Developing and Evaluating a Design for Online STEM Education on Environment for Secondary School Students

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Developing and Evaluating a Design for Online STEM Education on Environment for Secondary School Students

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Article Info	Abstract
	This study aims to present a sample online STEM education design that can be used at secondary school level. In the exemplary design, "environmental issues" were used with a focus on how important it is that the students approach the problems from an ecological perspective. The study was carried out with the "action research" pattern, in which each cycle feeds each other. The study group consist of 11 students in the 6th grade. The action research, which was completed in two cycles, lasted a total of 10 weeks. The data, collected by qualitative means, were analyzed through "descriptive analysis" and "content analysis". At the end of the study, suggestions were made for the development and implementation of lesson activity to be used for online STEM education. It has been concluded that the in-class (synchronous) and extra-curricular (asynchronous) parts of the activity are included in the activity and it is carried out through learning management systems like Padlet. It is important to include activities that employ social and emotional skills in the prepared content. Digital panel tools or instant communication applications are used for the continuity of communication. In addition, the course materials used were prepared with tools like Teachermade so that the teacher can give interactive feedback.

Introduction

In the 21st century, we face complex problems. Since a single discipline would not be sufficient to solve such problems, we need to use more than one discipline holistically (Kırkıç et al., 2018; Rogers et al., 2015). In this context, an approach that integrates science, technology, engineering and mathematics disciplines has been proposed by the National Science Foundation [NSF] (Breiner et al., 2012). This approach is indicated by the abbreviation "STEM", which is formed by combining the initials of science, technology, engineering and mathematics disciplines. The STEM approach is conceptualized as "STEM education" in teaching (Akgündüz, 2018). STEM education is defined as an approach that aims to integrate at least two of the disciplines of science, technology, engineering and mathematics, and to acquire knowledge and skills that can be used in solving complex real-life problems (Akgündüz, 2018; Breiner et al., 2012; Gomez & Albrecht, 2014; Gülhan & Şahin, 2018; Sanders, 2008).

In STEM education practices, students are expected to solve an engineering design-based problem using other

disciplines such as science, mathematics, technology, engineering and entrepreneurship, art, and coding (Çepni, 2018; King & English, 2016; Topçu & Gökce, 2018). The engineering design-based problem is contextually related to real life and requires creating a design. This solution-oriented design is justified using STEM disciplines (Sutaphan & Yuenyong, 2019). Students are expected to use the "engineering design cycle" in solving the engineering design-based problem highlighted in STEM education practices (King & English, 2016; Siverling, Flores, Mathis & Moore, 2019). In this cycle, first the problem is defined and alternative solutions are produced. The best one is chosen and the prototype is built, tested and finalized by making improvements (NRC, 2009). Cunningham (2009) presented a model for the use of the engineering design cycle in science education and defined the steps as "ask", "imagine", "plan", "create" and "develop". Çepni (2018) suggested using these steps in STEM education. The STEM activities implemented during this study were also planned within the framework of Cunningham's (2009) model.

Over time, real-world problems have become differentiated and complex. In addition to the basic four disciplines of STEM education used to solve these complex problems, disciplines such as entrepreneurship, coding and art have also been included (Akgündüz, 2018). The problems of today and the future that need solutions are multifaceted environmental problems such as global climate change, sustainable energy, air and water pollution (Kelley & Knowles, 2016; Levrini et al., 2019). Environmental problems require an interdisciplinary or integrated approach, and therefore the use of such an approach in STEM education stands out as an alternative (Blackley & Sheffield, 2015). It is thought that a STEM education curriculum integrated with environmental education will enable individuals who will produce solutions to problems in the future to create solutions with environmental awareness and to be motivated to protect the environment (Bybee, 2010; Gupta vd., 2018; Kelley & Knowles, 2016).

Concerns about current teaching practices can be another justification for the integration of STEM education and environmental education. These concerns are that current teaching practices "legitimate the climate crisis" (Eaton & Day, 2019; Tasquier et.al., 2014) and that STEM education "contributes to wasting Earth's ecosystems and resources" (Watson & Smith, 2019). Levrini et al (2019) suggest that STEM education, which aims to raise a productive future generation, should address future-oriented issues such as climate crisis and global warming. It is thought that STEM education, which will focus on these issues, can provide critical skills and understanding for the future and can be used to contribute to the entire ecosystem (Nguyen et al., 2020; Watson & Smith, 2019). For all reasons, environmental education and STEM education are also common in terms of developing 21st century skills, being real-life-based and attracting students' attention.

The relevant literature includes studies on environmental issues in STEM education (Blackley & Sheffield, 2017; Dallı, 2019; Gupta et al., 2018; Kelley & Knowles, 2016; Nguyen et al., 2020; Levrini et al., 2019; Rogers et al., 2015). The context for the STEM education course design to be developed under the study was built in consideration of the concerns about STEM education. These concerns are that the "techno-optimistic perspective" offered by STEM education leads to a waste of ecosystems and resources and is not economically, socially or ecologically sustainable (Smith & Watson, 2019). In this framework, the themes of "global warming" and "air pollution" were used in the course design used in the first cycle of the study, and "renewable energy sources" in

the second cycle. In the national and international literature, it is aimed to develop, implement and review the sample course design at the secondary school level regarding the topics selected for this study (Atabey, 2018; Cebesoy & Ayaz, 2018; Christenson, 2004; Johnson et al., 2020) and within the framework of STEM education.

The purpose of this study, which aims to set an example for future online STEM applications, is to lay a foundation for the course design contexts to be chosen for environmental problems, which is a critical concern of today and the future.Considering how critical the STEM education is today and for the future, it is important that it is implemented in a sustainable manner. In order to ensure such sustainability, problems such as time and material limitations and the inaccessibility of STEM education for some people (Ejiwale, 2013; Eroğlu & Bektaş, 2016) should be eliminated. It is stated that sustainability can be achieved by providing STEM education partially or completely in technological environments (Jeong et al., 2020; Kırkıc & Kırkıc, 2018; Poyraz & Kumtepe, 2019). In this respect, studies in which STEM education is transferred through digital media are in teacher education (Dede et al., 2016), university level (Chen et al., 2018, Ardissone et al., 2019), secondary school level (Poyraz & Kumtepe, 2019), adult education (Artsın & Deligoz, 2019; Burns et al., 2020; Mohammadi et al., 2020) albeit in limited numbers.

The education applied in these studies is conceptually digital STEM (Chen et al., 2018), online STEM (Ardissone et al., 2019; Burns et al., 2020; Liu et al., 2020; Marcum-Dietrich et al., 2021; Ozdemir, 2021) and it has been defined in different ways such as remote STEM (Tekin Poyraz, 2018). The general tendency in the literature is to use the concept of "online STEM". In addition to the current requirements, online STEM education has been included in future action plans following the COVID-19 pandemic, using virtual learning environments at all educational levels, and the importance of educators who can facilitate online STEM education (National Science Foundation [NSF], 2020; STEM Education Coalition, 2020). Online STEM education can be carried out synchronously and asynchronously with the use of various media tools through a virtual learning environment supported by different digital materials (American Department of Education, 2019; Liu et al., 2020). It can be defined as an educational method that eliminates the concept of distance and basically aims to integrate the fields of science, technology, engineering and mathematics by employing the active participation and evaluation of the student (Chen et al., 2018).

Various studies on online STEM education have been presented in the national and international literature. These studies aimed to determine the opinions and experiences of teachers and prospective teachers on online STEM education (Doğru & Yüzbaşıoğlu, 2021; Özdemir, 2021; Sintema, 2020; Sahinoğlu & Arslan, 2021; Turk & Duran, 2022), to develop suggestions by making practices with teachers and pre-service teachers on how to conduct online STEM lessons (Aykan & Yıldırım, 2021; Evagorou & Nisiforou, 2020, Larson & Farnsworth, 2020; Marcum-Dietrich et al., 2021), to reveal any pros/cons of online STEM education (Brunelli & Macirella, 2021; Kazu & Işık, 2021) and to evaluate the participation of disadvantaged higher education students in online STEM education (Chacko & Jones, 2021; Flowers et al., 2012; Ramdoss et al., 2021). Studies in the literature define the pros and cons of the application of online STEM education. Online STEM applications face difficulties in employing teamwork and collaboration skills, providing motivation and interaction (Brunelli & Macirella, 2021; Doğru & Yüzbaşıoğlu, 2021; Keaton & Gilbert (2020); Larson & Farnsworth, 2020; Özdemir, 2021). In

addition to these difficulties, online STEM education significantly increased positive emotions such as fun and satisfaction with the lesson (Özdemir, 2021; Prieto et al., 2021) and improved motivation (Yunita, 2021).

On the other hand, no study has been found in the relevant literature on the application of online STEM education to secondary school students and the presentation of a sample course design developed by considering the pros and cons. This study, on the other hand, aims to reveal the pros and cons of online STEM education with a course design that will be applied directly to secondary school students and to present it as a sample course to be designed in line with the application data. However, since the interaction of the student with the teacher and classmates is limited in online STEM activities, the support of the parents becomes critical in the online school environment. It is believed that parent participation is required in online STEM activities in areas such as motivating students, guiding and supporting them when they have any difficulties, monitoring their performance in the process (Keaton & Gilbert, 2020) and preparing the necessary tools and materials for the activity (Yunita, 2021). Opinions on online STEM education practices also emphasize the importance of family support at preschool and secondary school level (Özdemir, 2021; Türk & Duran, 2022). In this context, the roles of parents should be considered in the design to be established with the observations of the parents towards their students and their practical feedback.

