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The use of mobile augmented reality supported flipped learning model in general chemistry laboratory: Electrolysis experiment example

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ABSTRACT

The aim of this study was to determine the effect of Mobile AR (MAR) supported Flipped Learning Model (FLM) applications on the academic achievement of first year undergraduate students in General Chemistry Laboratory course and to investigate the students' views on MAR supported FLM. In the study carried out with a quasi-experimental design with pre-test-post-test control group, the course in the experimental group was conducted according to MAR-supported FLM, while the course in the control group was conducted conventionally as prescribed by the curriculum. The results of the independent sample t-test for the quantitative data of the study revealed that FLM implementations supported by MAR had a positive effect on student achievement. The interviews with the students were analyzed by content analysis and it was determined that the students evaluated the applications positively and found them useful. The findings of this study are preliminary for future studies in this field.

Keywords: augmented reality, chemistry education, electrochemistry, flipped learning model, general chemistry lab

INTRODUCTION

The COVID-19 pandemic, the effects of which we are still feeling, has affected 21st century teaching and learning environments as well as our daily "normal" life. Today's learning environments, where digital technology and digital competence are at the center, are being reinterpreted in terms of the way of teaching and the content to be emphasized (Siddiq et al., 2024). Even before the pandemic, current digital technologies were being integrated into teaching environments, but the pandemic has accelerated this process. Popular immersive technologies such as virtual reality (VR) and augmented reality (AR) have the potential to provide solutions to challenges in 21st century teaching environments (Poupard et al., 2024). These technologies are particularly useful for experiments that cannot be simulated in reality or have a high probability of negative outcomes (Cai et al., 2014). These technologies have made it possible for students to experience interacting with virtual objects. AR technology, which is still an emerging field, uses computer technologies to create realistic images, sounds and other sensations to integrate into a real environment (Zhu et al., 2018). AR technology, which is used for various purposes in many different fields, has the potential to improve students' conceptual understanding, problem solving, collaboration, and communication skills (Ke & Hsu, 2015). Nowadays, these advances in multimedia technologies have also influenced the understanding of higher education and brought to the forefront a more student-centered approach that seeks to embrace technology as a teaching tool (Blair et al., 2016). Educators have started to incorporate technology into learning environments to create learning environments that encourage interaction among students and provide rich information content (Chang & Hwang, 2018). Flipped Learning Model (FLM) is a student-centered learning approach that has gained popularity in recent years and facilitates the integration of current educational technologies into the learning environment. Based on inductive methodology, FLM focuses not on "teaching the lesson correctly" but on ensuring that "students learn the lesson" (Ruiz-Jiménez et al., 2024). The importance of students learning by practicing and experiencing in an authentic learning environment was proposed by John Dewey (1916) in the last century and is still important today. FLM allows students to be active and interact with each other during class time, such as problem solving and practicing, and to construct knowledge through their own experiences (Kadıoglu & Oskay, 2023). With all these features, FLM

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has great potential for creating teaching environments with strong classroom interaction with the help of current digital technologies.

THEORETICAL BACKGROUND

Flipped Learning Model

FLM is an effective learning model for creating a learning environment based on the constructivist approach that allows students to take an active role in constructing the knowledge to be learned. In this model, theoretical knowledge is provided to students outside of the classroom before the lesson and thus, student-centered practices and studies are carried out with the guidance of the teacher in the classroom environment (Bergmann & Sams, 2012). When the model first emerged, the concept of "flipped classroom" was used because "classroom" was the focal point, but recently this concept has been replaced by the concept of "flipped learning" because this point has shifted to learning (Hayırsever & Orhan, 2018). FLM provides students with the opportunity to access the subjects they will study at their individual pace outside of school with the help of digital technology, while creating the necessary environment for students to correct possible problems that students may experience in the process of accessing information outside the classroom with in-class activities and to allocate more time to students through these activities (Abeysekera & Dawson, 2015; Torun & Dargut, 2015). The key to the success of FLM is the use of well-designed in-class activities and effective learning management approaches rather than the switching of in-class and out-of-class activities (Bergmann & Sams, 2012; Chang & Hwang, 2018).

Student achievement is an important factor in investigating the effectiveness of FLM. When the literature is examined, the effect of FLM on student achievement in different grade levels and subjects has been investigated (Akgün & Atıcı, 2017; Debbağ & Yıldız, 2021; Gayeta & Caballes, 2017; Kara & Kayacan, 2023; Olakanmi, 2017; Putri et al., 2019; Schultz et al., 2014; Tan et al., 2020). In these studies, student achievement was addressed with dimensions such as "performance", "academic achievement", "conceptual understanding" and evaluated together with variables such as motivation, student opinion and attitude. For example, Schultz et al. (2014) compared FLM and traditional teaching methods in their study conducted with middle school students in chemistry course. FLM was applied to the students in the experimental group, and 10-15-minute lecture videos were sent to the students before each lesson. The researchers used Google Forms to control the viewing of the videos. After the students watched the video, they filled out the video viewing evaluation through Google Forms. In the study, students' academic performance was measured by chapter and final exams, while a Likert-type questionnaire with open-ended questions was used for student perception of FLM. At the end of the study, it was found that the students in the FLM group performed better. In addition, it was also observed that students generally had positive perceptions towards FLM. One of the most important reasons for students' positive views is that they can pause, rewind and review the lecture videos, as well as the individualized learning environment and easier access to the teacher. Similarly, Olakanmi (2017) investigated the effects of FLM on middle school students' academic performance and attitudes towards chemistry about reaction rate. In the experimental group, FLM was used, and students were sent video lectures and reading materials to review at home before the lesson. In the control group, traditional methodology was used. The results of the study revealed that FLM provided significantly more change in students' conceptual understanding of chemical reaction rate than the control group. Kara and Kayacan (2023) investigated the effectiveness of FLM in science teaching laboratory applications course with 47 undergraduate students. In the experimental group in which FLM was used for a total of 5 weeks, students studied the topics by watching lecture videos at home and then performed activities and experiments related to these topics in the laboratory environment. PhET simulation programs, Khan Academy videos and videos prepared by the researchers were used for the course videos that the experimental group students would follow at home. In the classroom activities, students performed experiments with their friends in the science teaching laboratory applications course. At the end of the study, no significant difference was found between the post-test scores of the conceptual understanding levels of the experimental and control groups. In addition, semi-structured interviews were conducted to evaluate the positive and negative aspects of FLM. As a result of the interviews, although the opinions of the pre-service teachers about the model were generally positive, the negative opinions of the pre-service teachers especially about FLM were noteworthy. It was observed that the negative opinions of the pre-service teachers were generally related to the fact that the time could not be used efficiently with FLM because the information remained at an abstract level, and that interaction and learning by doing were limited. These findings once again show the necessity of a well-designed learning environment for FLM to be effective, especially in subjects and courses that mainly contain abstract concepts.

