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The instruction of a laboratory lesson on the Internet with STEM-based hands-on activities: Electrochemistry sampling

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ABSTRACT

This study examines pre-service science teachers' opinions about STEM-supported hands-on activities and emergency remote teaching performed in laboratory courses during the pandemic. It was conducted with 14 pre-service teachers; they were asked to design an experiment by integrating STEM concepts and hands-on activities. The participants designed seven activities in the process. Data collection tools used in the study were expert evaluation, self-assessment, peer review, and interview forms. The data obtained from these tools were subjected to qualitative analysis. The entire process was carried out through online portals due to the pandemic. The study results indicate that the participants discovered the concepts of STEM, designed hands-on activities, and enjoyed the learning process. In addition, they suggested that laboratory courses enriched with STEM and hands-on activities can be an alternative to existing learning, and they were minimally affected by the adverse effects of the pandemic.

Keywords: electrochemistry, emergency remote teaching, hands-on learning, high school, laboratory instruction, multidisciplinary, physical chemistry

INTRODUCTION

The massive spread of COVID-19 worldwide has made it mandatory for schools, colleges, and universities to switch from face-to-face education to emergency remote teaching (ERT). ERT is a temporary shift from face-to-face formal education in schools to another alternative mode due to crisis conditions (Hodges et al., 2020). Regular training is resumed when the crisis or emergency is over. Many trainers and teachers were caught unprepared for this process. It was not easy to teach experimental fields such as biology, chemistry, medicine, and physics, which require application and laboratory work, in the virtual environment, both in terms of curriculum and infrastructure (Pagoto et al., 2021). Many theoretical courses were easily implemented online, just like in face-to-face education. However, it was very difficult to conduct online classes in laboratory lessons. Most instructors provided sample experiment videos or taught theoretical lessons. This problem was especially common in chemistry laboratory courses.

Laboratory practices are important in teaching chemistry lessons (Hodson, 2001; Hofsten & Lunetta, 2004; Ottander & Grelsson, 2006). Regarding the literature, laboratory activities increase students' interest in learning chemicals and concepts, trigger a sense of curiosity and research, and motivate students' learning (Hodson, 2001; Högström et al., 2010; Leopold & Smith, 2020). Similarly, it is known that laboratory practices reinforce students' theoretical chemistry knowledge and make their learning more permanent.

Chemistry laboratories have numerous expensive technical devices, equipment, and safety measures. In laboratory practices, students learn to take high-level safety precautions and use equipment and devices. The separation and reaction of chemical components using technical equipment and devices require careful and precise work. In laboratory applications, students develop many scientific skills such as working carefully, designing experiments individually and in groups, experimenting, observing, and analyzing. In addition, students can experience firsthand learning by doing and observing chemicals, components, and reactions in the laboratory.

Laboratory practices cannot be separated from chemistry education because they have an essential function in chemistry education. In the ERT process adopted during the pandemic, the chemistry was also taught to students online, using digital platforms such as Google-classroom, zoom meeting, and WhatsApp. Due to the lack of opportunity to work in laboratories under pandemic conditions, teachers have let students observe and conduct experiments in a virtual environment using alternative methods, media, and technology. They used interactive simulations, augmented virtual reality, virtual laboratories, YouTube videos, or chemistry experiments performed with simple materials (Jimenez, 2019; King et al.,2019; Leopold & Smith, 2020). In addition, some teachers did the experiments in the laboratory, recorded, and shared these videos with students.

These methods provided the students with a lab-work experience in a virtual environment; however, some problems were encountered in distance chemistry education. These are the students' inability to work in groups, the teacher's inability to control the experiments, the lack of technical infrastructure, the problems arising from the internet connection, and the difficulty of checking whether the students understood chemistry concepts.

One of the areas most affected by the pandemic has been STEM (science, technology, engineering, and mathematics) (Pagoto et al., 2021; Sedaghatjou et al., 2021) like laboratory education. STEM education is an applied field where science, technology, engineering, and mathematics are integrated with an interdisciplinary approach (Moore et al., 2014). STEM educators give ample coverage to hands-on activities, outdoor trips, laboratory practices, and face-to-face group work to explain theoretical concepts to students. STEM education is based on inquiry-based teaching and teaches students to question, think scientifically, solve problems, and offer solutions to real-life problems (Kelley & Knowles, 2016).

Especially providing STEM-based laboratory education has become almost impossible during the pandemic period. The pandemic also caused disruptions in STEM education, which is based on outdoor, hands-on practices and laboratory work, due to the quarantine measures, social distance rule, postponement of face-to-face education, and the inability to perform laboratory practices (Hallett & De, 2020). With the COVID-19 pandemic, STEM education had to undergo several changes, whether teaching remotely, face-to-face, or under a hybrid model. Security measures, spatial limitations, and student schedule changes have required a new and flexible approach to STEM lessons. As in other fields, STEM education was also offered to students in the virtual environment during the ERT process. As it is based on practice, travel, observation, and group work, it is challenging to teach STEM education in virtual environments; however, educators tried to overcome these challenges with individual and group projects, virtual trips, and simulations.

This study aims to contribute to the existing literature by showing STEM-integrated lab-work experiences performed during the pandemic with practices and examples. For this purpose, the STEM tasks in electrochemistry, performed by 14 students who took the chemistry laboratory course with the experimental materials available at home, were analyzed and presented in detail. For this purpose, the following questions were addressed:

1. Is it possible to integrate laboratory lessons into online or internet-based education?
2. Is it possible to integrate e-learning and hands-on activities with online education?
3. How can pre-service teachers design STEM-based experiments on electrochemistry with limited financial resources?
4. How did the pre-service teachers' perspectives on STEM change with this method?
5. How e-learning platforms can effectively facilitate hands-on activities in STEM education during distance learning?

The case study method was used to investigate STEM-based hands-on activities in electrochemistry that pre-service science teachers performed with the materials they found at home during the pandemic. The STEM works of 14 pre-service science teachers performed at home were analyzed and presented in detail. Pre-service teachers' opinions on STEM activities were also given.