The context for the STEM education course design to be developed under the study was built in consideration of the concerns about STEM education. These concerns are that the "techno-optimistic perspective" offered by STEM education leads to a waste of ecosystems and resources and is not economically, socially or ecologically sustainable (Smith & Watson, 2019). In this context, it is stated that the use of future-oriented topics such as "climate change" in STEM education (Levrini et al., 2019) and other problems related to environmental science will enable students to gain a perspective that the products to be revealed as a result of STEM education will affect the "human" and "nature" elements (Kırkıç & Kırkıç, 2018). In this framework, the themes of "global warming" and "air pollution" were used in the course design used in the first cycle of the study, and "renewable energy sources" in the second cycle. In the national and international literature, although there are studies on the development, implementation and examination of the sample lesson design at the secondary school level regarding the topics selected for this study (Atabey, 2018; Cebesoy & Ayaz, 2018; Christenson, 2004; Johnson et al., 2020) and within the framework of STEM education (Cebesoy & Ayaz, 2018; Çilek, 2019.; Dallı, 2019; Johnson et al., 2020; Machuve & Mkenda, 2019; Mukaromah & Wusqo, 2020; Yıldırım & Sevi, 2016) no study has been found for its use in online STEM education. The purpose of this study, which aims to set an example for online STEM applications in the future, is to lay a foundation for the course design contexts to be chosen for the environmental issues, which is critical for today and the future.

The aim of the study is to develop and present the environmental lesson design developed for STEM education conducted online, by applying it to secondary school students, based on the opinions of students, teachers and parents in the process. Prospective teachers, teachers and curriculum developers are expected to benefit from the online STEM education course design offered. For this purpose, the problem of the research has been defined by considering the cons and pros of STEM education designed online on environment for secondary school students and proposed as

How should the online STEM education design for secondary school students be?

Method

Since the research aimed to develop an activity design for online STEM education on environment, the action research design was used. The action research design, which can also be used with quantitative approaches (Johnson, 2014; Kemmis & Mctaggart, 2005), was used in the study. Action research is defined as a systematic research process that focuses on specific problems encountered in daily life, has defined boundaries, does not aim to generalize, and provides effective solutions (Stringer, 2007).

Action research can be used to focus on a problem at school or classroom level, to change a situation, and to evaluate teaching methods and to create programs (Johnson, 2014; Özpınar & Aydoğan Yenmez, 2015; Stringer, 2007). Saban (2021) argues that action research means that teachers and students test their educational practices, take action and reflect, rather than an intervention to educational practices. The action research design was preferred since it aimed to design a course by improving the deficiencies of the online STEM education, which is applied with the need arising from the problems of STEM education and its sustainable implementation.

Although there are different approaches to the conduct of the action research process (Hendricks, 2009; Johnson, 2014; Stringer, 2007), this research is structured based on the "action research spiral" proposed by Kemmis et al. (2003). This spiral consists of cycles in which the phases of "plan, do, and reflect" follow one another. In the research, the "plan" phase of this spiral structure includes the literature review before the application, the determination of the participants, the creation of the lesson plans and their contents. The "Reflect" stage includes evaluating the data obtained during the process and reflecting it to the next cycle. The loops forming the spiral end when the obtained feedbacks repeat each other or when data saturation is reached.

The research consists of two action cycles. The first cycle is a practice for solving an engineering design-based problem on "climate change". The content of this practice is given under three headings being "plan", "implement" and "reflect" as defined by Kemmis et al (2003). The second action cycle, on the other hand, was planned in line with the reflections from the first action cycle, under the theme of "renewable energy", another environmental-based topic, and presented with the steps of plan, implement and reflect. Since the action plan applied in action research is experience-specific, it is important to describe the participants in detail (Johnson, 2014). In this respect, it was ensured that both cycles had the same participants and consistency was reached in the development of the presented course design. Since the same participants were involved in the second cycle, a different engineering design-based problem was used than in the first cycle. As a matter of fact, Yıldırım and Şimşek (2018) suggested that different practices can be employed in the cycles of action research. In the next cycle, starting from the current focus area, a new action plan can be developed and implemented on a different aspect of it (Saban, 2021). The participants included in the study, the research environment and the digital tools used are presented below and the action research is detailed.

Determination of Participants

Three kinds of participants, which are students, teachers and parents, were included in the research. In this context,

the participants of the study consist of 11 students, 11 parents, including the parents, and a teacher.

The students participating in the research were determined by criterion sampling, which is one of the purposive sampling methods used in qualitative research by Creswell (2020). In criterion sampling, the participants consist of people with the qualifications determined by the researcher (Büyüköztürk et al., 2013). These qualifications determined by the researcher are as follows:

→   The willingness of the student and his/her parents to participate in the study,

→   The student is studying in the 6th grade,

→   Having a computer or tablet and an internet connection to continue online STEM education applications.

Students participating in the application were selected from among those studying in the 6th grade in different cities in Turkey and met the specified qualifications in line with the independence of time and place, which is considered to be one of the advantages of online education. To contact the selected participants, a poster of the application containing its subject, duration, program, and communication e-mail was shared via social media. Participation in the research was carried out entirely at the request of the students for the application. All students were accepted as participants, and all the 19 applications received via e-mail were eligible.

Online course links and Parent Approval Form were sent to the accepted participants via e-mail, and signed consent was obtained for the video and audio recordings of the application. Relevant e-mail indicated that there would be no grading during the process, that it was voluntary, that the data would be used anonymously for scientific research purposes and that they could leave the study at any time. The researcher teacher taught the participants only during the application, and the participants interacted with each other for the first time during the application.

The permission of the Ethics committee was obtained from the university where the researcher was a student. PSF was applied to describe the general profiles of 19 students whose participation was finalized (Participant Student Form). 11 out of 19 students regularly participated in and completed the process. Action research differs from traditional research which requires a large number of participants and can be conducted even with a single participant. In this context, the number of participants in action research does not matter (Johnson, 2014; Nodoushan, 2009). Accordingly, 11 participants were considered to be sufficient for the study. Since it is thought that the detailed description of the study group may be critical for the applicability of the designed activities, the gender and technological equipment and STEM education attitude scores of 11 continuous participants are presented in Table 1.

Table 1. Information on Participating Students

Information		*n*	*%**
Gender	Female	2	18
	Male	9	82
	Total	11	100

Information		n	%*
Technologic Tools	Computer	11	100
	Tablet	6	54
	Smart Phone	7	64
Tinkercad Usage Experience	Yes	4	36
	No	7	64
	Total	11	100

*Percentages are rounded to nearest units or tens.

Research Environment

The research was carried out entirely online, with the teacher's screen sharing over the Zoom platform. Follow-up of the course, sharing of resources, data collection tools and communication of students with each other and with the researcher teacher were ensured through the digital panel created. There are special areas reserved for each student's name on the digital board created via Padlet. Students shared about the application in these areas. The digital board also allowed other students and the researcher teacher to comment on the shared posts and to communicate outside the classroom.

Digital Media Used During Implementation

Padlet is used in the function of the teaching management system where the digital board is prepared to be used by the student and the teacher for material tracking, communication and sharing during the application (SEE Figure 1). Google Form is used to prepare digital worksheets, follow the implementation steps and answer the questions about the project. Tinkercad is an environment where students model their designs in 3D.
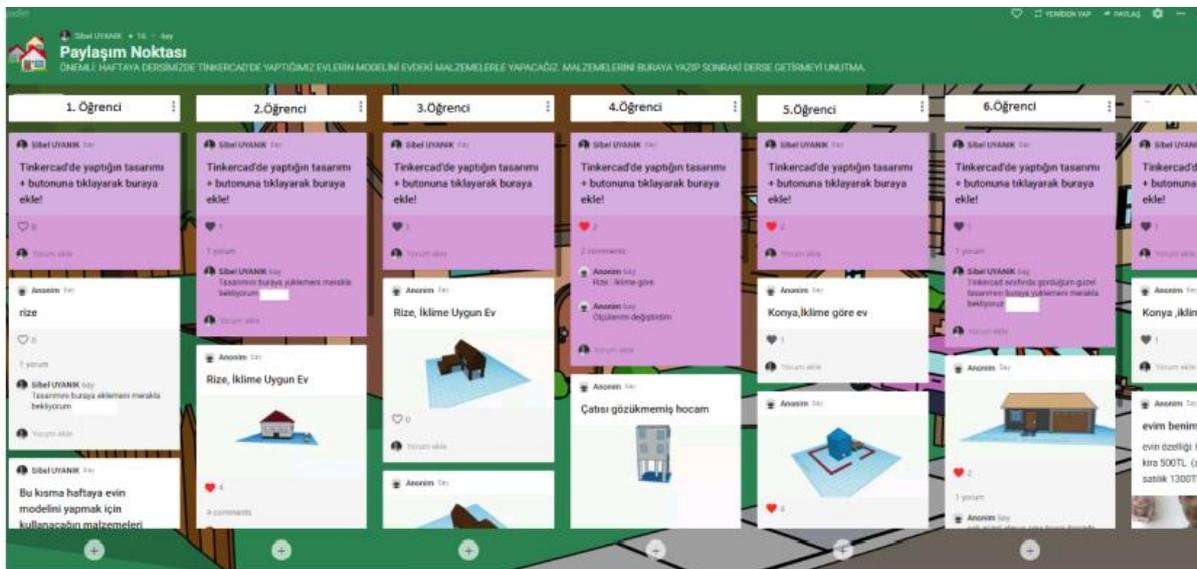

Figure 1. View of the Padlet Digital Panel

First Cycle and Its Steps

The engineering design-based problem provided to the students in the first action cycle of the practice is "How should a house design be based on the conditions of provinces with different climate types?". The course design prepared for producing solutions to this problem by using STEM disciplines was tested with plan, apply and reflect phases, and the action cycle was completed.

