Augmented Reality Labs: Immersive Learning in Chemistry

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Abstract. Physical hands-on labs can be costly and time-consuming. Due to the advancements in hardware and computer vision technologies, virtual labs are being implemented to cut costs and save time. As augmented reality becomes more popular, the goal is to bring this technology into the education system by implementing a platform that can be accessed through common devices, such as phones and internet browsers. We developed a phone application to bring augmented reality to classes, with a focus on the field of chemistry. In addition to the mobile application, we developed a companion web application that enables professors to create classes, 3D objects for student interaction, and manage assignments, including grading, for the chemistry class. Finally, three laboratories were introduced for the chemistry class to execute a case study on the effectiveness of augmented reality in education. These laboratories are designed to instruct students on constructing 3D compounds through an assignment-based system, creating neutrally charged ionic bonds, and observing their ratios using an ionic table. Additionally, the labs aim to foster teamwork by providing a shared augmented reality experience, enabling students to collaboratively interact with the periodic table within the same virtual space. The overall feedback of the sixty students who interacted with the application was positive, with 53% strongly agreeing that augmented reality is more engaging than a standard lecture and a good learning tool in chemistry and other fields. Additionally, 39% of students strongly agree that a shared augmented reality experience promotes teamwork in the lab.

Keywords: Augmented Reality, Chemistry Lab, Immersive Learning.

1 Introduction

Theory supported by hands-on practice is one of the principal keys to learning in several fields, such as electrical engineering [1]. Students can process and retain information more efficiently by visualizing the theory via hands-on practice during labs. However, physical hands-on labs can be costly due to the fast and ever-changing technology. It can also be time-consuming to assemble and disassemble various tools and objects. Thus, a remote and digital approach to hands-on labs can be taken to keep up with technology and cut costs. Even so, research papers [2], [3] showed that students consider virtual labs as effective as physical labs, if not more effective. Even though already proposed computer-based interactive laboratories focus on engineering [1], [4], the same proposed architecture and approach can be applied in different fields, such as Chemistry [5], [6], [7]. Also, with cost efficiency and hands-on practice in mind, as well as safety by removing hazardous materials from the Chemistry lab, the ARChem application [5] uses augmented reality to implement an interactive lab. In short, the application aims to teach students how to create chemical reactions using various substances' pH levels and assess students with a final quiz. Our platform aims to focus on the field of chemistry and solve the issues of cost and time efficiency that come with a physical hands-on lab. Thus, creating a platform that places virtually atoms on the table eliminates the need to acquire numerous plastic atoms for each student and eliminates the need to disassemble and repack after each class, eliminating the possibility of losing objects. Moreover, it bridges the gap of being limited to the school lab to interact with such objects and allows students to have hands-on interactions outside faculty premises. Finally, being a digital and remote lab, students can get useful information, such as molecule name, ion charge, and ratio, directly from the platform as they place and build objects without asking a professor.

Studies show that students tend to focus more on their laptops, thus eliminating the potential for collaboration [8], [9]. During the Chemistry class, the students would interact more and develop their social skills by focusing on a single object around a table, such as a 3D molecule. Previous collaborative Augmented Reality (AR) implementations in education include a mathematics lab that allowed students to draw shapes, such as cones, learn to build via pre-recorded tutorials, and even take exams [10]. However, implementing such software should not require additional equipment, like AR glasses, but instead use a more common device: the smartphone. Anatomy is perhaps one of the most targeted subjects for AR learning. A study showed how students performed better when they studied the parts of the skull while using AR, compared to just paper or VR [11].

Our platform aims to offer versatility and freedom to the professor to add any class with its corresponding models. The web platform will give access to the professor through their Florida Polytechnic e-mail account to create classes to which they can add, remove, and edit classes. Moreover, to each class, they will be able to add students and 3D objects, which will then be available to the students to interact with via the mobile application, which can download the objects from the cloud without constantly having them saved locally. Also, each 3D model will have a reference image, which, as an example, can be used to anchor 3D objects to the reference image in books. Thus, this offers versatility in the number of classes and 3D objects that can be added by not having a memory limit or by not needing any additional developing time to add the objects. The application's primary focus is to shift the focus from anatomy classes to Chemistry labs to help students understand concepts such as ion charges and compound elements. Thus, two custom labs are implemented for the Chemistry class to support the students' further understanding of complex chemistry topics such as compounds and ions. This will be made by creating an “assignment” based system, allowing the professor to create tasks in which the student has to build a compound or an ion using the available 3D models. The compound assignments can be added automatically by using an API or manually created by the professor as a fallback for the API via the web platform. The students can view a 2D image alongside general information about the compound and build it in 3D using the already available periodic table.

Moreover, after the building phase is done, the student will be able to take a picture and submit the assignment to the professor while also receiving a partial grade for placing the correct molecules and, later, a full grade updated by the professor based on the connections the student made between the molecules. A similar approach will also be available for the ion charge assignments, guiding the students into creating neutrally charged ions. Each ion will be selectable from a menu and, on tap, will be displayed in front of the student with a name, the current formula, and the charge. By having more tangible and visual cues, the goal is to provide a more engaging way of learning previously mentioned subjects in the chemistry domain.