Relevant Literature

The current pandemic has increased technology's importance in the learning process. Technology made it possible to carry out learning situations that cannot be brought into the classroom, or a complete performance is impossible even brought into the classroom. Students who can observe their environment, make sense of their observations and know the facilitating possibilities offered by technology will effectively develop science and scientific knowledge. Along with the pandemic, the concepts of internet-based learning (IBL) and e-learning, which include technology in education, have come to the fore and have been widely used in higher education. The flexibility of internet-based education in terms of location, space, and time made it more functional in pandemic conditions. Students participated in online education from home due to the social isolation required in the pandemic. The ERT concept, introduced during the pandemic, differs from IBL or e-learning (Fuchs, 2022; Hodges et al., 2020). ERT covers temporary education in extraordinary emergent situations such as natural disasters, wars, and pandemics, and when the extraordinary situation disappears, the usual formal education process restarts.

Students cannot reach the school during distance education. However, they have to participate in the education process of the lessons requiring laboratory activities such as physics, chemistry, and biology, using the materials they can find at home. In this context, hands-on activities come to the fore. Although many researchers have suggested different definitions for hands-on activities (Ajayi & Ogbeba, 2017), they can be described as learning through experiences (Holstermann et al., 2010). In addition, hands-on activities allow students to carry out a scientific process following appropriate steps or re-direct this process differently (Furlan, 2009). In this process that has to be carried away from school, it is possible to turn every place into a laboratory using materials that are easily accessible and a part of our daily life.

With hands-on activities, students' participation in learning and curiosity will increase, enabling them to gain new skills and contribute to their learning by doing (Kibga et al., 2021). In addition, such activities increase students' interest in learning (Holstermann et al., 2010). In chemistry education, which includes unseeable abstract concepts such as chemical reactions and subatomic particles, hands-on activities will be effective in clarifying the content and gaining chemistry learning skills (Kibga et al., 2021). In the study by Kibga et al. (2021), hands-on activities positively affected the participants' chemistry learning and their curiosity about learning chemistry. Similarly, Morais (2015) reported that hands-on activities increased students' interest in learning chemistry, and they perceived chemistry learning as a more enjoyable process. In another study, Tesfamariam et al.

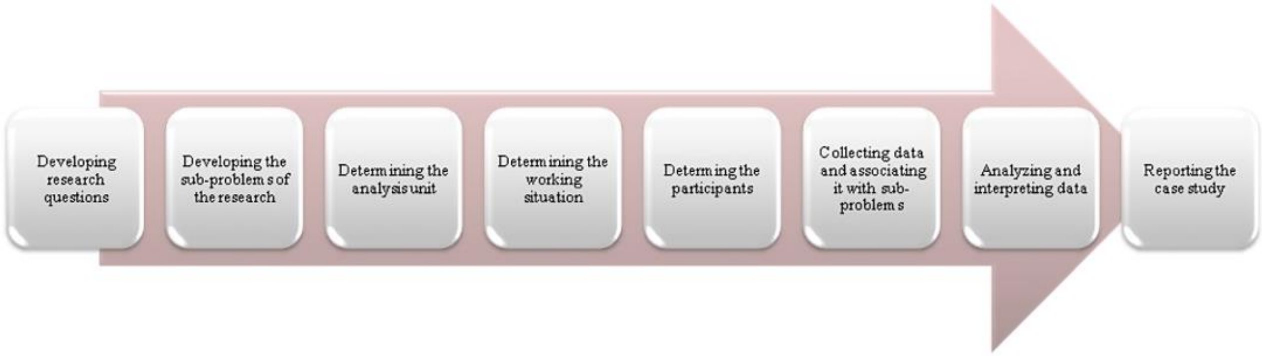

Figure 1. Case study steps (Yıldırım & Şimşek, 2013)

(2014) taught chemistry with hands-on activities and reported that such activities let participants learn chemistry concepts better and supported their learning by having fun.

Hands-on activities are part of STEM education. STEM is an approach based on science, technology, engineering, and mathematics working together in daily activities (Breiner et al., 2012). The literature review showed some studies in which hands-on and STEM activities are carried out (Chonkaew et al., 2019; Christensen et al., 2015; Glaroudis et al., 2019; Rao & Dave, 2019; Spyropoulou et al., 2020; Yannier et al., 2020).

Chonkaew et al. (2019) created STEM environments using hands-on materials in their studies. They created a small laboratory kit to determine the stoichiometric mole ratios of hydrogen and oxygen gases. This kit allowed teachers to work cheaply and quickly and experience hands-on materials. Moreover, it has been prepared considering the green chemistry criteria. The study results indicate that STEM-based hands-on activities positively affected students' high-level thinking skills, chemistry learning, and inquiry-based learning.

In another study, Glaroudis et al. (2019) conducted STEM-based hands-on activities with 60 summer school students. The study results showed that students' STEM skills increased at the end of summer school, and the practice was influential in students' career expectations.

Similarly, Yannier et al. (2020) used hands-on activities structured by artificial intelligence software and reported that hands-on activities supported with STEM were four times more effective in students' learning than hands-on activities carried out alone, without STEM. The studies mentioned above indicate that hands-on activities positively affect students' learning. Moreover, studies show that STEM-supported hands-on activities are more effective in learning.

As usual in STEM education, this study has followed an inquiry-based approach. In inquiry-based learning, the student is active in the learning process, and the teacher guides and encourages the student. In this approach, the teacher motivates students to do research by asking questions and presenting real-life examples. In this study, students first received online training on basic chemistry laboratory subjects for four weeks; then, they attended the online chemistry laboratory course for seven weeks. They designed their experiments with the materials available at home under the lecturers' leadership and created a product.

METHODOLOGY

Research Model

The primary purpose of this study is to examine the effects of STEM-supported hands-on activities on pre-service science teachers' opinions about laboratory courses and ERT. In this context, a study was conducted using the case study design, one of the qualitative research designs.