Plan: The process, which started with the literature review before the application, continued with the determination of the participants after the determination of the engineering design-based problem and the course content.

While designing the STEM activity, the subject of the environment was chosen as context. Since the subject of environment is related to real life and open to more than one solution, it has been found suitable for use in STEM education (Akgündüz, 2018). In STEM education, it is aimed to create an engineering design suitable for the desired solution by filtering the knowledge and skills of the disciplines of science, mathematics and technology (Topçu & Gökce, 2018). In this context, the engineering design-based problem used in the online STEM activity on the environment is designed in such a way that the disciplines of science, mathematics and technology are used in an integrated manner. The use of the achievements in the "Human and Environment" unit related to the field of science, the scaling of the design to be made on Tinkercad for the field of mathematics and the calculations of the problem situation, and the use of Tinkercad for the technology discipline are included.

In light of the relevant literature, the elements the online STEM education activity would contain were identified. Online STEM includes videos that have limited access and are posted on platforms such as YouTube or cloud-based sources, as in online courses, lessons recorded based on the STEM methodology, or lectures simultaneously broadcast by the teacher (Zi-Yu Liu et al., 2020). However, online STEM should be built using a virtual learning environment focusing on active learning, student participation, and assessment (Chen et al., 2018). In this respect, the STEM education applied in the study was carried out from a virtual learning classroom with synchronously and asynchronously planned sessions and the use of different digital tools.

In the selection of the activity, a pool was created by gathering the activities suitable for the grade level and achievements among the engineering design cycle-based design tasks compiled by Teach Engineering-Activities (2020). The activities in this pool were presented to expert opinion and the activity "Teach Engineering Construct and Test Roofs for Different Climates, 2020" was chosen in terms of originality and openness to various solutions for the problem. The grade level of the participants was determined by considering the readiness for environmental issues. In this regard, 6th grade students who completed the "Humans and Environment" unit in 5th grade were preferred. It was deemed appropriate for the participants to be included in online STEM education, taking into account the criteria such as technological equipment and volunteering. The students included in the first cycle consist of 19 students attending the 6th grade. At the end of the cycle, 11 students completed the application.

In the process of determining the participants, the researcher designed the lesson plans for the application, the

contents of the digital board in Padlet, which is a digital learning environment, and the contents of the digital worksheets in Google Forms.

Apply: The application phase lasted a total of three weeks. In the first week, a seminar was held on digital applications to be used. In the second week, a design task was assigned, where the students could experience the skills they would use to solve the given engineering design-based problem. In the third week, the design for the solution of the engineering design-based problem was produced and tested.

In first week, the students were informed on how to access, share, and interact with other students and the teacher on the board, and the digital board and course contents configured by the teacher by using Padlet, which is used in the learning management system function, through screen sharing. In addition to this, the students were shown how to perform the "calculation, interface recognition, creating 3D objects, adjusting their size, grouping, copying, drilling, dimensioning and scaling, and creating a design consisting of at least two objects" that they should use in the Tinkercad tool while making 3D modeling of the product they will design, through screen sharing, and they were asked to apply them simultaneously.

Figure 2. View of Worksheets Created with Google Forms

After the seminar course, they were asked to design a castle in a task called "I'm Designing a Castle for the King/Queen", where they could experience the knowledge and skills conveyed in the seminar lesson on Tinkercad. This design task was assigned with an interactive worksheet prepared by the teacher via Google Form and accessible via Padlet. As stated in the worksheet, the students made their designs by considering "the problem to determine the real and scaled dimensions of the design, the design constraints such as the sizing, hole creation, the use of grouping features that they should use when designing the castle, and the physical features of the castle such as the number of doors, columns and windows". They also have experience in the steps to be followed in their duties. The lesson was concluded by giving the problem related to the big design task named "I'm Designing a House According to the Climate" to be done in the 2nd and 3rd lessons of the application. The relevant problem is given through a digital story. It is summarized as follows in the digital story: "You are the chief engineers

selected for the residences to be built in Rize, Van and Konya! You are asked to design an exemplary building model for the residences to be built in each of these provinces. In such a big project, it is not possible to get the opinion of the people of the region. But the people cannot come to a common decision, they are divided into two groups with different views. In the voting held in the region, both parties' requests received equal votes. You will make the decision as the chief engineer…"

In the digital story, half of the people in the region support a design suitable for the climate conditions, while the other half support skyscraper-type structures that take into account the needs of the people. The students were asked to explain with their justifications which group they would design by supporting their decision. In the 2nd and 3rd week courses of the practice, it was explained that the desing- based engineering problem on "climates" and "climate change". In second week, the design task was given through the digital story prepared by the teacher, and the factors that should be considered in the house design of the students was discussed with the students. As a result of the discussion, the students wrote down the physical characteristics (roof shape, number of windows, height from the ground, etc.) and dimensions of the city they selected based on the different climate conditions of the provinces of Van, Konya, Rize, and their dimensions in the relevant places on the interactive worksheet. They were asked to design "a house that can withstand heavy snow masses and keep warm" for the province of Van, "a house that will keep it cool in summer and warm in winter" for the province of Konya, and "a house that will not be affected by heavy rains and resistant to floods" for the province of Rize. The students produced alternative designs by considering the criteria they determined and given by the researcher. Relevant information, criteria and test conditions are given in Table 2.

Table 2. Information on the Problem of the Major Design Information, Criteria and Test Conditions

	Information	Criterion	Test Condition
Van	Number of snowy days in 1 year: 79 Lowest air temperature in 1 year: -3.7 Highest air temperature in 1 year: 21.2	The house to be designed should keep the occupants warm on cold days and should be resistant to large snow masses.	The building, which will withstand heavy snow masses, will be tested by tossing 5-10 coins over the roof.
Konya	Number of rainy days in 1 year: 82 Lowest air temperature in 1 year: -28 Highest air temperature in 1 year: 40 12.2	The house to be designed should keep the people living in it cool on hot summer days and warm on winter days.	An ice cube to be placed inside the house should be able to remain without melting for at least 1 minute when a hair dryer is held from outside the house.
Rize	Number of rainy days in 1 year: 172 Lowest air temperature in 1 year: 10 Highest air temperature in 1 year: 26	When it rains a lot, you should design a house that will protect people from the rain and not get wet. It should also be resistant to flooding.	When 1 glass of water is poured from the roof of the house, the interior of the building must remain dry

In the second lesson, each student modeled the best design solution on Tinkercad. Students shared their models on Padlet and presented them to their peers. Until the next lesson, they were asked to develop design solutions based on their peers' opinions and to write the necessary materials for their prototypes on the digital board. Feedback was given to the models and material ideas shared by the teacher until the following week. A Tinkercad

design designed in accordance with the climatic characteristics of Rize province, the Padlet interactions for the design and the product version of the design are given as examples in Figure 3.
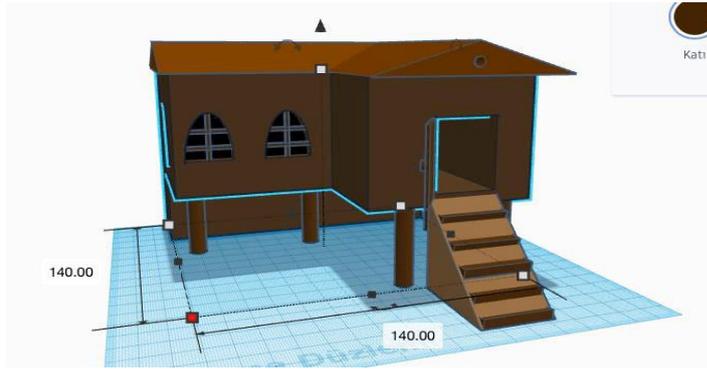
Tinkercad Model

Student Product

Malzemelerin gayet uygun. Karton ve mukavva yerine evde bulunan kullanılmayan karton kutuları da kullanabilirsin :) — SİBEL UYANIK

öğretmenim evi haftayaki derste mi yapıcaz yoksa bir sonraki derse kadar kendimizmi — ANONİM

derste yapıcaksak süre yetmeyebilir yani ders saatini 3-4 saate kadar çıkarmanız gerekebilir(bence) — ANONİM

Harika olmuş,evin şeklini çok beğendim — ANONİM

Haftaya 1 saat süremiz olacak, bu süre içinde yetiştirmeye çalışacağız. Çok uzun süreceğini düşünüyorsan yapmaya şimdiden başlayabilirsin. Fakat tamamen bitirme ki 1 saatlik derste arkadaşlarınla birlikte evini yapmaya devam et :) — SİBEL UYANIK

Examples of teacher and student interaction through the padlet
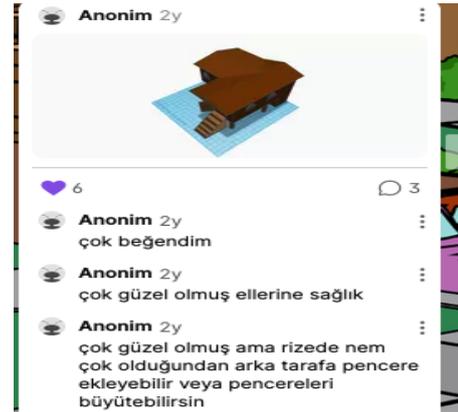
Peer comments on Padlet