Augmented Reality Technology in Education

Milgram and Kishino (1994) defined AR as a virtual continuum scale that extends from a completely real environment with only real objects at one end to a completely virtual environment with only virtual objects at the other end. AR does not completely replace the real environment but provides the user with the perception that virtual and real objects coexist in the same space at the same time (Mazzuco et al., 2022). Azuma et al. (2001) argue that AR has three main characteristics:

(a) it combines real and virtual objects in a real environment

(b) it works interactively and in real time

(c) it makes real and virtual objects compatible with each other.

With the help of wireless devices, learners interact with virtual images superimposed on mobile physical landscapes in the real world (Dunleavy et al., 2009). Although the emergence and primal implementation of AR technology dates back decades, it has become a part of our lives in the last 10 years, especially with the widespread use of smartphones (Plunkett, 2019). The main reason for this situation is that devices such as smartphones and tablets are "powerful and ubiquitous platforms" (Azuma et al., 2011). The realization of AR experience with special tools such as mobile devices without time and place restrictions is called Mobile Augmented Reality (MAR) (Höllerer & Feiner, 2004).

When the literature is examined, there are studies examining the effect of AR use in teaching environment on students' academic achievement (Badilla-Quintana et al., 2020; Berson et al., 2018; Ibáñez et al., 2014; Silva et al., 2023; Yılmaz & Batdı, 2019). Since it is especially important to be able to visualize the sub-particle dimension for learning chemistry, investigating the effect of AR technology on chemistry achievement is an important research area. For example, Silva et al. (2023) investigated the effect of AR applications on undergraduate students' academic achievement, motivation and technology acceptance towards chemistry course. In the study, the experimental group used AR while the control group used 2D pictures for the topic of carbon bonds in a university level chemistry course. At the end of the study, it was determined that the academic achievement of the experimental group students using the AR application increased and the motivation scores were not statistically significant between the experimental and control groups.

Although AR has the potential to help students understand concepts related to processes that cannot be directly observed, it should not be perceived as a solution to all problems (Bullock et al., 2024). The use of AR in the teaching environment only because it is a current and popular technology will not help learning and may cause undesirable situations such as reinforcing students' existing misconceptions or developing new misconceptions. Care should be taken in the design and use process so that it does not interfere with students' learning (Bacca et al., 2014; Bullock et al., 2024). For example, Akçayır et al. (2016) developed different applications for different physics experiments in their study investigating the effects of AR use in science laboratory on university students' laboratory skills. The researchers used video, graphics and links to supplementary materials for the augmented components in the applications and were careful not to increase students' cognitive load. At the end of the study, it was found that AR technology helped students both to improve their laboratory skills and to change their attitudes towards physics laboratories in a positive way. Due to its proximity to the real environment, AR is an extended version of the real world, complete with virtual objects, and is a useful tool to support teaching methods (Mazzuco et al., 2022). Therefore, FLM and AR can help improve students' performance together. Although there are studies in literature where FLM and AR are implemented in combination, they are limited (Chang & Hwang, 2018; Çelik et al., 2021; Pozo-Sánchez et al., 2021). Chang and Hwang (2018) compared the effects of AR-based flipped learning guidance approach on students' learning achievement, critical thinking, group self-efficacy, learning motivation, and mental load on electromagnetism at the 5th grade level. A total of 111 students participated in the study. Students in the experimental group used AR-based FLM, while those in the control group learned with traditional FLM. The students' in-class activity task was to develop an electromagnet motor. All FLM activities used the same learning content in both experimental and control groups. In addition, the motor development process in the experimental group was conducted with AR support. The learning content taught in the control group was the same as the content in the AR guidance system used in the experimental group. After the experimental interventions, post-tests were administered to the students and five students from each group were interviewed. At the end of the study, it was found that the AR-based flipped learning guidance approach not only helped students improve their project performance but also improved their motivation, critical thinking tendencies and group self-efficacy. Çelik et al. (2021) investigated the effectiveness of AR-supported FLM method for 5 experiments in general physics lab-II course.

RESEARCH PURPOSES

Chemistry is a science that tries to explain how events in the macroscopic dimension take place in the submicroscopic dimension and therefore includes many abstract concepts (Taber, 2013). Chemical phenomena are represented at 3 levels: macroscopic, submicroscopic and symbolic (Johnstone, 1991). It is necessary to transfer chemistry concepts between these three levels by connecting them cognitively to prevent misconceptions (Chittleborough & Treagust, 2007).

