject is weak. When the answers given at the end of the process are examined, it is seen that the concept of sustainability is associated with appropriate examples and the knowledge structures of the students about this concept are enriched. The concept network created for the words and phrases associated with the key concepts as a result of the pre-test is given in Figure 4.

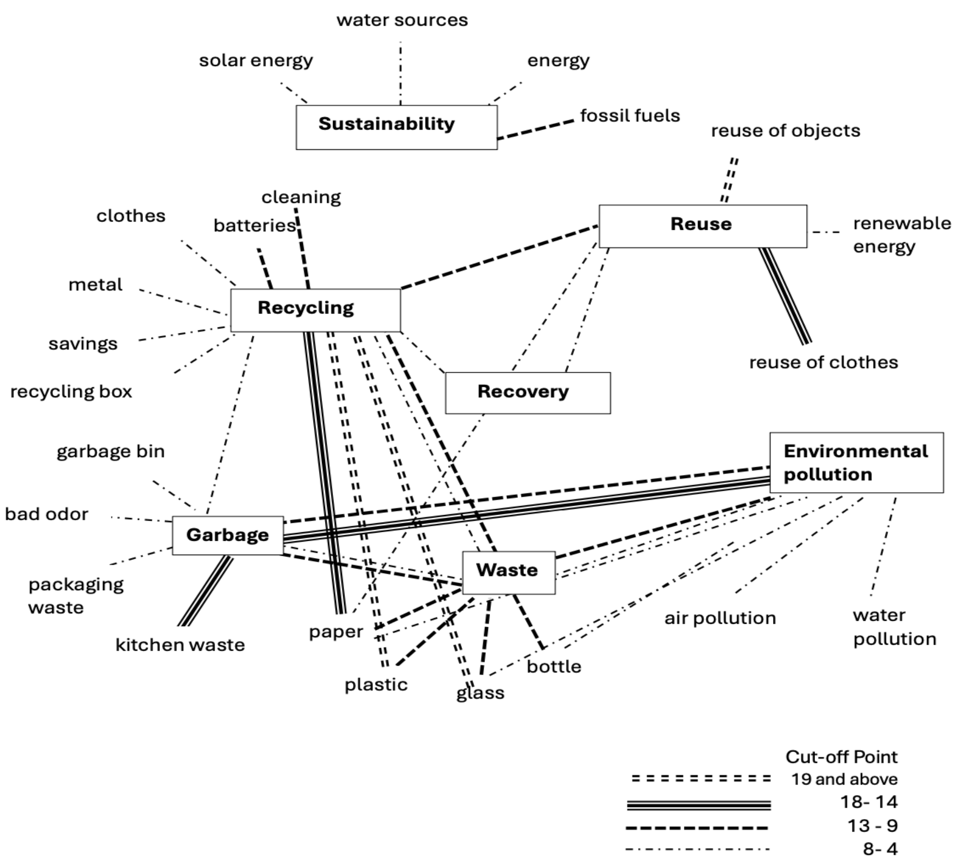

Figure 4. Concept network for the words associated with the key concepts as a result of the pre-test.

When the concept networks of the pre-test were examined, it was found that the words plastic and glass were associated with the key concept of recycling in the range of cut-off point 19 and above, and the words reuse of objects were associated with the key concept of reuse.

In the range of cut-off point 18-14, it is seen that the answer word paper is associated with the key concept of recycling; kitchen waste is associated with the key concept of garbage; and reusing clothes is associated with the key concept of reuse. It was also found that the key concepts of garbage and environmental pollution were associated with each other in this range.

In the range of cut-off point 13-9, it is seen that the key concept of sustainability is associated with fossil fuels; the key concept of recycling is associated with batteries and cleaning; and the key concept of waste is associated with the answer words paper, plastic, glass and bottle. It is also seen that the key concepts of reuse and recycling, recycling and waste, garbage and waste, garbage and pollution are also associated with each other in this range.

In the range of cut-off point 8-4, it was determined that the keywords solar energy, water resources and energy were associated with the key concept of sustainability; paper, renewable with the key concept of reuse; clothes, metal, saving, recycling bin with the key concept of recycling; garbage, bad odor and packaging waste with the key concept of garbage; water pollution, air pollution, bottle, glass and paper with the key concept of environmental pollution. In addition, the key concepts of environmental pollution and waste, garbage and waste, recycling and waste, recycling and recovery, reuse and recovery, recycling and garbage were associated with this range. In light of these findings, it is possible to say that the answer words given by the students to the key concepts are appropriate, but they are low in both number and variety. The concept network created for the words associated with the key concepts as a result of the post-test is shown in Figure 5.