Figure 3. Examples of Interactions through Tinkercad Design, Student Product and Padlet Designed in Accordance with the Climatic Characteristics of Rize Province
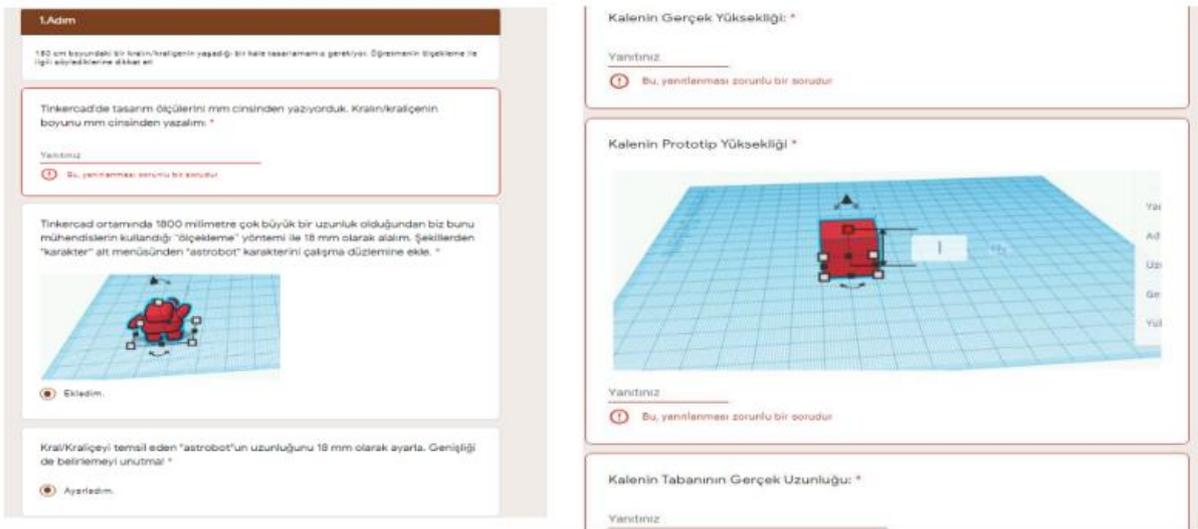

Figure 4. Sharing of the Product with the Introduction Letter of a Student who Finalized His Product

In the third week of the application, the students created their products with the materials they determined and subjected them to the test conditions given in Table 2. They developed their products in line with the test results and peer opinions and uploaded them to the digital board with an introductory text. The sharing of a student who finalized his product is shown in Figure 4.

Reflect: The action research process is carried out to ensure the change or improvement in application in the working environments of the participants (Saban, 2021). This change or improvement in application is ensured by using the experiences of the participants (Johnson, 2014). In this context, the experiences of the students, the researcher and the parents regarding the process were taken from their own perspectives with different data collection tools and reflection was made. Through the holistic evaluation of the data collected from students, teachers, parents, and material sources throughout the process, "pros and cons regarding the applied online STEM education" were revealed.

The fact that the products developed by the students as a result of the application of the course design, which is built for use in action research, comply with STEM principles reflect the strengths of the action plan and its aspects that require improvement. The reflections of the students, parents and the researcher before, during and after the application were obtained through different data sources. With these data, the pros and cons in the course design were identified and the action plan was prepared to be used in the next cycle.

Second Cycle and Its Steps

The engineering design-based problem presented to the students in the second action cycle of the application is "How can an environmentally friendly car be designed that reduces the number of harmful gases released into the atmosphere?" The course design prepared for producing solutions to this problem by using STEM disciplines was tested with plan, apply and reflect phases, and the action cycle was completed.

Table 3. STEM Disciplines and Tasks

Relevant STEM Discipline	Tasks
Science	Learning about wind as an energy source
	Choosing the appropriate energy source for the vehicle to be designed (The lifetime of the energy source, its cost and the amount of harmful gas it emits will be considered.)
Technology	Making a tool design prototype in Tinkercad according to the specified limitations
Engineering	Learning the structure of wind turbines
	Determining the appropriate materials and plan to turn the prototype into a product
	Developing and finalizing the product according to test results and peer-teacher recommendations
Math	Calculating the cost for energy

Plan: Since the second cycle included the same participants, the seminar lesson was not held, and the design task was planned to be allocated for two classrooms. Also, a different topic was discussed in the continuation of the study. In this regard, the mini design task and the major design task were created under the themes of "renewable energy sources" and "air pollution". In the interactive worksheet used during the preparation and design phases of the engineering-based problem: "How should a car design be based on the conditions of provinces with renewable energy?" It was asked to determine the points to be considered in car design based on a short news. The tasks at each step in the course design developed and the related STEM discipline are given in Table 3.

In line with the reflections from the first cycle, the course materials were prepared by choosing digital tools in which students would be more active, EdPuzzle for interactive videos, and TeacherMade, which provides effective feedback instead of Google Forms for transferring design tasks.
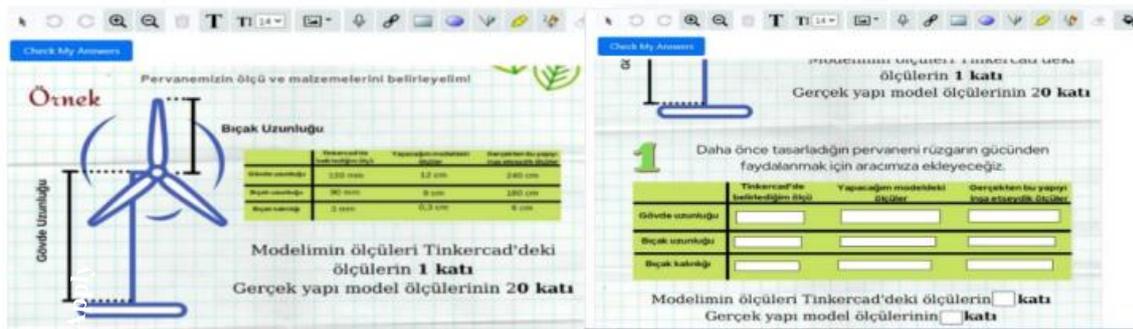

Figure 5. The Part of the Worksheet with Questions for the Major Design Task

Apply: In the first week, the structure and working principles of wind turbines were provided through Edpuzzle and interactive worksheets, and a "mini wind propeller" was designed with Tinkercad. In the second week lessons, the "ask, imagine, and plan" phases were carried out during the lesson, and the "create" part was carried out outside the lesson.

First of all, the problem related to the big design task called "I'm Designing Cars" was given with the words "The UK announces that it will ban the sale of diesel and petrol vehicles from 2035" and "The amount of harmful gas released into the atmosphere by the vehicles to be produced in your company is requested to be at a minimum level". For the problem, the students read and discussed the effects of "renewable and non-renewable energy sources" on the environment and made calculations such as determining the problem, choosing the fuel they will use in car design, the cost of the fuel and the amount of CO_2 released to the environment. Having defined the criteria for their designs, the students established the dimensions and other details of their designs on the digital worksheet and created their possible design solutions in Tinkercad. In the second lesson, the students determined the best design solutions by discussing possible design solutions with their peers in the group rooms made over Zoom. With the intent of turning their design solution into a product, they defined the necessary materials on the digital worksheet and presented them to the teacher's opinion. The students were asked to complete their products until the following week, together with the materials determined by the teacher's feedback given in the course and on the digital worksheet.

Table 4. Information, Criteria, and Test Conditions for the Problem of the Large Design Task