The case study is a research design that allows a phenomenon to be examined in real-life conditions. It is mainly used where the boundaries between the phenomenon and its content cannot be determined, and there is more than one data source (Spyropoulou et al., 2020; Yıldırım & Şimşek, 2013). The feature that distinguishes the case study from other types of qualitative research is that this research type allows the researcher to examine the subject in depth within its own boundaries. According to Yin (2017), case studies should be preferred when it is inappropriate to manipulate the participants' behavior during the research process. Moreover, case studies should be preferred where the boundaries of the relevant research topic cannot be clearly determined. For the stated reasons, the case study was chosen as the research model for this research. Because with the case study, it will be possible to investigate the opinions of participants who were contacted remotely due to pandemic conditions.

The steps followed within the scope of the study are the case study steps suggested by Yıldırım and Şimşek (2013). These are outlined in **Figure 1**.

Outline of the Study

The study was carried out with the third-grade science teaching program students within the scope of the laboratory course, a compulsory course. The chemistry laboratory course covers acid-base, electrochemistry, gasses, chemical reaction subjects, and experiments. The decision of the subject selection is left to pre-service teachers who selected electrochemistry. The university was not open to students during the specified year, and the courses were held online. To achieve the objectives of the laboratory

Table 1. Basic knowledge given to pre-service teachers

Subject	Basic concepts of electrochemistry
Electrochemistry	Galvanic batteries
	Electrolysis
	Electrodes
	Electrolytes
	Salt bridge
	Conductors
	Insulators
	Faraday's laws

Table 2. Guideline for the implementation process

Rules of the process
An online presentation for the participant about STEM-based hands-on activities
Presentation of partcipants about STEM-based hands-on activities
Two academicians and one engineer will evaluate the activities.
Expert opinions
Peer assessment
Self-assessment
Rules for STEM-based hands-on activities
STEM activities are limited to electrochemistry from basic chemistry knowledge.
Experimental activities should be based on engineering.
The experiments should be designed with materials available at home, and the cost should not exceed $10.
The designed activities should be functional.
The designed activity should be as original as possible.

course, which was carried out under ERT, participants were gathered through online portals first, and their views on the instruction of the course were taken. Then, the course outlines were determined, and a road map was prepared. The headings and subheadings are listed in **Table 1**.

First, the subject that the participants would work on during the term was identified, and the boundaries of the subject were drawn. In addition, both hands-on and STEM concepts were used together in the activities to minimize the harm of the ERT process on students. The course was 4 hours per week.

The study was carried out in the spring term of the 2020-2021 academic year. The study group consisted of 14 third-grade pre-service teachers studying at the Department of Science Education at the University. Pre-service teachers were divided into seven groups consisting of two people.

Learning groups communicated through online portals and met face-to-face once or more to conduct experiments by setting appropriate conditions. While forming their groups under the pandemic conditions, the groups were formed by peers who could come together or were close geographically.

They were given online electrochemistry training for a total of four weeks. Then, the study continued with online presentations of the hands-on activities presented by pre-service teachers for seven weeks.

Each learning group designed an activity. An activity was presented each week for seven weeks. The learning group presenting the activity was identified by lot, and the remaining learning groups evaluated their activity. Activity presentations were conducted using online meeting applications.

The experiments recorded by experts in the laboratory environment were shown and explained in training. Every week, the necessary documents for assessment and evaluation, such as reports, peer review, and interview forms, were requested from the participants about their activities. The activities were also evaluated by three academicians who are experts in their fields. At the beginning of the process, basic electrochemistry training was given through known experiments. Regarding STEM, only theoretical information was provided, no example was given, and no experiment was conducted. Afterward, a guideline was given to the participants about the activity they would perform. The items in the guideline are, as follows (**Table 2**).

Participants researched online libraries and video sites fitting the abovementioned conditions because physical libraries were not open to visitors during the pandemic.

Data Collection Tools

Interview form

The interview is a method that is rapidly gaining popularity today, from social sciences, especially psychology, to humanities (Brinkmann, 2014). Although the interview may seem easy at first glance (Yıldırım & Şimşek, 2013), it is a scientific approach that requires skill and sensitivity, understanding, dedication, and trust between the interviewer and the interviewee.

A semi-structured interview form was used in this study to understand participants' opinions about the process. The objective of the interview form was to collect qualitative data about pre-service teachers' opinions on STEM-supported hands-on activities. In this context, a form consisting of eight questions was created.

Table 3. Interview process

Part	Guideline
Interview questions	Did you know about hands-on activities before? Please explain.
	How did you proceed while preparing an online experiment? What do you think this process has brought you?
	What resources did you use while identifying the subject of your experiment? What did you learn in this process?
	Please tell us your general opinions about the laboratory lessons before the application.
	What problems did you encounter during the laboratory course in distance education?
	Anything to add?

Table 4. Expert evaluation form

Part	Guideline
Each item is 10 points	Preliminary preparation
	Presentation rules
	Scientificity
	Chosen topics
	STEM concepts
	Hands-on concepts
	Cost
	Originality
	Contribute to the field
	Functionality

Expert opinion was consulted to ensure the content validity of the interview form. After the expert opinions, the questions were rearranged, and the number of questions was reduced to five. The interview questions were asked of 14 pre-service teachers in written form in the eighth week of the study via online platforms (**Table 3**).

Expert evaluation form

The expert evaluation form evaluates the performed activities from an expert's eye for the study's reliability. In this context, two science field experts and an engineer participated in the courses remotely and evaluated the activities. A checklist consisting of ten items was used in the evaluation process. The form consists of two parts. The first part includes information about the student group that carried out the activity, the date, and the experiment's name. The second part includes ten evaluation criteria and the scoring. The outline of the form is shown in **Table 4**.