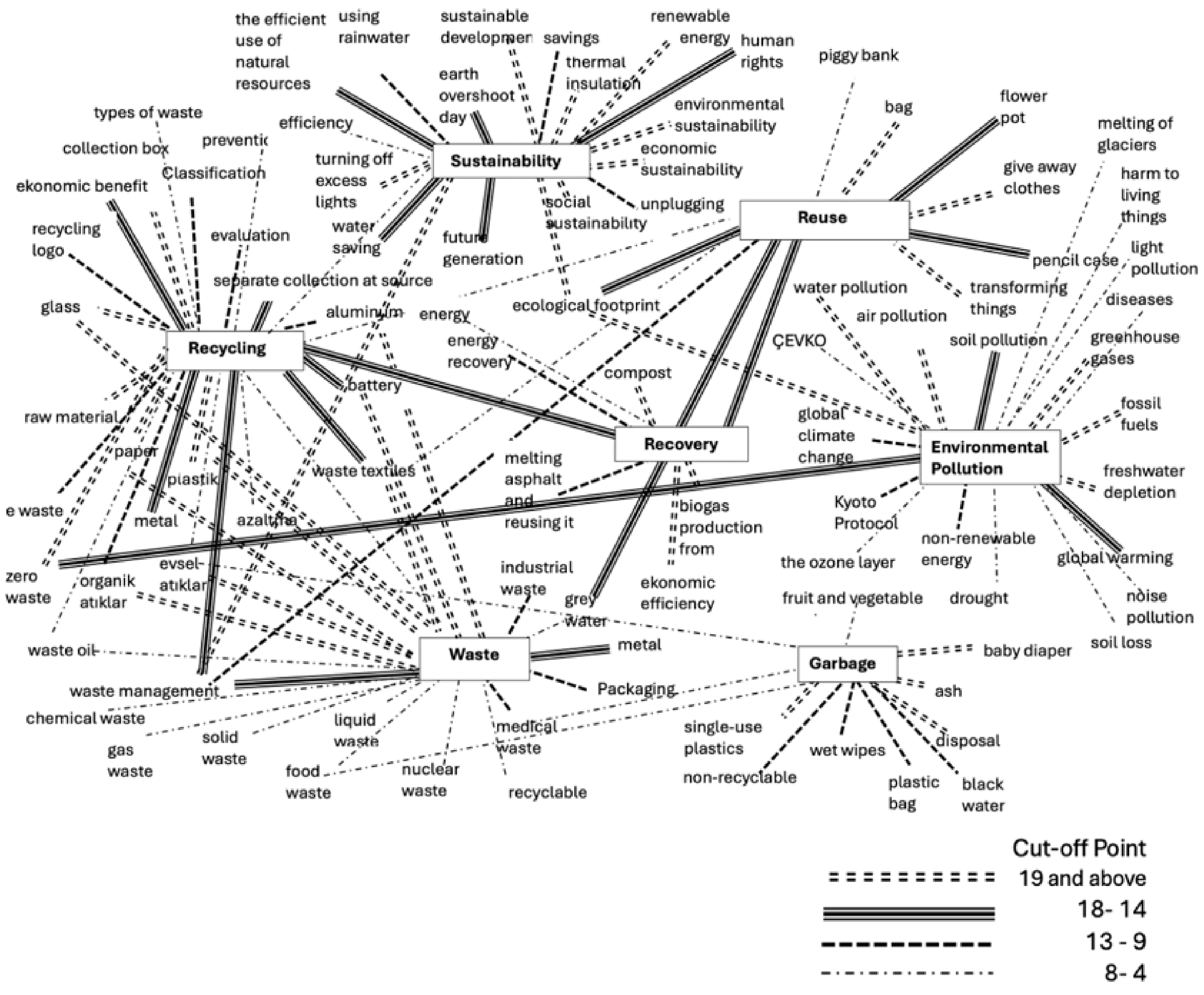

Figure 5. Concept network for the words associated with the key concepts as a result of the post-test.