|	Information (per Tool)			Criterion	Test Conditions
Energy Source	The amount of harmful gas released into the atmosphere	Remaining life of fuel	Total cost	Considering the lifetime, cost and amount of harmful gas released into the atmosphere, one of the two energy sources should be preferred and a vehicle should be designed according to the preferred energy source.	- It should be able to stand in balance with the car body and all the structures on it. - The car moves when the hair dryer is held - The car must be able to move along a straight line.
Wind	0 ton	It doesn't run out	5500 dollar		
Petroleum	5 ton	42 year	6600 dollar		
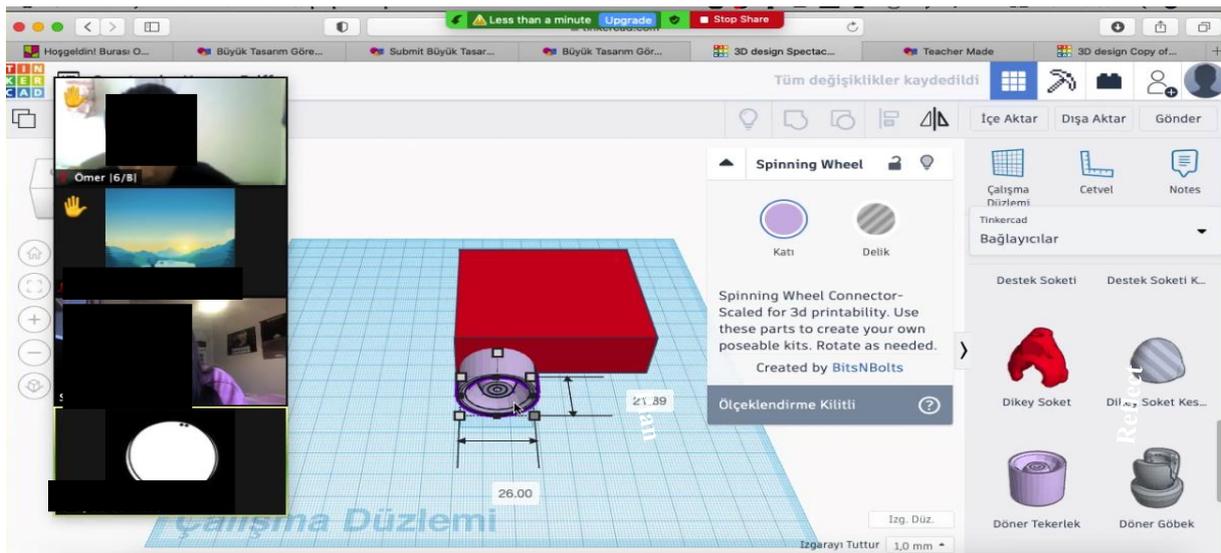
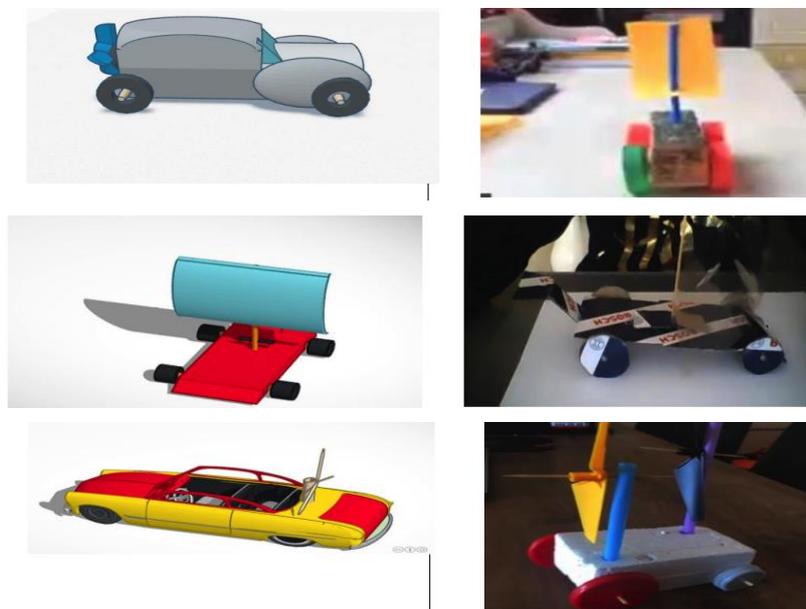Figure 6. A View from the Working Moment in the Group Rooms Performed via Zoom

Figure 7. Examples of Models and Prototypes Prepared by Students on Tinkercad

In third week, while the students who completed the "create" phase before the lesson tested the robustness of their prototypes and made their presentations guided by questions about science, technology, engineering and mathematics disciplines prepared by the teacher, the students who did not complete their prototype continued to the "create" phase. Until the end of the lesson, all students reached the "development" stage and gave their final form to their prototypes, sharing them on Padlet.

Reflect: As a result of the evaluation of the data obtained during the second cycle, no results were found to improve the online STEM education application. Data from students, parents and teachers consist of statements about the continuation of the application, the performance of different activities or their satisfaction. Since the data formed such a pattern, the research was terminated with the second cycle.

Researcher Teacher and Its Role

According to Köklü (2001), since action research is where the roles of teacher and researcher are undertaken together, the researcher-teacher, who is a graduate student and a science teacher, took on the role of both researcher and teacher by conducting the design and application of the research. The researcher teacher has experience in applying face-to-face and online STEM activities to secondary school students and developing STEM activities. The researcher also has the title of a psychological counselor and has guided students throughout the process, especially on motivation. In this study, the development of STEM activity by conducting the application provided the professional development of the researcher. All stages and contents of the research were supervised by a science education specialist other than the researcher teacher. To prevent bias that may arise from the fact that the researcher and the practitioner are the same person, external reliability and data diversity were ensured with various data collection tools, and the data were presented in detail.

The researcher-teacher observed that in their pre-research lesson experiences, students were motivated for the lesson by reflecting their feelings of excitement, curiosity and happiness while doing online STEM activities. When they asked the students whether they applied STEM activities at school and whether they were aware of similar activities in the textbook, they stated that the science teachers at the school did not perform such activities and they were not aware of the STEM activities in the textbooks or did not know how to do the activities.

The need for methods to conduct the STEM education activities during the compulsory remote education in the global pandemic was also included in these observations. Thus, the researcher teacher determined the subject of the research, considering the necessity of the research that presents an exemplary course design on "online STEM education", which will ensure that STEM education can be maintained in an accessible and qualified manner independent of time and place.

Research stages and contents were supervised by a science education specialist other than the researcher teacher. External reliability and internal reliability were quaranteed by diversifying data with different data collection tools and presenting the data in detail, to prevent bias that may occur due to the fact that the researcher and the practitioner are the same person.

Data Collection Tools

Due to the nature of the research, the data collection process conducted along with all the stages of the application was also held online. All the data collection tools selected were used in an online format. These tools were applied to the components of students, teachers, materials, and parents, which were determined as the four basic pillars of online STEM education in the study, at different stages, including before, during and after the application.

Prior to the application, Personal Student Profile Determination Form (PSPD) was applied to the participating students to obtain their personal information, define their knowledge about technological equipment and Tinkercad use, and the STEM Education Attitude Scale to determine their STEM education attitudes. These data were used only to identify the participants.

During the application, students' views, feelings and interactions regarding the online STEM application were reviewed, a digital student diary was applied to determine its pros and cons, and lessons and Padlet board posts were recorded. The researcher-teacher, who was another participant in the process along with the students, aimed to define the pros and cons of the application by keeping a researcher diary and observation notes. These data collection tools aimed to collect feedback on the implementation of the course design throughout the process.

As another participant of the process, it was aimed to collect the opinions of the parents participating in the research with the Parent Opinion Form and to express their opinions about the practice, teachers and students.

Data Collection Tools Used Before Implementation
Personal Student Profile Determination Form (PSPDF)

In the "Personal Information" section of the form, which consists of 2 parts and 7 questions, 5 questions focus on demographic information. In the "Determination of Student Profile" section, there is 1 filtering question prepared to determine their knowledge of technological equipment and their experience with the Tinkercad application. This question revealed that those who used the Tinkercad application before could recognize the Tinkercad interface, adjust the size of 3D objects and objects, create, group, drill holes, copy, make simple designs consisting of at least two objects, and design projects.

Data Collection Tools Used During Application
Digital Students Diaries

In order to enable the participants to freely express their feelings, thoughts, positive or negative feedback about online STEM training and themselves, they were asked to fill in diaries consisting of 6 headings formed via Google Forms at the end of each lesson. They can be briefly summarized as "the points that attract the attention of the student, the moments of difficulty, the parts they want to change, what they feel, what they think they are doing well, and what they want to add apart from these".

Digital Sharing and Products

Digital sharing and products refer to the participants' written and visual sharing of in-class and extra-curricular activities over the Padlet, which is used in the function of the learning management system, and the digital board configured by the researcher, and the "teacher-student", "student-student" and "student-material" interactions on this system.

The posts in Padlet include the 3D designs created by the students on Tinkercad, the photos of these designs turned into products with concrete materials, the promotional texts of the products and the comments made by the students on other designs.

Researcher's Diary and Observation Notes

The researcher teacher kept a diary including their evaluations of the application after each lesson. In the diary, the teacher freely expressed their opinions on the pros and cons of the application. They also added short observation notes they took during the lesson.

Data Collection Tools Used After Application.
Semi-Structured Focus Group Interview

The semi-structured focus group interview was applied with a form consisting of 6 open-ended questions prepared to get feedback on the application, the digital tools used, their communication with their peers and teachers, and their views on themselves and their products within the framework of group dynamics. The interview questions were formed in accordance with the "opening, introduction, transition, key and closing questions" categories recommended by Krueger and Casey (2000) to be used in focus group interviews and were finalized with the opinion of a science education expert. The sample question, purpose, and category of the question regarding the semi-structured focus group interview form are as follows:

> *Question 1: What do you think about the application we carried out for 3 weeks? (You*
> *can talk about what you like, if you have any difficulties, or what do not understand.)*
> *Purpose: To get feedback on the application*
> *Category: Starting question*

The interview was conducted online via "Zoom" and lasted for 45 minutes. All 11 participants attended the focus group discussion at the same time.

Parent Opinion Form

For the parents to evaluate their students, the application of online STEM education and the researcher teacher, a form consisting of 12 open-ended questions was applied to receive feedback. The expert opinion recommended that the parent opinion form and the focus group interview form applied to the students should have parallel contents. In this respect, the form prepared to explore the opinions of the parents about the application, the digital

tools used, their students, and their communication with the teacher was transferred to Google Forms and delivered to the parents. It was filled out by the parents of all 11 participating students. The sample question and category regarding the parent opinion form are as follows:

> *Question 9: Did your student have any difficulties? If yes, what are they?*
> *Purpose: To get opinions on student and parent participation*

Analysis of Data

The data were analyzed using "descriptive analysis" and "content analysis" methods, which are required to be used in qualitative data analysis by Corbin and Strauss (2014). Since digital student diaries, semi-structured focus group interview and parent opinion form consisted of headings and questions determined by the researcher, the data obtained were subjected to descriptive analysis in which these questions were accepted as themes according to Yıldırım & Şimşek (2018). The researcher's diary and course records were subjected to content analysis, which was also stated by Yıldırım & Şimşek (2018) as the themes were created by analyzing the data in detail.