In the field of chemistry education, the electrolysis of water and aqueous salt solutions, which are the subtopics of electrochemistry, are important, and although it seems that the related experiments can be done easily, it is often difficult to grasp the basis of the subject (Chang et al., 2020). Since electrochemistry is a subject with most sub-microscopic processes that cannot be directly observed, it is generally considered as one of the "difficult" subjects at both high school and undergraduate levels (Rahayu et al., 2021). Laboratory practices are very important for understanding this abstract structure of chemistry and establishing a meaningful relationship between theory and practice. However, in hands-on courses such as laboratory courses, there are many tasks for students such as understanding the theoretical knowledge, setting up the experimental setup, and following the experimental steps completely. This leads to negative consequences such as students ignoring the important content and focusing only on the application to make the practice smoothly. For this reason, it is important to organize the learning environment in a way to prevent this situation for the applications to be effective. It is thought that it is very important for students to have the opportunity to visualize the sub-microscopic dimension of chemistry while physically doing experiments in the laboratory environment to construct their knowledge. As mentioned above, FLM is in good harmony with the constructivist approach as it enables students to actively learn and construct their knowledge. By embedding AR in this environment, interactive, immersive experiences that increase students' cognitive engagement and facilitate deeper understanding of complex chemical concepts can further enhance this process (Ibáñez & Delgado-Kloos, 2018). AR can concretize the abstract structure of chemistry and thus fill the gap between theory and practice, which is one of the basic principles of the constructivist approach (Akçayır & Akçayır, 2017). In the light of this information, this study aims to answer the following questions:

RQ1: What is the effect of the implementations in the General Chemistry Laboratory course designed according to FLM supported by Mobile AR (MAR) on undergraduate students' conceptual understanding of Electrolysis?

RQ2: What are the views of undergraduate students on the applications in the General Chemistry Laboratory course designed according to FLM supported by MAR?

METHOD

This study was conducted with a quasi-experimental design with pretest-posttest control group since it was not possible to randomly assign students to the experimental and control groups. One of the groups was randomly assigned to the experimental group and the other to the control group. In the experimental group, the course was conducted according to FLM supported by MAR, while in the control group, the course was carried out conventionally as required by the course instructor.

The Study Group

The participants of this study consisted of 37 first-year students in the Departments of Biology Education and Chemistry Education at a state university who took the General Chemistry Laboratory course.

Materials Used in the Study

In this study, the effectiveness of FLM supported with MAR in copper plating experiment with electrolysis is investigated. For this reason, the researchers prepared materials suitable for both FLM and the content of the experiment in which MAR application (MAR-app) can be integrated.

The MAR-app used in this study was designed by researchers and a software developer. The researchers and the software developer held meetings to define the requirements and select the technologies to be used, and the Unity game engine was chosen as the main tool for the development of the project. Using Unity's AR Foundation plugin, it was designed to run on both IOS and Android platforms using C# language. This choice enables access to a wide range of users and increases the overall accessibility of the project. Next, the basic structure and user interface of the application were designed. The objects of the experiments targeted in the process were designed in Blender environment and exported to Unity engine in ".fbx" format. The objects used in the application were animated with the "Animation" feature offered by the Unity Engine.

The electrolysis experiment in MAR-app consists of two stages. The first stage of the app is for the preparation of the experiment. There is an experiment set-up on the MAR-app screen. **Figure 1** shows the experiment set-up.

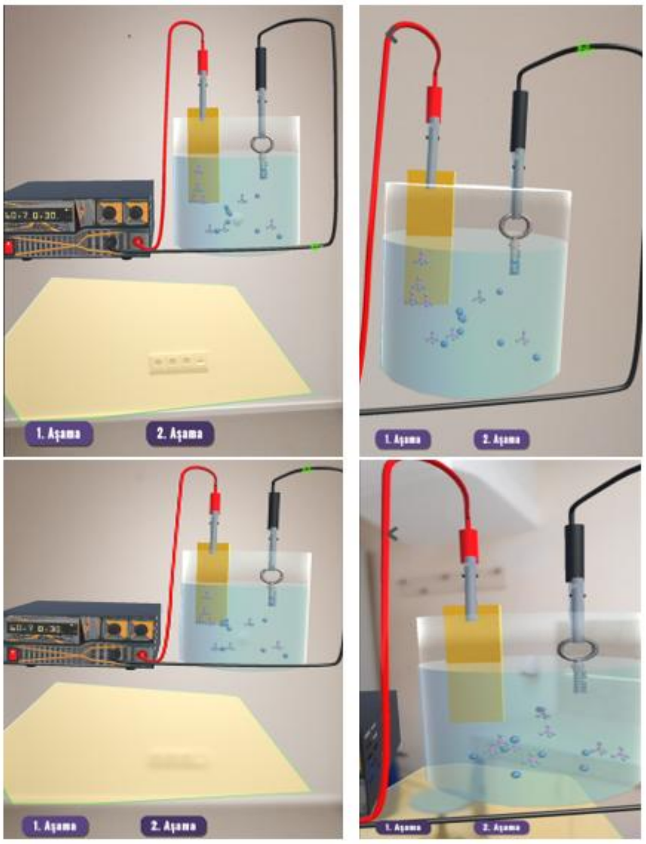

Figure 1. Experimental set-up-MAR-app screen (Source: Screenshots were taken from the authors' own MAR application)

This image shows a copper plate and switch connected to a power supply. These electrodes are immersed in a container with $CuSO_4$ solution. At this stage, only the Cu^{2+} and SO_4^{2-} ions in the solution are moving freely because the electrolysis has not started yet. In the second stage of the App, the electrolysis circuit is working. While electrolysis is taking place, Cu^{2+} and SO_4^{2-} ions in the solution migrate to the electrodes and accumulation is observed on the cathode. It is also possible to see electron flow from anode to cathode in the electrolysis circuit.

The content of the lecture video to be sent to the students in the experimental group before the lesson was prepared. At this stage, it was decided to prepare two lecture videos based on details such as the theoretical knowledge on which the experiment was based, the duration of the lesson, and the length of the video. Canva graphic design platform and Google meet video conferencing tool were utilized to prepare the lecture videos. The presentation prepared by the researchers on the Canva platform was presented using the screen sharing feature with a meeting created in the video conferencing tool and the lecture was recorded. **Figure 2** shows the screenshot of the lecture video.