Course records

As this study was conducted online, all lessons were recorded during the semester. The students listened to the theoretical parts of the course, presented their experiments and applications online, and were evaluated by their friends. The researchers thoroughly analyzed all lecture records, student presentations, and experiments.

Data Collection Process

The data collection period of the study was eight weeks. The study was carried out with third-grade pre-service teachers from the university during the chemistry laboratory course. In the first week of the study, an online seminar was given to pre-service teachers. Participants were informed about STEM-based hands-on activities in the first hour of the seminar. They were given the subjects they were responsible for in the second hour. The objective of narrowing the subjects is to increase the students' creativity. At the end of the session, pre-service teachers agreed with the majority of votes on electrochemistry. Then, one learning group presented the hands-on activity they designed to other groups each week for seven weeks. Presentations of hands-on activities were completed in the seventh week of the study. At the end of the study, a semi-structured interview form consisting of five questions was administered to the pre-service teachers.

Data Analysis and Credibility

The data collection tools of the study were the interview, peer review, and expert evaluation forms. The data obtained from the specified forms were subjected to content analysis, and the codes belonging to the forms were determined. Later, these codes were divided into themes, combining similar themes. To ensure the validity and reliability of the data obtained after the content analysis, the method proposed by Miles and Huberman (1994) was applied. The authors make a few revisions after the experts. In addition, some opinions of the participants were directly quoted. The participants were coded as P1, P2, ... As in quantitative studies, credibility is crucial in qualitative studies as well. To improve the credibility of this study, data were collected using multiple methods, and two researchers analyzed the findings. The researchers reached a final consensus by discussing and comparing differences that occurred during the data analysis process.

FINDINGS

The primary objective of this study is to examine pre-service science teachers' opinions on STEM-supported hands-on activities performed in laboratory lessons and ERT. In this context, the study was conducted using the case study design, one of the qualitative research methods. Findings related to the study were grouped, as follows.

Table 5. STEM-based hands-on activities

Week	Evaluation criteria	Title of the experiment						
		1. Lemon battery	2. Electrolysis of water	3. Liquid conductors	4. Natural Indicators	5. Salt bridge	6. Lemon-potato battery	7. Electrolyte liquids
1	Preliminary preparation is sufficient.	10	10	10	10	10	10	10
2	They complied with presentation rules.	10	10	10	10	10	10	9
3	The content is scientifically sufficient.	10	10	10	10	10	10	10
4	The activity is related to electrochemistry topics.	10	10	10	10	10	10	10
5	The activity is related to STEM concepts.	5	9	6	8	5	5	4
6	The activity is suitable for hands-on concepts.	8	8	8	10	8	8	4
7	The activity complied with cost requirements.	10	10	10	10	9	10	9
8	The activity is original.	5	5	5	9	5	5	5
9	The activity may contribute to the field.	8	6	8	10	7	5	6
10	The design produced as a result of the activity is functional.	6	8	8	10	6	8	7
Total		82	86	85	97	80	81	74

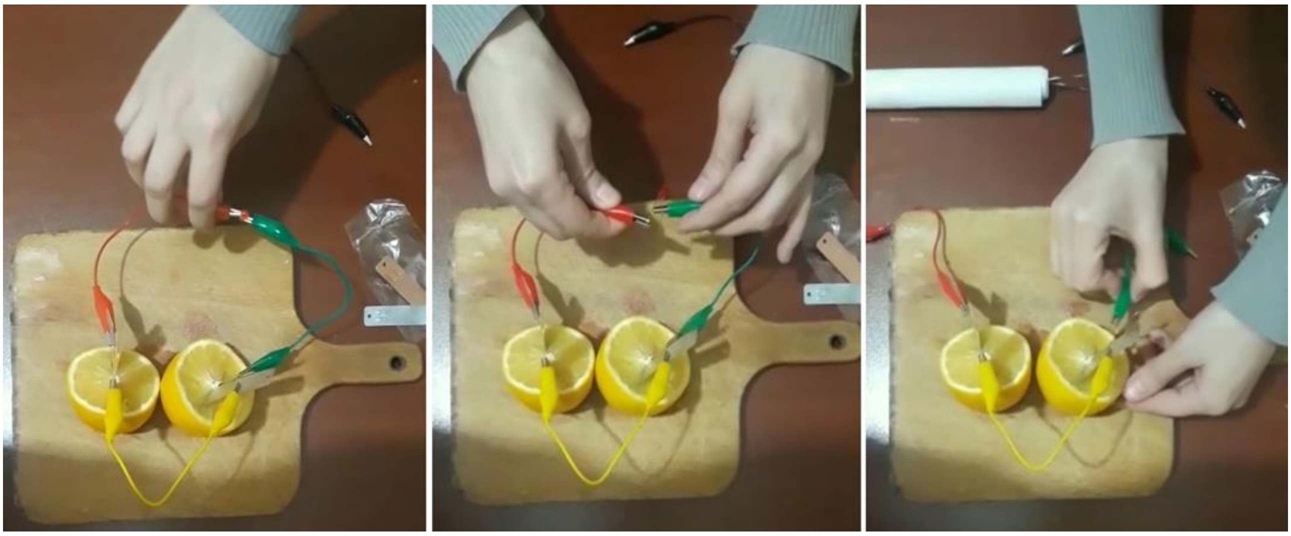

Figure 2. Images from activity 1 (Source: Field study)

Findings on the Hands-on Activities of Pre-Service Teachers

It was observed that the participants were enthusiastic about learning throughout the process, were highly engaged, and were open to learning. In addition, they developed research skills and were willing to do similar activities for the following lessons.

Pre-service teachers designed seven activities within the scope of the study. Two expert academicians examined the hands-on activities separately and scored according to ten essential criteria. In addition, the engineering basis of the study was evaluated by an engineer. The highest score that can be obtained from the scoring was 100. "70" was accepted as the base point for evaluating the activity. Each activity's overall score was calculated by taking the average of the scores given by the academicians. **Table 5** shows the information about learning groups and the activities they designed.