Analysis of Digital Student Diaries

In the first cycle, digital diaries filled by 11 students in the first week, 7 students in the second week and 6 students in the third week were read by the researcher teacher and subjected to descriptive analysis for 3 weeks. In the analysis of the diary, which consists of 6 structured titles, the themes of "the points that attract the attention of the students, the parts that are difficult and the problems, the parts that need to be changed, the feelings harboured, the parts that the student thinks they did well and what they want to add" were used, while the codes collected under the themes were created by analyzing the sentences written in the diaries. The data set, themes and codes were presented to 1 science education specialist, 2 science teachers and 1 psychological counselor. Science education specialist suggested that the evaluation of student diaries should be done by considering the course content. In this context, course recordings and digital student shares were also used in the analysis of digital student diaries. It was seen that all the coders agreed on the themes and codes. In the second cycle, the diaries filled by 8 students in the first week, 6 students in the second week, and 8 students in the third week were analyzed.

Digital Sharing and Analysis of Products

All of the written and visual posts shared by the students on Padlet were collected in a single document and subjected to content analysis to be used to support other data.

Analysis of Researcher's Diary and Observation Notes

The diary and notes of each week, which were written freely in both cycles, were subjected to content analysis and two themes were determined as "problems" and "advantages". Categories were created to detail these general themes and codes were presented under these categories. These themes, categories and codes were presented to the science education specialist.

Analysis of Course Records

For each cycle recorded through the Open Broadcaster Software (OBS) program, the course records consisting of 80 minutes for 3 weeks were watched and written down by the researcher. The data set for each week was read and the codes were determined under the themes of "technical glitches and technological difficulties, learning contents and expressions related to STEM fields, in-class interaction, prototyping and development" and shared with the science education expert and opinions were obtained.

Analysis of Semi-Structured Focus Group Interview

Interviews at the end of each cycle lasted 45 minutes. The interview records were transcribed by the researcher teacher and the themes and codes were extracted from this text. Based on the 10 open-ended questions, the themes were determined as "thoughts about the STEM education application, what is wanted to be removed or added to the STEM education application, thoughts about technological tools, student-teacher and student-student communication and statements about the prototype". Under these themes, categories were defined in accordance with the data, and codes and direct quotations were presented under these categories.

Analysis of Parent Opinion Form

The themes of "thoughts about STEM education, its effect on school success, timing, materials, parts that the student likes, the points that the student has difficulty with, communication with the teacher, evaluation of the student and recommendations", which were created based on the questions of the opinion form, were presented to the expert opinion and found appropriate. The relevant codes were extracted from the data and collected under the themes.

Validity and Reliability

The criteria and concepts of validity and reliability in qualitative research are credibility, transferability, reliability, and verifiability (Lincoln & Guba, 1985). Strategies aimed at providing these criteria and concepts expressed by Krefting (1991) were used in the research. Reliability, which expresses internal validity, can be achieved with long-term field experience and detailed transfer of this experience (Buyukozturk et al., 2013; Krefting, 1991). In this regard, the researcher teacher took part in the 6-week application process as both a practitioner and a researcher, and recorded the process in detail with the researcher's diary and observation notes. However, during the application, diversity was ensured by collecting data from the students and parents as well as the data of the researcher teacher. In ensuring external reliability, transferability is critical only for the intelligibility of research results by other researchers (Büyüköztürk et al., 2013) as qualitative research does not aim for generalization (Johnson, 2014; Özpınar & Aydoğan Yenmez, 2015; Stringer, 2007). In this respect, Krefting (1991) suggested that the sample should be given in detail, the data be examined precisely, and the research report be detailed. In the study, the participants were defined by means of "PSPDF" and "STEM Education Attitude Scale". The data collected during the research were analyzed simultaneously, reflected in the study in accordance with the dynamic

process of action research, and presented in detail at the end of the study.

Büyüköztürk et al. (2013) defines the concept of reliability as "recording everything that occurs as data" (p.245). In this regard, reliability was ensured by the processes of recording the data, writing it down, and evaluating the data obtained from various data sources from various data collection tools in a holistic manner. According to Krefting (1991), verifiability, which indicates the objectivity of the research, can be achieved by the triangulation method. Triangulation is defined by Breitmayer et al. (1993) as an approach that combines multiple methods, data sources, theories, or researchers to reveal a subject in various dimensions, and where all these components complete one piece of the research puzzle. In the research, the students, teacher, parents, and material data sources were used within the triangulation method and also diversified the data collection tools used. Moreover, to ensure verifiability, the coding processes in the data analysis were conducted by a field expert who is an associate professor in the field of science education at the university, 2 science teachers, and 1 psychological counselor who is an expert in emotion-focused therapy. While the field experts and science teachers coded all the data, the counselor coded only the data belonging to the "feels" sub-theme in the student diaries. In this way, a psychological counselor's opinion was asked to obtain student opinion about the online STEM education.

Results

In this section, the findings of the two cycles in the development of environmental STEM education design are presented holistically by expressing the data obtained from all data sources (student, teacher and parent) and collection tools with common themes and codes. The frequencies of the codes are the sum of the statements of all participants, including students, teachers and parents, in all data collection tools used in the first and second cycles of the study. Therefore, the frequency values are different from the total number of participants and show the number of expressions. The sections that work smoothly in the implementation of the environment-based STEM activity designed and are considered to be positive by the students, teachers and parents are defined as "pros". The pros are reintroduced into the design to be implemented in the next cycle. On the other hand, the sections that cause problems in the implementation of the environment-based STEM activity designed and are considered to be negative by the students, teachers and parents are called as "cons". Such aspects are included, if possible, optimized for the next cycle, or not included at all.

Results for the 1st Cycle

The pros and cons of the application made in the first cycle, as well as the themes and codes related to the suggestions are presented in Table 5 with their frequencies.

Table 5. Cons in the First Cycle, Pros and Suggestions

Themes	Codes	Categories	f	Quotes
Cons	Use of Technology and Technical	Using digital tools	24	"…Now I entered Tinkercad, the dimensions came out a little bit, it seemed like I had chosen wrong. Am I going to go and replace these in the form now? It's hard to go back. ", (M.A.,

Themes	Codes	Categories	f	Quotes
	Content			2nd week Lesson Records)
		Using digital course environments	13	"..Padlet can have its own special forms. It would be better to be able to fill out the form on your own instead of using the Google form." (M.A., Focus Group Interview) "Sir, I can't even do anything how I did it because it's my first time using it." (Z. Week 1 Student Diary) "In the Tinkercad design part, the students made their designs more easily than in the first week." (Research teacher, 2nd week Researcher's Diary)
	STEM and Course Content	Following the lesson and the application at the same time	5	"This pace was suitable for some students, while others found it very difficult. At the end of the lesson, there were students who were left behind and missing." (Research teacher, 1st week Researcher's Diary) "…I can't watch the practice and listen to the lesson at the same time" (Y., 1st week Lesson Recording)
		Determining the material for the prototype	10	"I had a little trouble finding the right material. I did some research. I tried which ones are waterproof and which ones are not…" (Y.S., Focus Group Interview) Maybe we could give a few examples of easily available and waterproof materials at home." (I., Focus Group Interview)
		Simultaneous preparation of the prototype	8	"I started the design on Saturday morning and finished in the middle of the first class. He wouldn't be able to catch up in class time." (A.Ş., Focus Group Interview)
		Making a prototype presentation in writing	10	"The last half hour of the second lesson was over before that. Time was enough." (E.K., Focus Group Interview)
		Understanding scaling (Math)	6	"I had some trouble adjusting the lengths…" (S.E., Week 1 Student's Diary) "They had trouble understanding the actual height on the form and the prototype height." (Research teacher, 2nd week Researcher's Diary)

Themes	Codes	Categories	f	Quotes
Features Going Well	Emotions for Application	Be Fun	15	"It was a lot of fun, I liked the lesson very much" (Y.S., Focus Group Interview)
	Behaviors for Class Interaction	Solidarity	9	"During their Tinkercad designs, students helped each other when they had difficulties." (Researcher Diary)
	Favorite Features for the Application	Designing	12	"My son met and loved designing…" (Parent 8, Veli Opinion Form
Suggestions	Making Different Designs		8	"Maybe we can make more difficult designs as 3d designs using tinkercad or designs using different materials."(A.Ş., Focus Group Interview)
	Gradual Progress		2	"I expect them to complete the 1st training and go to the 2nd training. So they can go step by step."_(Parent3, Parent Opinion Form)
	Incorportaring Different Uses of Technology		6	"You can use technology differently" (Parent7, Parent Opinion Form)
	Group Work		1	"Group work can be done." (Parent11, Parent Opinion Form)

As seen in Table 5, most shortcomings in the online STEM education application are under the theme of "Technology Use and Technical Content" (f=37). The most problematic aspect under this theme is digital tool use (f=24). Since it is difficult to access, provides limited feedback and interaction, and students cannot access their answers asynchronously, Teachermade, the digital handout tool that can meet these needs, was used in the second cycle instead of Google Forms.