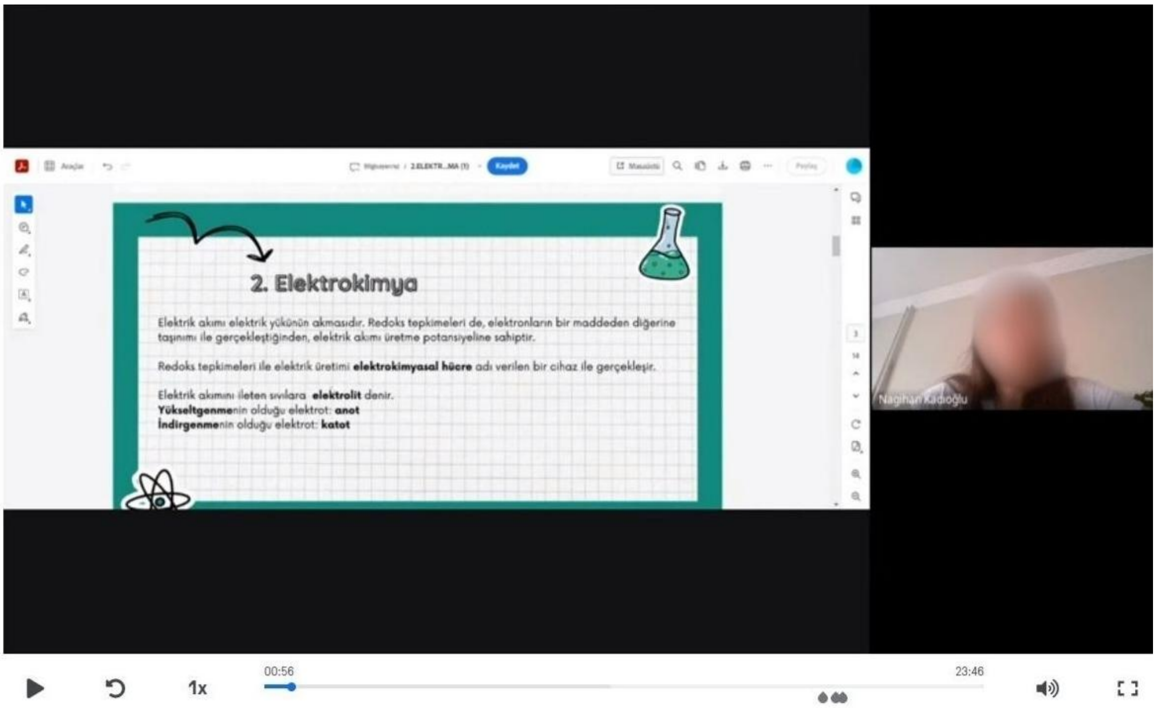

Figure 2. Screenshot of the lecture video (Source: Screenshots were taken from the authors' own lecture videos)

In these videos, students can see both the image and the screen of the researcher and hear the voice of the researcher. These videos were edited with the EdPuzzle platform to shorten their duration and to add questions to certain parts of the videos. EdPuzzle is a free teaching platform available on the internet. On this platform, the instructor can create a virtual class group and share lecture videos with students. Instructors can edit the videos they upload on this platform and add questions or notes to the videos. They can also access information such as the time intervals in which the videos can be watched and when the students watched the videos.

Implementation Steps

1. Week 1: Electrolysis Conceptual Understanding Test (ECUT) prepared by the researchers was administered to all students participating in the study as a pre-test. All students in the experimental group were informed about both AR and FLM.
2. Week 2: All students in the experimental group continued to be informed about both AR and FLM.
3. Week 3: A virtual classroom was created on the EdPuzzle platform and each student in the experimental group registered to the EdPuzzle platform. Instructions were prepared by the researchers for students to register to the EdPuzzle platform. After all students in the experimental group registered to EdPuzzle, they were informed about the platform and the course. Trial videos were uploaded and tested to familiarize the students with the EdPuzzle platform. In addition, for the students to make the best use of the lecture videos according to their own pace, their opinions on when the videos should be uploaded to Edpuzzle were taken and time planning was made according to these opinions.
4. Week 4: The lecture videos were uploaded to the Edpuzzle system 5 days before the lesson in line with the students' requests, and the students' video watching status was monitored by the researchers until the lesson day. In addition, questions were added to the relevant sections of the lecture videos to determine whether the students watched the videos or not. Students were required to answer these questions to watch the videos in their entirety.
5. Week 5: Implementation
   In the control group, the implementation week proceeded as conducted by the course instructor and no materials were sent to the students before the lesson. Before the lab lesson started, the subject was explained, the students performed their experiments individually according to the steps specified in the lab sheet and left the laboratory by recording the experimental data. The following week, they submitted their experiment reports to the course instructor.
   In the experimental group, the laboratory lesson was conducted according to the stages of FLM. According to these stages:
   Pre-class: In line with the opinions of the experimental group students, 2 lecture videos were sent to the students via EdPuzzle on the weekend before the lab lesson. Students were given until the end of the day before the lesson to complete the lecture videos.
   Lab Class: Before the start of the lesson, the students' watching the lecture videos and solving the preparatory questions were checked and all students who completed their pre-lesson tasks were admitted to the lesson. Before the

experimental phase, a brief lecture was given about the lecture videos and the questions in the videos and the questions that the students could not solve/ had difficulty in understanding were explained. Then, the experiment phase started. Students were divided into groups of two according to their own wishes and performed the experiment together. Students benefited from MAR-app at two stages of the experiment. The students were asked to examine the experimental set-up in MAR-app and before the students started the experiment, they were asked questions about concepts such as anode-cathode, electrolyte and the working logic of the experiment. There was no time limit for students to work with the MAR-app. Students were able to examine the experimental set-up in MAR-app as much as they wanted and accordingly, they were able to set up their own experimental set-ups. After this first step, the students cleaned and weighed the piece of metal that they wanted to coat, set up the experimental setup and carried out their experiments. Students worked in collaboration with their groupmates during the experiment. After completing the experimental process, the students opened the second stage of MAR-app and tried to observe the submicroscopic dimension of the copper coating. At this stage, guiding questions were asked by the researchers and students were encouraged to make inquiries for the students to use the MAR-app effectively. After the experimental process was completed, students were given a worksheet about the experiment and asked to solve the questions as a group. The researchers guided the students during their question solutions. The lab lesson ended after the students solved the questions on the worksheets.

Post-class: The students in the experimental group wrote reports as a post-class activity like the students in the control group and submitted their reports to the researchers the following week.

At the end of the implementation, the reports of all students in both the experimental and control groups were examined and feedback was given to them.