Regarding **Table 5**, pre-service teachers conducted different activities for seven weeks. They designed functional products that correspond to daily life using the materials available at home. STEM-based hands-on activities have been prepared for electrochemistry topics. The activities carried out throughout the process are detailed below.

1st activity: Lemon battery

The objective of the first activity was to observe the effect of liquid conductors on converting electrical energy to light. In this context, pre-service teachers designed a circuit consisting of two lemons, a small light bulb, and conductive wires. With this activity, the participants aimed to apply their scientific process skills to practice. Details of the activity are given below.

In activity 1, pre-service teachers cut a lemon in half and placed a metal plate in each part. Then they attached conductive wire to the plates. A small light bulb is connected to the end of the conductor. The bulb was briefly illuminated with a feeble light. **Figure 2** shows an image of the activity.

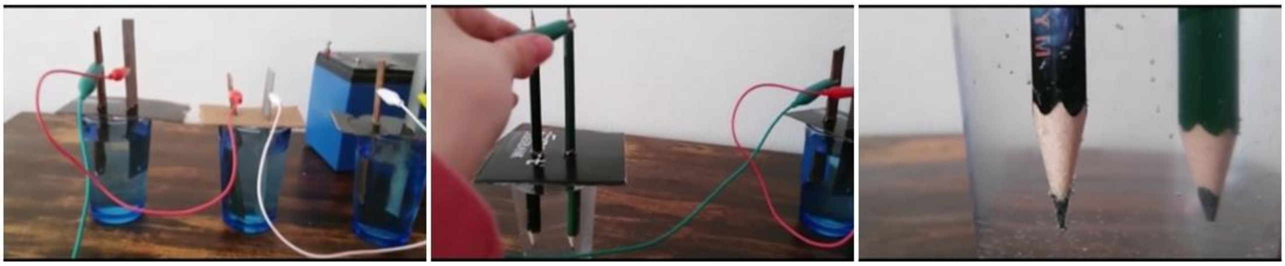

Figure 3. Images from activity 2 (Source: Field study)

Figure 4. Images from activity 3 (Source: Field study)

2nd activity: Electrolysis of water

The objective of the water electrolysis experiment was to observe the chemical recovery of the elements that make up a compound. The participants used water, salt, metal plates, and pencils in this activity. The experiment aimed to improve the observation skills of the participants and increase their awareness of the concepts of induction and deduction. Details of the activity are given below.

In activity 2, pre-service teachers electrolyzed the water. They first put some water and salt in a glass. Then they placed two wooden pencils in the glass. Electrolysis was observed around the pen tips when an electric current was applied to the water. Then the same process was repeated with three glasses. This time, metal plates were placed inside the glasses, and the experiment was repeated. Electrolysis was observed around the metal plates as in the pencil tips. In the third stage of the experiment, single-cup and 3-cup setups were combined, and the changes were observed. **Figure 3** shows images of the activity.

3rd activity: Liquid conductors

Liquid conductors activity allowed pre-service teachers to observe how different liquid materials they use in daily life conduct electricity. For this purpose, they used detergent water, bleach, vinegar water and lemon juice. This experiment aimed at teacher candidates to transfer their learning to daily life and be in an active learning environment. Details of the activity are given below.

In activity 3, pre-service teachers examined the conductivity of different liquids. They used four different liquids in this setting: detergent water, bleach, vinegar water, and lemon juice. For each liquid, experimental setups consisting of two batteries, a light bulb, and conductive wires were designed, and the light output levels of the bulbs were observed. Then, the current and voltage passing through the ends of each bulb were measured. **Figure 4** shows the images of activity 3.

4th activity: Natural indicators

This activity aimed to obtain a simple indicator from various liquids encountered in daily life. Pre-service teachers used five different liquids. Tap water was the control variable of the experiment. This experiment served to develop participants' higher-order thinking skills. Details of the activity are given below.

The fourth learning group examined natural indicators on six different liquids, i.e., pomegranate juice, turnip juice, tea, kale juice, radish juice, and tap water as control. Two pieces of graphites were attached to a power source of two batteries to observe the colour change in the specified liquids. Then, the graphites were dipped in each liquid, and the circuit was activated. The electric current formed different colours on the graphites attached to the battery. The images of activity 4 are shown in **Figure 5**.

5th activity: Salt bridge

The purpose of the salt bridge activity was to observe the effect of liquid conductors on the conduction of electric current. Within the scope of the activity, the participants prepared a circuit consisting of 5 glasses, some water, salt and conductive wires. The activity aimed to develop the experiment ability and observation power. Details of the activity are given below.

The learning group first put equal amounts of water and salt in 5 glasses and mixed them to build a salt bridge. Then, they placed two metal plates in each glass and connected the plates with conductive wires. After completing the setup, they applied current to the circuit and observed the changes (**Figure 6**).

Figure 5. Images from activity 4 (Source: Field study)

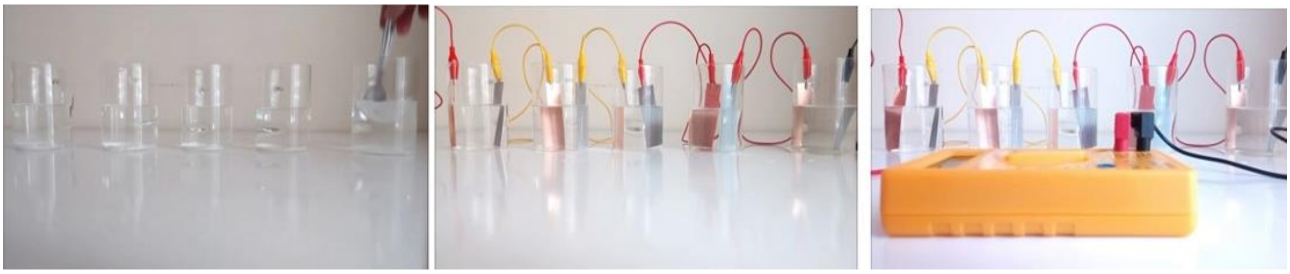

Figure 6. Images from activity 5 (Source: Field study)