The students had difficulty using Tinkercad, for 3D modeling of students' designs, in the first week (f=14). However, this difficulty decreased in the second week (f=5). In the focus group meeting held at the end of the application, when asked about their opinions on Tinkercad, their answers focus on the problems arising from the interface of the application and their desire to make different designs on Tinkercad. In this context, as Z. stated, these problems are caused by inexperience, and the difficulties related to Tinkercad use disappear as the students gain experience. Since the second cycle continued with the same participants, the tool was still in use, taking into account their experience in using Tinkercad.

The second biggest con in practice is using digital course environments (f=13). It was resolved by sharing the link of the Padlet digital panel used in the learning management system and giving the students preliminary information about accessing the digital lesson environments before the lesson. In addition, the students made suggestions about preventing peers from being inspired by each other about the designs they shared on the digital board regarding Padlet and not keeping the students who commented anonymously. As can be seen in Table 5, other aspects that hinder the practice of remote STEM education are preparing the prototype under the theme of STEM and course content at the same time, following the course and the application at the same time, determining

the material for the prototype, making the prototype presentation in writing and understanding scaling.

Preparing the prototype at the same time means that students transform the designs they model into products with the materials they choose. Prototype preparation, which was planned as a synchronous activity in the first cycle, was carried out asynchronously by 7 students and synchronously by 4 students. While there are students (f=3) who state that the duration of the course is insufficient for this job, there are also students who find the duration sufficient (f=2). In this respect, in the second cycle, it was decided to carry out the prototype preparation asynchronously in order to bring the students together on a common time denominator. Regarding the material determination (f=10) for the prototype, it was found that the asynchronous execution was disfunctional since the students needed guidance while determining the material, and the teacher could not observe the process.

In the first cycle, it was planned to make the prototype presentations in writing and asynchronously via Padlet, and the students made these presentations superficially (f=9). In this context, it was deemed appropriate to conduct the presentations in the second cycle verbally and synchronously.In practice, students had difficulties in understanding scaling, which is the content of the discipline of mathematics, which is used to determine the design and prototype dimensions in accordance with their actual dimensions. (f=6) In order to solve this problem, it was planned to repeat the concept of scaling by applying it on the digital worksheet in the mini design task in the second cycle. In the big design task, the students would apply scaling on the digital worksheet on their own, and the teacher would give written feedback to these applications. Considering the pros of the application, it is seen that the students found the application fun (f=15), they exhibited the behaviors of helping each other in class interaction (f=9) and participating in the discussions (f=6) and designing (f=12) was the part they liked the most.

The suggestions most frequently made by students and parents regarding the repetition of the application are also presented in Table 5. Considering the most frequently expressed suggestion of "designing different vehicles" (f=8), the design tasks of the second cycle were determined as wind propeller and car design. Again, considering the gradual progress (f=2) suggestion, these designs were planned to be higher level in terms of knowledge and skills. However, the proposed "coding activities" to include different uses of technology (f=6) could not be included due to time constraints. The use of different digital tools is provided by the previously mentioned Teachermade, Wooclap and EdPuzzle tool, which is used to present the course contents with interactive videos. The pros and the suggestion of doing group work (f=1) were reflected in the second cycle as increasing the interactive and interactive environments where students can experience fun, cooperation and classroom interaction actions together. For this purpose, at the stage of deciding on the design solution in the "imagine" step, it was ensured that they were able to present their views to each other in small groups by using the group rooms feature of Zoom.

Results for the 2nd Cycle

The pros and cons of the application made in the second cycle, as well as the themes and codes related to the suggestions are presented in Table 6 together with their frequencies.

Table 6. Cons in the First Cycle, Pros and Suggestions

Themes	Codes	Categories	f	Quotes
Cons	STEM and Course Contect	Simultaneous preparation of the prototype	15	"Sir, it is better to do it during the lesson. For example, if we do what we couldn't finish in class, we can do it more clearly." (S.E., Focus Group Interview) "Teacher, I try hard to do it, I think the duration of the lesson is a little short. That's why I find it appropriate to do it outside of the classroom. Then I can do it more carefully and diligently." (Y.S., Focus Group Interview)
		Needing help preaparing the prototype	14	"I had a hard time building the car. It was going well at first, I made the body, but I couldn't find the wheels. He started not to go, I got angry, he broke down. After that … we did it with my uncle, it was beautiful. (S.E., Focus Group Interview) "…When I pull myself back to improve dexterity, the project either does not progress or gets sluggish. He decides on the materials himself. While designing his model, he designs it alone. He asks for help in the construction phase." (V6, Parent Opinion Form)
		Performing mathematical calculations	8	"Calculate the total cost for the wind energy source, what are we going to do there?" (T, 1st week Course Recording)
Pros	Use of Technology and Technical Content	Tinkercad	7	"My teacher, I developed in Tinkercad according to me. Because I didn't know how to put a tiny box in the past, but now I'm building a huge car." (Ö., 3rd Week Student diary)
		Interactive Worksheet	9	"The interactive worksheets have been helpful…" (Researcher Diary)
		Padlet	10	Teacher, I enter Padlet often. I'm following my course there.
		Group Discussion	3	So it was nice, I think teacher, it was appropriate for us to use it." (Y.S., Focus Group Interview)
	STEM and Course Content	Understanding Scaling	8	"I wrapped silicone around the wheels for more grip and friction." (M.A., 3rd week Course Recording)
		Talking About Science Concepts	15	"If I put the propeller according to the direction the car is going, it can put the balance." (G., 3rd week Course Recording)
		Talking About Engineering Concepts	13	"My car is light so the wind is affecting it, pushing it. Its wheels are turning too. My car drives better because the propeller balances the wind." (Y.S., 3rd week Course Recording)

Themes	Codes	Categories	f	Quotes
		Expressing Prototype Features and Structure	7	"I just had a little trouble adjusting the lengths…" (S.E., Week 1 Student's Diary) "They had trouble understanding the actual height on the form and the prototype height." (Research teacher, 2nd week Researcher's Diary)
		Expressing Prototype Purpose	8	
Features Going Well	Emotions for Application	Be Fun	10	
		Feeling Like an Engineer	5	"I feel like I have become an engineer…" (S.E., Focus Group Interview)
	Behaviors for Class Interaction	Advising Peers in Group Work	8	"It can take better advantage of the wind if you sharpen the front of the car." (M.A., 2nd week Course Recording)
		Solidarity	4	"G: I give up, I can't make sail. S.E.: You will make a hole in the paper so that the straw will enter. Connect the two sides, here's a sail for you." (Week 3 Course Registration)
	Statements on Contributions of the Application	Positive impact on school success	8	"The fact that there are platforms like this where children can support their interests contributes a lot to their lessons… During the distance education process, the lessons started to disappear completely. Better now…" (V5, Parent Opinion Form)
Suggestions	Wanting to Make Different Designs		6	"…When my child was asked to choose elective courses from his school for the 7th grade based on this course, he wanted to choose science applications, mathematics applications and informatics courses from 13 courses… Because he said that he wanted to be an engineer and that these three courses would contribute to his becoming an engineer." (Parent7, Parent Opinion Form)
	Requesting the app to continue		7	
	No Want to be Added		19	

As seen in Table 6, the failing aspects are grouped under the themes of course content and STEM content. The biggest con of the course content is the simultaneous preparation of the prototype (f=15). Students are divided into those who finished the prototype before the lesson (f=3), those who started with the lesson (f=2), and those who started before the lesson but could not finish it (f=4). The students prefer to determine the prototype construction time based on their personal preferences because of the process carried out synchronously in the first cycle and asynchronously in the second cycle.

Another con of the application is related to the prototyping processes of students (f=14). While the students were

preparing the prototype asynchronously, they stated that they received help from their parents in the procedures that required manual dexterity. Parents' opinions also stated that they provided support as well as motivation for this need for help. Looking at the pros in the second cycle, it is seen that the theme of using digital tools, which includes the biggest cons in the first cycle, is at the forefront of the pros in this cycle. The data collected for using digital tools show that students have improved in their use of Tinkercad, the interactive worksheet is useful, Padlet is functional for course follow-up, and Zoom's group room feature is appreciated.

Statements for STEM content focused on "understanding scaling," which was a leading con in the first cycle, to become a pro thanks to the improvements in the second cycle. (f=8) In addition, the students used concepts and expressions related to the STEM content throughout the process in the fields of science (f=15) and engineering (f=13). These concepts and expressions can be summarized as "aerodynamic structure, energy conversion, air resistance, balance, center of gravity, fossil fuels, reverse engineering, friction force". The students also stated that they felt like engineers (f=5), although the "fun" of the practice continued (f=10). It is seen that helpfullness continues in classroom interaction (f=4) and students make suggestions to each other (f=8) with the group study room application.

In the second cycle, it is seen that the synchronous and verbal prototype presentations are more functional. While expressing the features and structure (f=7) and purpose (f=8) of their prototypes in their presentations, the students also conveyed their knowledge and skills in the field of engineering (f=11). The expressions obtained from the lesson record regarding the prototype structure are "it has 2 floors, it looks like a truck, and the structure of the wheels increases the roadholding". Statements related to the prototype purpose can be summarized as "environmental friendliness, low cost, renewable energy use, not harmful to the atmosphere", while statements regarding the engineering field can be summarized as "designing the vehicle lightly, making use of air resistance by sailing, lowering the height of the hull, making the front of the vehicle inclined".