When we examine the final implementation concept networks, it can be seen that in the range of the cut-off point 19 and above, the recycling key concept includes collection bins, glass, raw materials, zero waste, paper and plastic; the waste key concept includes paper, organic waste, glass, plastic, textiles, batteries, household waste, aluminum and e-waste; the garbage key concept includes disposable plastics, diapers, ashes and disposal; the reuse key concept includes transforming things, give away clothes and bags; greenhouse gases, fossil fuels, water pollution, ecological footprint, freshwater depletion and air pollution; recycling key concept was associated with biogas from organic waste, economic efficiency and compost; sustainability key concept was associated with renewable energy, waste management, thermal insulation, economic sustainability, turning off excess lights, environmental sustainability, ecological footprint, social sustainability and sustainable development. When the words that students wrote as answers at this cut-off point are considered, it is seen that the key concepts related to environmental sustainability are correctly associated with the answers. Considering that the response frequencies of the students were high, especially at this cut-off point, it can be concluded that the training improved the cognitive structures of the students.

It is seen that the key concept of recycling is associated with the answer words waste management, economic benefit, separate collection at source, textile waste, battery and metal in the range of cut-off point 18-14. It is possible to say that students associated recycling, which is a part of waste management, appropriately in their minds, were aware of the importance of separate collection at source for recycling and exemplified recyclable materials appropriately. It was determined that the key concept of waste was associated with waste management and metal; the key concept of reuse was associated with pencil holders, gray water, flower pots and ecological footprint; the key concept of environmental pollution was associated with global warming, zero waste, and soil pollution; and the key concept of sustainability was associated with efficient use of natural resources, future generations, earth overshoot day human rights and water conservation. In addition, it is seen that the key concept of recovery is associated with the key concepts of recycling and reuse in this range. When both the association of some key concepts and the answers given to key concepts are examined, it is possible to conclude that appropriate answers were given and their mental associations were shaped correctly. In particular, the answer words “efficient use of natural resources, future generations, earth overshoot day and water conservation” given in the key concept of sustainability reveal that rich and in-depth learning about environmental sustainability has taken place. In addition, the answer “human rights” expresses that correct connections have been formed in students' minds about the social dimension of sustainability.

It was determined that the key concept of recycling was associated with the answer words recycling logo, organic waste, e-waste, aluminum, classification, and evaluation in the range of cut-off point 13-9. In light of these answers, it is possible to say that students have reached the awareness that organic waste, electronic waste, and aluminum can be recycled and that the classification and evaluation steps, which are the stages of recycling, have been structured in their minds. The association of the waste key concept with industrial waste, packaging and medical waste shows that students were able to exemplify waste correctly.

The association of the key concept of garbage with the words wet wipes, plastic bags, black water and non-recyclable answer shows that the concept of garbage was appropriately linked in students' minds. The association of the key concept of reuse with waste management indicates that reuse, which is a part of waste management, is constructed correctly. The association of the key concepts of environmental pollution with non-renewable energy, garbage, global climate change, and the Kyoto Protocol shows that the causes and consequences of environmental pollution and the existence of international efforts are appropriately associated. The key concept of recycling was associated with melting and reusing asphalt and energy recovery; the key concept of sustainability was associated with the answer words unplugging, using rainwater and saving. In this range, it is seen that the answer words given to the key concepts are the correct associations.

In the range of cut-off point 8-4, the recycling key concept includes household waste, reduction, waste types, prevention, and waste oil; the waste key concept includes liquid waste, nuclear waste, solid waste, waste oil, food waste, gas waste, gray water, recyclable and chemical waste; the garbage key concept includes medical waste, fruit and vegetable waste, napkins, food waste and household waste; reuse key concept evoked waste textiles and piggy banks (designing piggy banks by recycling items); environmental pollution key concept evoked diseases, light pollution, harm to living things, melting of glaciers, noise pollution, ozone layer, waste oil, black water, ÇEVKO (Environmental Protection and Packaging Waste Recycling Recovery and Recycling Trust), soil loss and drought; recovery key concept evoked energy; sustainability key concept evoked efficiency. In addition, it is seen that the key concepts of reuse, waste and sustainability are associated with the key concept of recycling in this range. When all the answer words given are analyzed, it is concluded that the students made appropriate associations with the key concepts in their minds and evoked a wide variety of examples.

In light of these findings, it was revealed that there was an increase in the answer words given to the key concepts in the post-test compared to the concept networks in the pre-test and that the answer words were repeated by more students. In addition, while the key concepts were associated with a limited number of words in the pre-test, the post-test, the key concepts were associated with a variety and large number of answer words in the post-test, especially within the scope of environmental sustainability, which was focused on in the research. In the pre-test, very limited answers were used, especially in associating the key concepts of recycling, reuse, and sustainability, while in the post-test, it was found that the students associated them with more diverse and appropriate answer words related to these concepts.