6. Week 6: The Electrolysis Conceptual Understanding Test (ECUT) prepared by the researchers was applied to all students participating in the study as a post-test. In addition, semi-structured interviews were conducted with 5 volunteer students from the experimental group and the data collection phase of the study was finalized.

Data Collection Tools

Electrolysis Conceptual Understanding Test: To determine the effect of MAR-supported FLM on students' conceptual understanding of Electrolysis, a conceptual understanding test developed by the researchers was applied. The conceptual understanding test consists of 4 open-ended questions. A test consisting of open-ended items has the potential to reveal both the success of the student and his/her ability to justify his/her knowledge and the quality of the teaching method (Badger & Thomas, 1992). While creating the achievement test, studies based on Electrochemistry, Electrolysis topics in the literature were examined and national/international textbooks used as resources in the field of chemistry education were scanned. An evaluation rubric was prepared to determine the points that can be obtained from the questions in the achievement test and the criteria required for the scorers to make an evaluation. In the evaluation rubric, the answers were categorized to analyze the questions. According to this rubric, the answers are:

- Complete Understanding: An answer in which all necessary steps and theoretical knowledge are complete and correct.
- Partial Understanding: A response in which the required steps and/or theoretical knowledge is partially correct
- Incorrect/ No answer: Coded as containing the wrong concept/processing step or left blank. Each of the 4 questions in the test is worth 10 points and the maximum score that can be obtained from the test is 40.

The content validity of the test and the rubric was ensured by obtaining the comments of two chemistry education experts after the preparation of the questions. To ensure the reliability of both the rubric and the test items, Miles and Huberman's (1994) formula was used to determine the inter-rater consistency. As a result of the formula Reliability = Agreement / (Agreement + Disagreement), the inter-rater consistency was found to be 0.83 for both the rubric and the test. With the calculated agreement percentages above 80%, it is possible to say that the open-ended questions and the rubric of the rubric are reliable.

Interview form

At the end of the study, an interview form consisting of 5 open-ended questions was applied to determine students' views on MAR-supported FLM applications. The questions in the interview form were prepared by the researchers and aimed to reveal the views of the participants about their experiences with both FLM and MAR. The interviews were conducted face-to-face with 5 volunteer students in the experimental group of the study outside the laboratory environment. Each student was given an interview form, and the students completed the interview form in writing. It took 30-35 minutes for the students to complete the interview form.

FINDINGS

The data obtained from the ECUT, which constitutes the quantitative data of the study, were analyzed by two researchers together. To answer the first research question of the study, "What is the effect of the applications in the General Chemistry Laboratory course designed according to FLM supported by MAR on undergraduate students' conceptual understanding of Electrolysis?", normality assumption was tested first. According to the results of Shapiro-Wilk test ($p_{exp\_pre-test} = .345 > .05$; $p_{control\ pre-test} = .577 > .05$; $p_{exppost-test} = .321 > .05$; $p_{control\ post-test} = .291 > .05$), it was seen that the pre and post-test scores were normally distributed. After the normality assumption was verified, an independent sample t-test was used to determine whether there was a significant difference between the ECUT scores of the students in both groups. Pre-test and post-test t-test analyses are given in **Table 1**.

Table 1. T-test results of pre-test and post-test means of ECUT scores of experimental and control groups

Variable	Group	N	Mean	SD	T	p	Cohen d
Pre-test	Experimental group	19	17.57	6.20	.21	.83	
	Control group	18	17.16	5.61			
Post-test	Experimental group	19	26.15	7.54	2.26	.03	0.747
	Control group	18	21.11	5.84			

According to the pre-test results given in **Table 1**, the equivalence of both groups was investigated, and no statistically significant difference was found. This result indicates that the students in the experimental and control groups were at the same level at the beginning of the study. After the application, the groups answered the same measurement tool as a post-test. The independent sample t-test results show that there is a statistically significant difference between the post-test scores obtained from the groups. The results reveal that there is a significant difference in favor of the experimental group in the post-test. It was determined that the FLM method supported by MAR had a positive effect on students' achievement. Cohen's d was calculated to determine the effect size of the difference, and it was found as .747. It is possible to say that this effect size is medium-strong. Effect size can be defined as moderate if the d value is greater than 0.5 and strong if it is greater than 0.8 (Cohen, 1988).

To answer the second research question of the study, "What are the views of undergraduate students about the implementations in the General Chemistry Laboratory course designed according to FLM supported by MAR?", the interview forms applied to 5 students (4 female, 1 male) in the experimental group were analyzed by content analysis. Content analysis is the process of categorizing the data obtained from the participants in the research process in accordance with the research topic (Özdemir, 2010). The findings obtained through content analysis were interpreted descriptively and themes were determined by categorizing them. To ensure the reliability of the study, the data set was coded separately by two researchers and the consistency between the two coding was calculated as 89.7% using Miles and Huberman's (1994) formula.

The first question of the interview form was related to the students' views on the FLM used in the study process. The codes obtained from the students' views are given in **Figure 3**.