Finally, regarding the theme, which is expressed as the contribution of the application, the parents emphasized the positive effect of the application on school success and stated that it contributed to the lessons, increased the desire to learn and made it easier to adapt to the distance education process (f=8). When the suggestions of the teachers, parents and students regarding the application were examined, it was stated that there was nothing to be added to the application other than wanting to continue the application (f=7) and wanting to make different designs (f=6) (f=19). Considering all the results related to the second cycle, the research was concluded without the need for a third cycle as it was thought that the cons of the course design developed could be corrected with suggestions, it was found to be functional in terms of knowledge and skills, and the stakeholders wanted the application to continue as a suggestion.

Conclusion

In this study, an online STEM course activity on environment was developed. As a result, suggestions were made about how to design an online STEM course activity on the environment, based on the cons and pros of the study. In the study, a course activity on the environment was designed to be used in the online STEM application, which

is thought to provide the continuation of STEM education in a common and sustainable way. Since the production and consumer-oriented approach of STEM education is criticized (Levrini, 2019; Smith & Watson, 2019), STEM activities to be developed with a focus on environmental issues will contribute to the sustainability of STEM education. In this context, it is believed that the study will guide practitioners and researchers in developing STEM activities on the environment. Dallı (2019) emphasized the importance of developing different STEM teaching plans on environmental issues. This study was also limited to the themes of "climate change" and "renewable energy".

As a result of the research, the flaws, and improvements in the applications of the online STEM education design on the environment, developed for secondary school students, and how a course design developed within this framework should be revealed. This section addresses the pros, the cons, and the suggestions for each theme given in the results section. Regarding technology use and technical content, Padlet, which is used as a learning management system, will be discussed first. Padlet has been found useful in terms of synchronous and asynchronous follow-up of the lesson. Erturgut (2008) suggested that digital environments used to ensure the quality and continuity of online education applications should be accessible both synchronously and asynchronously. In this context, online STEM education applications should be carried out through a learning management system. Similarly, in studies where online STEM courses were applied, the process was carried out through a learning management system (Chen et al., 2018; Jeong et al., 2020; Mohammadi et al., 2020). These environments should be used in online STEM education as it is necessary to both follow the course and improve peer-to-peer communication (Chen et al., 2018). However, it is stated that students in the disadvantaged group may fall behind in interactions conducted through the learning management system due to their lack of sense of belonging or lack of technology experience (Elliott & Luo, 2022).

A con of Padlet is that students have difficulty in accessing course resources in the first weeks. This difficulty disappeared in the following weeks. It is argued that students who have a certain level of digital competence and access to digital technologies and equipment in online educational activities are in an advantageous position (Bozkurt, 2020), and that learners at different levels should be considered in terms of these variables (Özkul & Girginer, 2014). In this respect, it is thought that these difficulties experienced in the first weeks may be related to the students' access to technology, experience, ability to use technology and digital competence variables.

Secondly, Tinkercad will be discussed regarding the use of technology and technical content. In the online STEM application, the designs made through Tinkercad had a positive effect on all participants (students, teachers, and parents). Students were asked to diversify the designs to be made with Tinkercad. In addition to this positive aspect, the students who did not have Tinkercad experience had difficulties in the first weeks of the application. However, it is seen that they thought that they make better designs as they gain experience during the application. It was proposed that experience should be gained for a certain period to make STEM-related designs with Tinkercad (Bhaduri et al., 2021).

The Zoom Breakouts feature of the Zoom application, which is another digital medium, was used in the second cycle of the application. It is important to improve the sense of belonging in the group and create different

communication channels in group activities to be held in online learning environments (Yıldız, 2020). It is important to ensure the sense of belonging and communication in group activities to be carried out in online STEM education applications. It is known that STEM education practices, in which students work in groups, lead to stronger communication among group members and result in a positive attitude towards teamwork (Karahan et al., 2015). Moreover, it is seen that students become more helpful in class interactions. In this context, it is predicted that increasing the number of group activities can strengthen communication, which is an important element in all stages of online STEM education. While studies in the literature (Doğru & Yüzbaşıoğlu, 2021; Larson & Farnsworth, 2020; Poyraz, 2019) similarly talk about the importance of communication and teamwork in distance STEM education applications, Poyraz (2019) mentions the importance of self-directed communication in which the individual interacts with himself and the material.

Technology use and other recently used interactive applications related to technical content will be discussed. As a result of the reflections made from the first cycle, different digital applications were included in the second cycle to improve the active participation of the students and to put their socio-emotional skills to work. It is known that active learning and participation in STEM education practices affect motivation positively and digital tools should be chosen accordingly (Brunelli & Macirella, 2021; Julia & Antoli, 2019). Presenting the questions related to the problem in the course design with the interactive video tool EdPuzzle, using Teachermade to prepare the digital worksheet, and group work with Zoom Breakouts yielded positive results. With the use of these tools, it was observed that the students use more expressions reflecting their knowledge of STEM fields, especially science and engineering. In line with these results, it is known that there is a relationship between social and emotional factors and interest and competence in mathematics and science (Hoffman, 2021). In this context, it is important to increase the number of environments where students are active and can use their socio-emotional skills, in terms of ensuring motivation and continuity in online STEM education.

It is seen that the only problem related to group work using Zoom group rooms feature, which is evaluated positively, is related to efficient use of time. Students initially abstained from sharing their designs and commenting on other designs. It is important to increase in-group belonging and create different communication channels in group activities to be held in online learning environments (Yıldız, 2020). It is important to ensure a sense of belonging in the group and communication in group activities to be carried out in online STEM education applications. It is known that STEM education practices, in which students work in groups, lead to stronger communication among group members and result in a positive attitude towards teamwork (Karahan et al., 2015). Furthermore, it is seen that students become more helpful in class interactions. In this context, it is predicted that increasing the number of group activities can strengthen communication, which is an important element in all stages of online STEM education. While studies in the literature (Doğru & Yüzbaşıoğlu, 2021; Larson & Farnsworth, 2020; Poyraz, 2019) similarly talk about the importance of communication and teamwork in distance STEM education applications, Poyraz (2019) mentions the importance of self-directed communication in which the individual interacts with himself and the material.

Another strength of the STEM course content, which is another theme, is that students find the content fun and love to design. Similarly, a STEM application found that students' reaching a concrete result through designing

positively affects their attitudes towards the lesson (Timur et al., 2020). In this respect, it can be said that the design process in the content is effective in expressing the positive feelings of the students towards the application content. Contrary to this study, Uyar et al. (2021) suggested that students had difficulties in designing, in face-to-face STEM applications. In this context, the determination of the reasons why designing, which is difficult in face-to-face STEM activities, is among the pros in online STEM application, is a limitation of this study.

There are also cons to STEM and course content. Other problems encountered are related to STEM and course content. These problems are the differences of opinion of the students in following the lesson, determining the necessary materials for the prototype, and preparing the prototype during or outside the lesson. It is thought that the difficulty experienced in following the lesson and the application at the same time is due to the limitation of time caused by the technical problems in the first lesson. The absence of statements about this problem after the first week may be associated with the students' gaining experience. It was observed that the students needed the support of their parents in determining the necessary materials for the prototype and preparing the product. In the literature, it is stated that there is a need for parent support for orientation (Keaton & Gilbert, 2020) and preparing the necessary materials (Yunita, 2021) in online STEM education courses. Accordingly, it can be concluded that parent support is required in the specified parts of online STEM education. In online STEM education applications, parents can be expected to help in providing the necessary materials and in the processes that require manual dexterity while preparing the student product.

In addition to these difficulties, students had a hard time scaling the design related to mathematics, one of the STEM disciplines, and applying the calculation with the data given about the problem. In the face-to-face STEM lessons, middle school students had difficulties with the content of the discipline of mathematics (Aydın & Baydere, 2019; Gülhan & Şahin, 2016). Since the problems found in online STEM education overlap with these results, it is recommended to conduct an interdisciplinary study in which mathematics education experts are included in preparing and applying the content related to the discipline of mathematics.

Considering the results, the online STEM education design example was finalized in the study. In the literature, online STEM education is supported in terms of providing accessible and quality STEM education for everyone, and it is recommended to ensure the participation of individuals from different ages and levels (Arts & Deligöz, 2019; Burns et al., 2020; Chen et al., 2018; Flowers et al., 2012; Mohammadi et al., 2020; Tekin Poyraz & Kumtepe, 2019). On the other hand, ensuring that online STEM education is accessible to all students may be an additional burden for teachers (Larson & Farnsworth, 2020) and cannot facilitate permanent learning at all levels (Türk & Duran, 2022). The view that continuing online STEM education is a necessity supports the increase in the number of studies that produce solutions considering these difficulties (Brunelli & Macirella, 2021; Kazu & Işık, 2021). This study also revealed the pros and cons of online STEM education, which was applied in parallel, and suggested solutions for the cons. With the use of this lesson design example by practitioners and curriculum developers, it is recommended to present and implement exemplary designs that can be integrated into STEM at different grade levels and subjects, including disciplines such as entrepreneurship, programming, and art.

Aykan and Yıldırım (2021), because of their work with teachers, stated that teachers should be encouraged to use

learning management systems and distance learning to develop high-quality lesson plans for STEM education. In the study conducted by Özdemir (2021) argued that the applicability of teacher opinions on online STEM education applications at secondary school level is difficult and complex; however, Sintema (2020) addressed the economic aspect of creating these plans. Nevertheless, it is also known that teachers are concerned about planning and implementing online STEM (Doğru & Yüzbaşıoğlu, 2021; Kazu & Işık, 2021; Larson & Farnsworth, 2020). In this context, more studies should be conducted on the preparation and implementation of online STEM education.

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