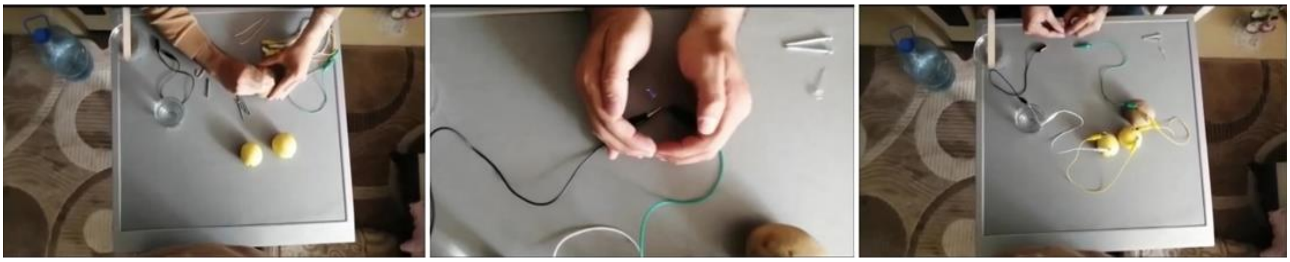

Figure 7. Images from activity 6 (Source: Field study)

6th activity: Lemon potato battery

Like the first activity, the lemon-potato battery examined an electric current's conversion into light energy through two different liquid conductors. The participants examined the conduction of electricity using a lemon and a potato. The activity aimed to observe the scientific learning steps of the participants. Details of the activity are given below.

In activity 6, pre-service teachers created a setup using two lemons and ane potato. Lemons and potatoes were connected to each other with conductive wires. A salt bridge was then added to the setup. Finally, a power source and a light bulb were connected to the circuit. It has been observed that the bulb gives light when the electric current is applied to the circuit. **Figure 7** shows the image of the activity.

7th activity: Electrolyte liquids

In activity 7, the participants worked on conductive and insulating liquids. In this context, the effect of liquids placed between the test leads of an electrical circuit on electrical conduction was investigated. Details of the activity are given below.

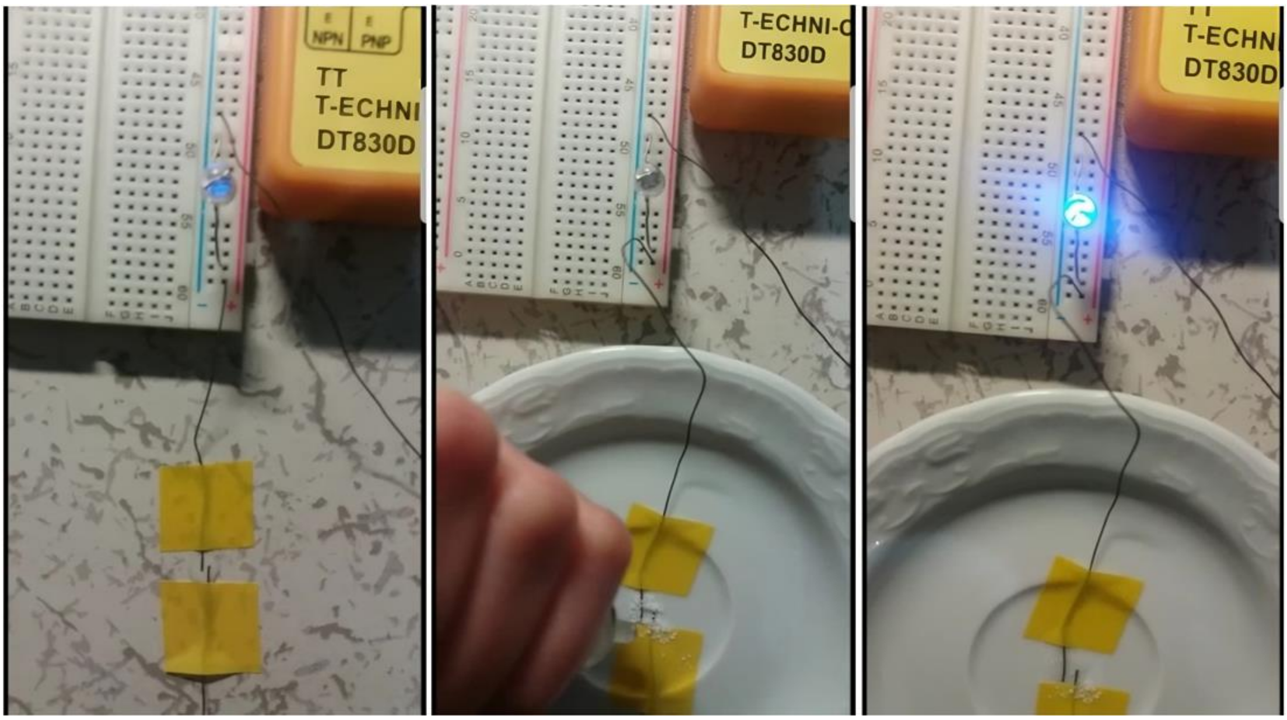

Figure 8. Images from activity 7 (Source: Field study)

In activity 7, the participants designed an electrical circuit and left space between the conductive wires in the circuit. Afterwards, they tried to complete the circuit with pure water, but they saw that the circuit failed to give light. Then they poured salt on the pure water and observed that the bulb gave light. **Figure 8** shows the image of the activity.

Findings on the Interview Form

Presentations of STEM-based hands-on activities were completed in the seventh week. After the activities were completed, a semi-structured interview form consisting of five questions was sent to 14 participants online, and the answers were subjected to content analysis. The data obtained are in **Table 6**.