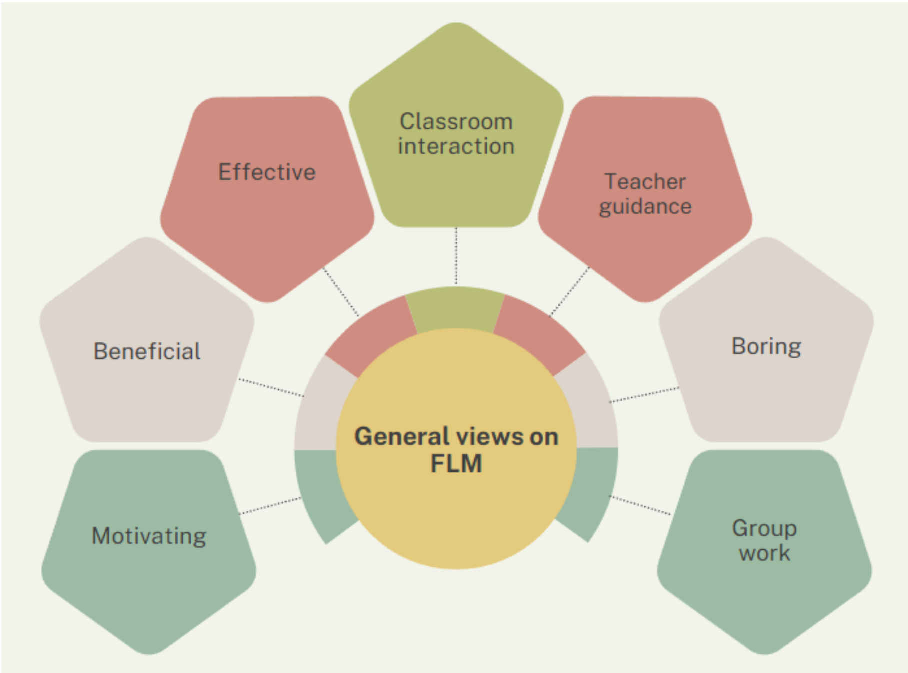

Figure 3. Students' general views on FLM (Source: Authors' own elaboration)

Students have positive and negative views on the use of FLM. When the positive views were analyzed, it was seen that students evaluated FLM from different perspectives. While some students emphasized in-class activities more, some students emphasized the materials sent before the lesson. The most frequently emphasized positive features were motivation and the efficiency they received from the lesson. Students stated that they felt motivated because they thought that they came prepared for the lesson, which increased their willingness to participate in classroom activities. Students with this view stated that it was useful for them to do the experiment and worksheets as a group. A student with a positive view towards group work stated that s/he came to class prepared by watching a video before class and therefore felt comfortable in the classroom. Examples of positive views towards FLM are given below (Translated from Turkish):

> "I think FLM is an effective model, especially doing it in class instead of homework was very good for me. Thus, I was able to write the experiment report more easily."

> "It's good to come knowing what to do... I saved time."

> "It was good to solve questions with the teacher in the lab. I could ask anything that was on my mind."

> "If I need to evaluate FLM, I can say that it was useful for me. I especially liked that there was a lecture video."

Students also had negative views towards FLM. When the negative views were examined, it was determined that the most emphasized concept was boring. It was seen that this negative view was related to the group work activity in the classroom. One student expressed that he found group work boring as follows:

> "I would have preferred to do the worksheet at home... it was very boring to do it right after the experiment".

The second question of the interview form was related to students' general views on AR materials. The codes of the students' general views are given in **Figure 4**.

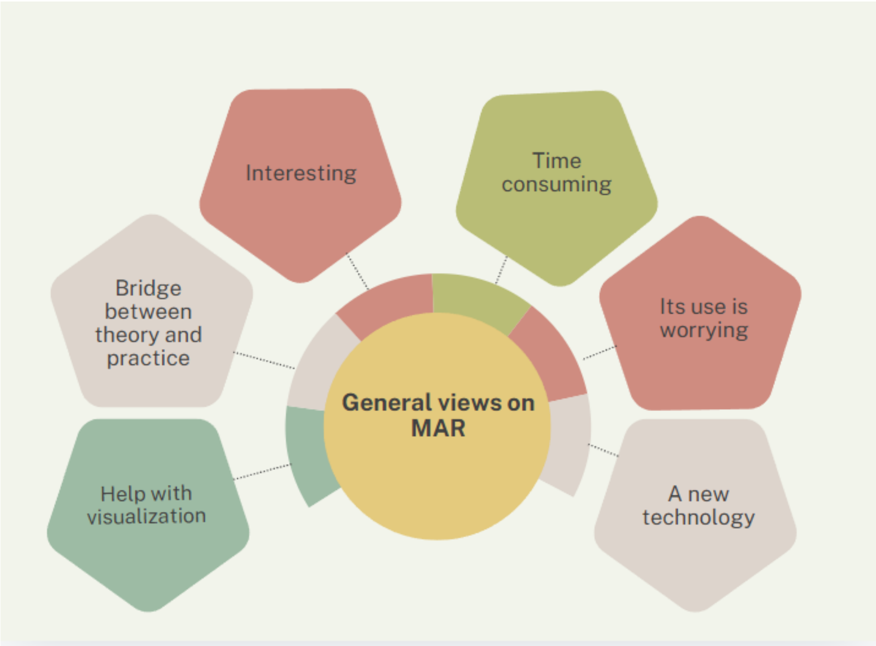

Figure 4. Students' general views on MAR (Source: Authors' own elaboration)

All the students stated that they had no previous experience with MAR. A student who said that she experienced AR for the first time in this study stated that using AR created anxiety in her/his, but s/he tolerated this situation by communicating with the course instructor and her/his groupmates. An example of this opinion is given below:

> "I am using augmented reality for the first time... At first, I was very nervous, I thought I would not be able to do it, then I used it with the help of my friends and the instructor. So, I was a little anxious at first, to be honest."

Another student stated that using AR was time consuming: "I am using AR for the first time...It took time to learn how to use it in the experiment." S/He stated as follows. However, it was also observed that the students had positive views towards AR. The most prominent and frequently emphasized concept in the students' positive views is that AR helps visualization. Students evaluated AR as a tool that helps to build bridges with theory. Sample statements related to this view are given below:

> "In the experiment I did, it helped me to imagine events that I could not see with my eyes, but which actually happened, so it was very interesting for me".

> "I liked working with AR in general...I have never experienced it before, but I might use it from now on."

In the third question of the interview form, students were asked to evaluate the lecture video sent before the lesson. The codes of the students' views on the lecture video are given in **Figure 5**.