4. Discussion and Conclusion

Flipped learning activities enriched with STEM activities used in teaching environmental sustainability topics were carried out with 8th grade female students for 6 weeks in order to examine the change in the students' cognitive structures towards environmental sustainability concepts. In this process, it was determined that there was a great difference between the concepts expressed by the students in the pre-test *(f*= 611) and post-test *(f*= 1943) regarding the key concepts (waste, garbage, recycling, reuse, recovery, environmental pollution, sustainability) given in the WAT used to determine the change in the cognitive structures of the students, and that they frequently included various concepts in the post-test that they did not include in the pre-test. In addition, while key concepts were associated with a limited number of concepts in the pre-test, it was revealed that key concepts were meaningfully associated with the activity topics of the research in the post-test. In line with the findings obtained, it was concluded that the students' previously existing weak cognitive structures towards the concepts related to environmental sustainability improved after the activities. It would be appropriate to say that with the activities carried out, the students structured the concepts of environmental sustainability appropriately with various examples, and both general and deep knowledge were acquired and developed.

When the literature is examined, studies combining STEM and flipped learning are very limited. Söndür (2020) concluded that the combination of STEM and flipped learning in the force and energy unit increased student achievement. Oktaviana et al. (2023) used a live worksheet supported by a flipped STEM classroom model to develop science literacy in their study. The results of the study show that this learning model is effective in improving science literacy. Fung (2020) used flipped learning to support STEM education in his study. According to Fung (2020), students coming to class by watching videos before the lesson can be a good tool for providing prerequisite knowledge, as well as an advantage, maximizing the effect of practical work, discussion, and STEM education in general. The results of the aforementioned studies are similar to the results of this study in that the concepts related to environmental sustainability are constructed more accurately and richly in the minds of the students with the flipped learning model enriched with STEM activities. In addition, it is thought that this study will guide future studies and researchers in terms of the limited studies on this learning model.

Contemporary approaches, including STEM education, should emphasize the challenges affecting societies and their solutions (Lee & Grapin, 2022). Environmental sustainability is one of the issues affecting societies, and the flipped learning model enriched with STEM activities is a contemporary approach that will enable students to make informed decisions and take responsible actions. In this study, in which technology was included in the process, the result of the development of eighth-grade students' cognitive structures towards the concepts of environmental sustainability reveals the importance of teaching the concepts through practice-based activities.

In line with the results obtained from this research, after the activities implemented, students associated concepts such as gray water, black water, Earth Overshoot Day, Kyoto Protocol, global climate change, single-use plastics, zero waste, environmental, social and economic sustainability, water saving, prevention of waste, ecological footprint with the key concepts; associated sustainability with expressions such as turning off excess lights, unplugging, thermal insulation, reusing rainwater; associated the key concept of recycling with products that can be recycled correctly; gave correct examples of the key concepts of garbage and waste; associated the key concepts of recycling and reuse with appropriate examples; and linked environmental pollution with appropriate words. Therefore, this study thought to have contributed to students' awareness of environmental sustainability.

In addition, the STEM steps applied in the face-to-face lessons part of the activities progressed comfortably without time problems. It is thought that determining the problem situation, doing research about the problem and planning for the solution were done by the students at home and they came to school prepared. This result of the study is an example for future studies.

5. Suggestions

- In this study, the study group consisted of female students. It was not aimed to examine students' cognitive structures according to gender. In future studies, the cognitive structures of male and female students regarding the concepts of environmental sustainability can be examined according to gender.

- In this study, the study group was eighth-grade students. The flipped learning model enriched with STEM activities can be applied at other grade levels.

- Environmental sustainability was studied as a subject. Different activities can be developed for the same subject or studies can be conducted with the same learning model in other subjects or units.

- The flipped learning model enriched with STEM activities can be implemented together with teachers and the model can be improved by taking teachers' opinions about the model.

- In this study, the change in students' cognitive structures during flipped learning enriched with STEM activities was examined. The effect of the model on other variables can be examined.

Compliance with Ethical Standards

Ethical approval was provided by the Gazi University Ethics Committee with the decision number 2024-1126 on 09.07.2024.

Conflict of Interest

The authors have no conflict of interest to declare.

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