Regarding **Table 6**, 78% of the participants did not hear about STEM applications at the beginning of the study, and 85% did not know the concept of hands-on activity. However, in the process, pre-service teachers learned STEM and hands-on activities by doing (85%). 50% of the participants stated that the application process was fun, 50% found it interesting, and 35% useful for the teaching profession. However, the participants also stated that the activity process was tiring (35%) and challenging (28%). Below are examples of participant opinions on the activity process.

> P3: I see that I better understood electrochemistry topics with these activities. I didn't think it would be this much fun.

> P14: I have never done a STEM project before. I had some difficulty choosing activities. Choosing a hands-on activity in electrochemistry was difficult. It was not as easy as it looked.

Regarding the participants' opinions on distance education, 56% said it could be an alternative to the current education method, and 30% said it was effective. However, the participants also stated that they experienced failure anxiety (35%), face-to-face training was more effective (21%), it was time-consuming (14%), and they had difficulty communicating within the group (14%). Below are examples of student opinions on distance education.

> P1: These activities could be an alternative to the laboratory lesson during the pandemic. I think it is effective.

> P6: I had a hard time communicating with my groupmate. The activity I chose was quite challenging because I was undecided about selecting the material. At first, I didn't know what to do because the university was closed.

Pre-service teachers preferred using free video sites to select the activity they designed (100%), and only 28% of the participants reviewed academic studies. In addition, 35% of the participants used MoNE books, and 14% asked for help from teachers working in the field.

> P7: I mostly searched on the Internet. There are too many pages involving this type of experiment. Then I watched their videos. I tried to add my comment.

> P14: The experiments on the Internet were similar, so I looked at the papers on the Internet. However, I couldn't find an experiment I wanted. Then I asked a science teacher friend for help.

Table 6. Qualitative findings of the interview form

Title	Theme	Code	f
Participant opinions before the implementation	STEM awareness	I don't know about STEM.	11
		I've heard of STEM.	1
		I've practiced STEM.	1
		I attended a seminar on STEM.	1
	Awareness of hands-on activities	I haven't heard of hands-on activities.	12
		I've heard of hands-on activities.	1
		I've witnessed the implementation of hands-on activities.	1
Opinions on the chosen science topic	Positive opinions	Applicable.	5
		I understood the subject better.	5
		It was suitable for the experiment.	4
		It was suitable for activity.	4
		Activities were easy to find.	2
		Activities were easy to create.	1
	Negative opinions	Tiring.	8
		Challenging.	7
		Activities were hard to create.	7
		I had a hard time understanding.	5
		Time was not enough.	1
Participant opinions on the implementation process	Positive opinions	I learned STEM by practicing.	12
		I learned how to implement hands-on activities.	12
		It was fun.	7
		It was interesting.	7
		I can use it when I become a teacher in the future.	5
		The results made me happy.	2
		Useful.	2
		I liked the chemistry lessons.	1
		I liked the lab lessons.	1
	Negative opinions	Tiring.	5
		I had a hard time choosing an activity.	4
		I had a hard time choosing activity materials.	4
Participant opinions on distance laboratory training	Positive opinions	It was an alternative.	8
		It was effective.	5
	Negative opinions	I was afraid of failing.	5
		Face-to-face training is more effective.	3
		It took a lot of my time.	2
		Intra-group communication was quite difficult.	2
		I was undecided.	1
Sources used to determine the subject of the activity	Online sources	Free video streaming sites	14
		Articles	4
		Theses	4
	Other sources	MoNE secondary school resources	5
		Science teachers	2

As seen in the pre-service teachers' statements, they used both the internet environment and the guidance of the trainers while designing these experiments. While designing STEM activities, pre-service teachers have added their own creativity to these resources.

The best discovery learning candidate

Activity 4, as stated, "Discovery learning prioritizes inquiry and research; it aims to create a product by using the student's background knowledge, creativity, observation, and research." With the consensus of three field experts participating in the study, it was concluded that activity 4 represents the best discovery learning example. In this activity, the participants determined whether the solution was acidic or basic by looking at the reactions occurring at the anode or cathode using a battery.

> Expert: Why did you do this experiment?
>
> P7: As I said before, many experiments on the Internet resemble each other. We asked ourselves what we could do differently.
>
> P8: We wanted to design an original and different experiment. We remembered the acid-base experiments that our teacher had performed for us before.
>
> P7: We asked ourselves what would happen if we energized an acidic or basic solution with a battery.
>
> Expert: What did you observe?

Table 7. Observations of the participants in activity 4

Solution	Observation at the anode (+)	Observation at the cathode (-)	Acid/base
Water	Colourless gas output	Colourless gas output	Neutral
Kale juice	Pink gas output	Yellow-green gas output	Neutral
Pomegranate juice (in the first 3 seconds)	Pink gas output	First pink, then blue-green gas output	Acid
Turnip juice	Pink gas output	Weak blue gas output	Acid
Radish juice	Pink gas output	Weak yellow gas output	Acid
Tea	Yellow gas output	Brown gas output	Basic

P7: We observed reactions at the anode and cathode.

P8: They were different in acidic or basic solutions.

Expert: What were the differences?

P7: We observed a colorless gas output at the anode and cathode for water. One gas was hydrogen, and the other was oxygen. However, when we energized a natural acid-base indicator like kale juice with a battery, we saw a pink gas output at the anode (+) and blue-green at the cathode (-).

P8: When we tried the pomegranate juice, we saw pink color at the anode (+); regarding the cathode (-), we observed pink first and then blue-green.

Expert: If we put these observations into a table, we can understand more clearly (**Table 7**).

Expert: What do you understand from these data?

P7-P8: When we energize acidic solutions with a battery, a clear pink color occurs at the anode(+), weak blue, weak yellow … and similar colors occur at the cathode(-). In basic solutions, yellow occurs at the anode and brown at the cathode. In neutral solutions, a very apparent pink color occurs at the anode, and obviously, green and blue colors are seen at the cathode.

Expert: Of course, you have tried very few basic solutions here.