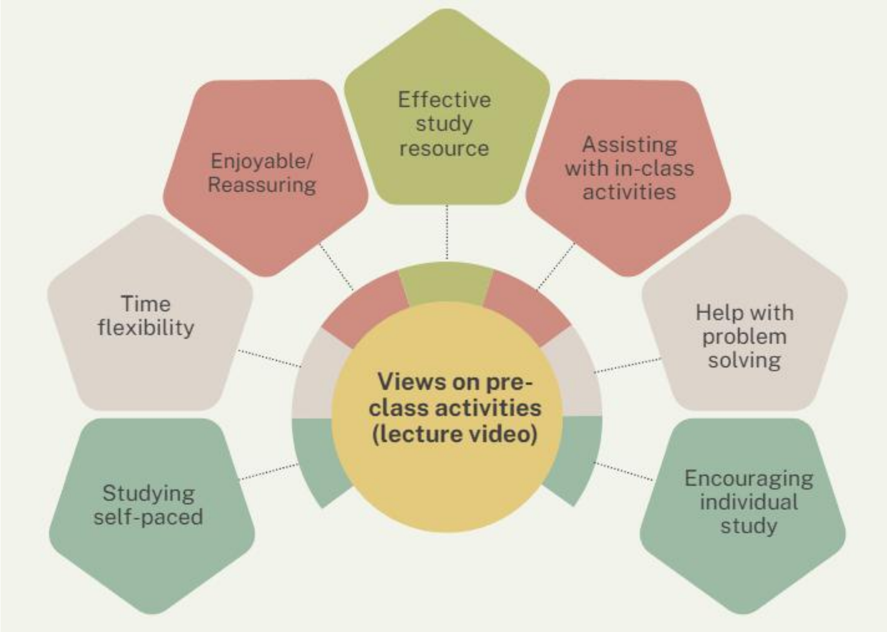

Figure 5. Students' general views on pre-class activities (Source: Authors' own elaboration)

When the views of the students about the pre-class materials were examined, it was seen that they frequently emphasized the ability to study at their own speed and time flexibility. While some students evaluated this situation positively, some students evaluated it negatively. Sample expressions related to these codes are given below:

> "I think it should be used in other courses as well. It was very nice to study at home by myself."

> "The lecture video was very useful for me. Because I usually cannot decide what to study, this video helped me while studying for the exam."

> "I liked watching the video before the class because the lecture time in the classroom was limited. I can watch this video whenever I want and as much as I want."

> "For me, the lecture video was not good because I had to study on my own."

> "I had difficulty solving the questions in the video, so I lost a lot of time watching the video."

Another most frequently emphasized code is that lecture videos are an effective study resource. Students with this view stated that they benefited from the lecture videos both when writing reports and when studying for exams. The statement of a student with this view is as follows:

> "The video helped me a lot in writing the report. Because I had an idea about the theoretical part of the experiment before I came to the lab."

The fourth question of the interview form was about the students' views on the advantages and disadvantages of using MAR while conducting experiments during the course. The codes related to this question are given in **Figure 6**.

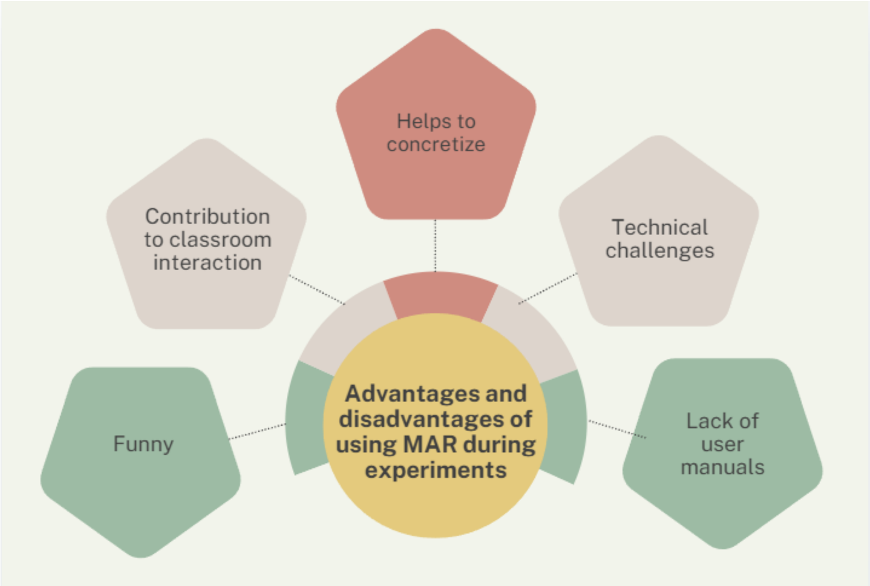

Figure 6. Students' views on the advantages and disadvantages of MAR (Source: Authors' own elaboration)

When the students' views on using MAR while conducting experiments were examined, it was seen that they evaluated MAR as a tool that helped to concretize the abstract dimension of the experiment and described this situation as an advantage. Students stated that MAR made the experiment more understandable and increased group interaction. On the other hand, some students stated that they had some technical difficulties during the use of MAR and considered this situation a disadvantage. Another noteworthy negative situation is that students need a user manual for MAR. At the beginning of the study, students were provided to spend time with MAR and were told how to use MAR, but they stated that they needed a written instruction manual. Sample expressions of students' views on the advantages and disadvantages of MAR are given below:

> "If I have to say what I found most positive about MAR, I can say that it helped me to concretize. For me, it helped me understand the experiment better. I liked it."

> "I think using MAR was different and fun. It was better because I used it with my group mate, and I felt more comfortable. If it was a homework assignment, I would have been a bit nervous because it was my first time using it."

> "Honestly, I had a little difficulty getting used to it. When I opened the MAR application for the first time, I had difficulty in placing the experimental setup in a suitable position. It would have been useful to have detailed information about this in the sheet."

In the last question in the interview form, the students were asked to explain their preferences for conducting other experiments in the General Chemistry Laboratory course with MAR application supported FLM. The codes related to the students' preferences are given in **Figure 7**.