Pre-service teachers discovered they could classify at least one acidic or basic solution by electrolysis regarding the color change at the anode and cathode.

Some other activities also fall under the discovery learning category, but activity 4 was presented separately by the experts, as it differed from the others. After the experts chose this activity, activity 4 was discussed separately between the experts and the pre-service teachers. The results mentioned above were reached by addressing the whole process.

DISCUSSION

The primary purpose of this study was to examine the effect of STEM-based hands-on activities performed in ERT on pre-service science teachers. In this context, a case study was conducted with 14 pre-service teachers. The participants were asked to design a STEM-based activity on electrochemistry. Before the activity, participants were trained in electrochemistry but were not instructed on any STEM studies or hands-on activities. Participants designed seven activities within the scope of the study. The designed activities were reviewed by experts and evaluated by the participants and experts. The entire study was carried out through online portals due to the pandemic.

The first result of the study is that the participants did not know the concepts of STEM and hands-on sufficiently at the beginning of the process. However, they learned both concepts at the end of the study and could apply them to the relevant chemistry subjects.

As a result of the study, it can be said that the STEM skills of the participants were observed and evaluated by experts. Such detailed and multi-skilled activities can improve participants' STEM skills. Such examples can be found in the literature. For instance, Glaroudis et al. (2019) designed a training program including STEM-based hands-on activities with 60 students and showed that the participants' STEM skills increased after the training. Quantitative data collection tools were not applied to the participants within the scope of this study. For this reason, participants' STEM skills could not be measured at the beginning and end of the process with numerical data. However, based on the participants' statements, it can be said that their STEM skills have increased.

Regarding the results, participants found the activities surprising and useful, instructive, helpful, and related to daily life. It is thought that the main reason for these results is that STEM-based hands-on activities allowed the participants to express themselves. In addition, with these activities, the participants took an active role in the learning process and managed the process by using the materials they could easily reach under pandemic conditions. Such responsibilities may lead to increased satisfaction in learning. Moreover, participants stated that such activities implemented during distance education made the lesson fun, and they enjoyed learning chemistry subjects. This result is similar to the studies of Kibga et al. (2021) and Yannier et al. (2020). Yannier et al. (2020) reported that STEM-supported hands-on activities increase learning, making students more open to learning. Similarly, after their studies on chemistry course topics, Kibga et al. (2021) reported that hands-on activities positively affected students' chemistry learning and curiosity. The main reason participants are more willing to learn is that STEM-based hands-on activities allow students to manage their learning in a challenging process, i.e., the pandemic.

Within the scope of the study, the participants created a product using hands-on activities. They realized the primary objective of discovery learning, "To keep questioning and research in the foreground, to create a product by using past knowledge and creativity, by making observations and research" (Bruner, 1960. This study showed us that as a result of STEM-based hands-on activities, the concept of discovery learning occurs spontaneously in students. Thanks to the essential questioning perspective of STEM, the search for hands-on activities to design different experiments with simple materials pushes the participants towards discovery learning.

Answers to some research questions were sought to examine the impact of the study. The most serious test was whether laboratory courses could be taught online. The second research question was about whether e-learning and hands-on activities could be combined with online education. According to the study, it has been understood that there is no need for a classroom environment to organize online activities with hands-on activities (Achuthan et al., 2021). Because setting clear goals, choosing the right activities, and using online tools that facilitate interaction were effective in the success of the study. Participants set the subject of electrochemistry, and the STEM experiments they could do with materials they could find at home as a clear goal (Karpudewan & Daman Huri, 2023). The right activities in electrochemistry were designed. After all this, the Internet environment was sufficient for effective communication. According to the data obtained from the students (opinions), it was seen that they had difficulty in finding innovative activities with the materials at home. It has been observed that they research articles and theses to overcome their problems on this subject. These problems have led students to serious research. For the first time, the participants encountered the pandemic process and were asked to design experiments outside the classroom environment with STEM and hands-on activities during the pandemic. They also emphasized the importance of education in finding and directing resources. However, here again, the trainer must plan the process well. Therefore, it is seen that e-learning and hands-on activities will be combined with online education. Hands-on activities offer very suitable options for STEM-based experiments. Because, as seen in this study, the participants were able to easily follow a process integrating science, technology, engineering, and mathematics, even with very simple materials they found at home. During the process, some of the participants even learned the discovery learning process. They learned to learn by exploring (Elkhatat & Al-Muhtaseb 2021). Although participants did not have access to many materials during the pandemic period, these restrictions led them to explore.

CONCLUSION

Regarding the study's findings, it was seen that applied STEM examples in the home environment during ERT under pandemic conditions were useful in teaching the lesson. As seen in the pre-service teachers' statements, it can be said that most of the pre-service teachers participating in this study did not know STEM, especially STEM-based hands-on activities, before this program. However, as a result of the study, their knowledge about STEM-based hands-on activities increased.

Another significant impact of the study is that the learning-by-doing and applying environment, in other words, a discovery learning setting, was provided to the pre-service teachers at home. The participants designed experiments using the materials available at home and presented them. In this context, this study set an example in creating and implementing a discovery learning environment in higher education.

This study is vital in showing how STEM-based hands-on activities in electrochemistry can be designed with simple materials, such as lemon juice, vinegar, and bleach, that can be reached in the home environment under pandemic conditions. The activities and findings are expected to contribute to the current literature.

The biggest limitation of this study is that participants and educators cannot communicate with each other face-to-face during the first online education process. However, the students who designed the activity came together under very difficult conditions. This situation made it difficult to manage the process. In addition, it was accepted that students evaluated each other and were objective in terms of self-evaluation.

Suggestions

1. This study was conducted under distance education conditions. The same application can be repeated under face-to-face education conditions and changes can be observed.
2. Participants' budgets are limited within the scope of the study. The study can be repeated with a larger budget.
3. No sample activities were presented to the participants within the scope of the study. In future studies, participants may be given sample activities and asked to design new activities.

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