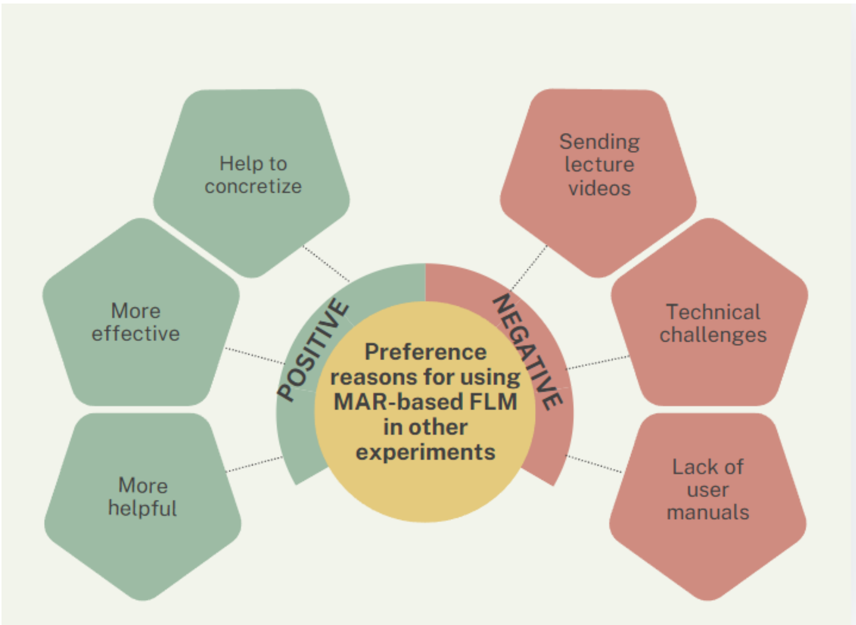

Figure 7. Students' comments on the use of MAR-based FLM in other experiments (Source: Authors' own elaboration)

Students' responses to the last question were generally related to students' suggestions. One student abstained from this question and stated that they did not have any preference. The other students stated that they thought that the use of FLM supported by MAR application in other experiments would be more effective. When the explanations of the students were analyzed, it was seen that with the expression “more effective”, they pointed out that the subject integrity related to the course would be provided better. The students stated that it would be more useful to conduct the whole course in this way instead of conducting only one experiment in the lab course in this way. However, the students, who once again stated the difficulties they experienced during the application, suggested that detailed usage instruction about MAR should be provided to them before the lesson. One student stated that if the lecture video was not required as a pre-classactivity, FLM supported by MAR application could be used in other experiments.

Examples of the students' responses to the last question are given below:

> “As I mentioned in question 2, I had some difficulty using AR during the experiment. It would be better if there was written information.”

> “I liked the FLM supported by MAR application. I think we can teach the whole lab lesson this way. I think it will be more efficient this way.”

> “It took me a lot of time to solve the questions in the lecture video. I could not advance the video without answering them. If this is not compulsory, I think we can use it in other experiments.”

DISCUSSION AND CONCLUSION

In this study, the effect of the use of MAR-supported FLM in general chemistry laboratory on students' achievement was investigated and students' views on these implementations were determined. The results of the study reveal that MAR-supported FLM activities have a positive effect on students' academic achievement. There are studies in the literature that show that FLM (Debbağ & Yıldız, 2021) and AR (Hsiao et al., 2016; Silva et al., 2023; Şahin & Yılmaz, 2020) have a positive effect on student achievement and support the results of the study. For example, Hsiao et al. (2016) developed a manipulative AR (MAR) system with 3D interactive models and manipulative aids to increase student achievement and carry out inquiry-based learning activities in the “Understanding Weather” unit in the natural science course. At the end of the 7-week study, the findings revealed that integrating the MAR system into inquiry-based fieldwork had a greater positive impact on students' academic achievement and motivation. Similarly, Şahin and Yılmaz (2020) investigated the effect of learning materials developed with AR technology for the 7^{th} grade “Solar System and Beyond” module on middle school students' course achievement and attitudes towards the course and concluded that students in the experimental group had higher achievement levels and more positive attitudes towards the course compared to those in the control group.

The results obtained from the interviews with the students in the experimental group also support the quantitative findings. Students generally had positive views about the applications in the General Chemistry Laboratory course designed according to FLM supported by MAR. When the responses of the students are examined, the most frequently emphasized positive views are in-class interaction, flexibility in terms of time and MAR's potential to help visualization. In FLM, it enables effective student-student and student-teacher interaction, especially in classroom activities (Moore et al., 2014). Thus, it is possible that increased interaction can positively affect students' learning outcomes (Fulantelli et al., 2015). The findings of the study also support this information. Students evaluated FLM positively as it helped them learn at their own pace and at their own time. The findings of Al-Ibrahim's (2019) study investigating the effects of FLM in teaching hearing impaired students were also in line with these results. Students generally described MAR as a bridge between theory and practice and evaluated it as a tool that helped them visualize their observations in the experiment. Uygur et al. (2018) investigated the views of pre-service teachers on AR applications and the results of their study revealed that pre-service teachers did not have enough knowledge about AR applications, while those who had knowledge found the applications facilitating learning. When the literature is examined, it is seen that AR technology and FLM applications positively affect students' perspectives (Onbasi et al., 2021; Pozo-Sánchez, 2021). It is seen that the negative opinions of the students with the applications are generally technical difficulties related to the use of AR. The MAR-app used in the study is a prototype in the testing phase, so user feedback is of great importance for the app to work under optimum conditions. These difficulties experienced by the students during use are an important source of data for future studies, both technically and in terms of application.

The results of the study are promising when evaluated in chemistry education. Because the inability to visualize the microscopic dimension of chemical phenomena that are difficult to comprehend can lead to a disconnect between theory and practice and hinder students' academic achievement, motivation and participation in the course (Herron, 1975). Therefore, it is of great importance that students learn these topics by visualizing them correctly, without time constraints, and by interacting with their peers and teachers. When the literature is examined, although there are AR applications (Aljets et al., 2022; Chen et al., 2015; Pradani et al., 2020) developed at different grade levels related to the electrolysis/electrochemical cell subject, they are quite limited. Especially at the undergraduate level, there are no AR applications used with FLM for the laboratory course.

As a result, this study contributes to the research gap in the literature with the application of an emerging new teaching methodology such as AR-supported FLM in undergraduate general chemistry lab and its positive results. This study is preliminary and limited to the electrolysis experiment only. It is recommended to expand the content of the study and to conduct more in-depth analysis by applying it to larger study groups.

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