Furthermore, previous iterations of applications that aim to teach chemistry using AR [5] have limited AR models due to a lack of database connectivity. By connecting the application to a database that supports the hosting of 3D models, such as Firebase, the application aims to break the barrier of having a limited number of models with which the students can interact. Additionally, the connection to a database will allow the students to interact with the professor to receive feedback on their work and interact with other students. Ultimately, students who join their AR session via their iPhone will be able to use the periodic table to build compounds together, thus being encouraged to socialize, collaborate, and not think individually. Moreover, as mentioned previously, one of the application's main features is the ability to go through books and interact with them on a multi-dimensional level via the 3D models attached to their reference images by the professors via the web platform. This will encourage the students to look more through the class-assigned books and not default to videos as often. Previous implementations of AR applications used marker tracking for their image tracking features [12], [13], which comes with various issues: the number of markers or generated QR codes can be limited and obstruct the image presented to the user.

Moreover, if the professor would like to allow students to track images from a book, it would mean that each student would have to attach the corresponding marker to their textbook, which is time-consuming and counterintuitive. Like more recent papers [14], by using the new technologies offered by frameworks such as ARKit, the application aims to eliminate the need for markers and automatically associate the uploaded image with the uploaded 3D model while also getting the data from the cloud instead of the local storage. This approach is possible due to the advancement of modern phones in computer vision and image processing, as well as at computing levels via very efficient and powerful chips built-in. Moreover, the project's scope is to provide a platform that is easily accessible to students via common devices that they already own, such as iPhones and iPads. This will result in the university or the student not purchasing additional devices, such as AR glasses, to interact with the application. However, due to the flexibility of the Swift programming language, the application will be able to run natively on the “Apple Vision Pro” AR glasses once they become available in early 2024. Additionally, the web application through which the professors will be able to add, remove, and edit 3D objects, as well as assignments, will not require any software installation from the user part since it will be available via any web browser, thus eliminating the need for a powerful machine, memory allocation or any knowledge of software installation.

To restate, augmented reality is the enhancement of the real world with virtually generated information [15], and has seen complex advancements in modern technology due to the higher processing power of phones and the improvement of their computer vision capability. While previous applications in AR [16] tend to focus on medical education and are limited to a number of 3D models [5], the main goal of this application is to provide the versatility and capability of adding any number of 3D models via a cloud database, while also focusing on a Chemistry lab with assignments which offer a more interactive and intuitive understanding of building compounds and Ions. What is more, the previously mentioned database will manage to connect both the web application and the mobile application for a seamless and cost-effective solution.

2 Methods

Our platform is divided into two sections: i) Web platform and ii) Mobile application. The mobile application is aimed at the professor to add, remove, and edit classes and create and grade assignments for a custom chemistry lab. The mobile application allows students to log in and interact with the 3D objects provided by the professor, build compounds, and learn about ion charges in the Chemistry Lab section. The two applications are connected by a shared database that stores user information, such as e-mail and password, student assignment submissions, and class data. The web platform is built in Dart, using the Flutter framework provided by Google. Flutter was chosen due to its simple learning curve and the option to build for Mac and Windows in case the professors require a standalone application. ARKit uses the device sensors to understand the scene and track the world and motion [17], while RealityKit seamlessly processes the data to render 3D objects in space [18]. Thus, being native frameworks provided by Apple, the two frameworks work hand-in-hand and can access all the native device features of the phone, such as true-depth cameras and LiDAR sensors. Lastly, we used Firebase, a NoSQL database provided by Google. The database is hosted on Google servers and lets the connection between iOS, web, and Android applications, thus being ideal for this project's scope. The connection between the two applications and the database can be seen in Fig. 1.

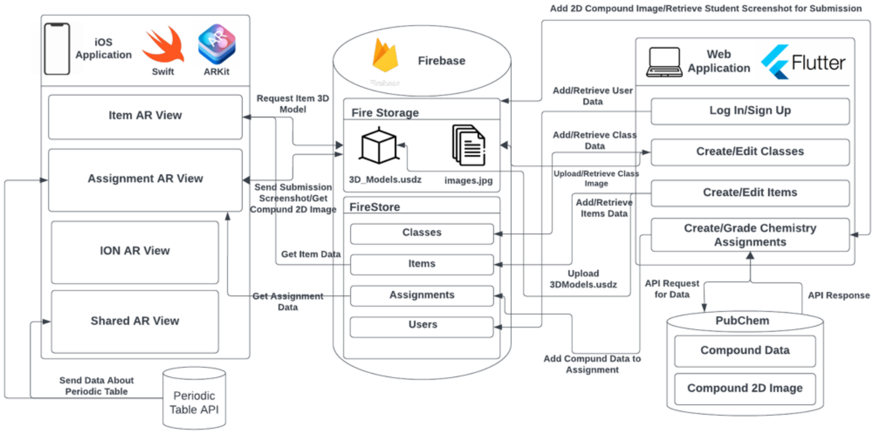

Fig. 1. Application Architecture Diagram

2.1 Designing and Connecting to the Database

Firebase is a service that Google offers a NoSQL database, web hosting, and cloud storage, which integrates with Swift and Flutter. The FireStore service is used to store raw data produced by both the mobile and the web app, such as class names, students enrolled in each class, and information processed by APIs to be sent to students. For example, when the professor adds a class, it will be added as a document to the class collection. Furthermore, for the chemistry class, an assignment collection is referenced to which several assignment documents are added, each containing specific data regarding each assignment. The structure continues and is respected for submissions for each assignment and books for each class.

When a professor adds a class via the web platform, it updates automatically on the mobile application without the user having to reload or sign in again. Files such as reference images and 3D objects are saved in a bucket in the Firebase Cloud Storage, thus eliminating the limit for 3D models which can be displayed in the application. The professor can add 3D models to each class via the web interface, while students can access and interact with them via the mobile iOS application. The interface section, which allows professors to add items to a class, can be observed in Fig. 2.

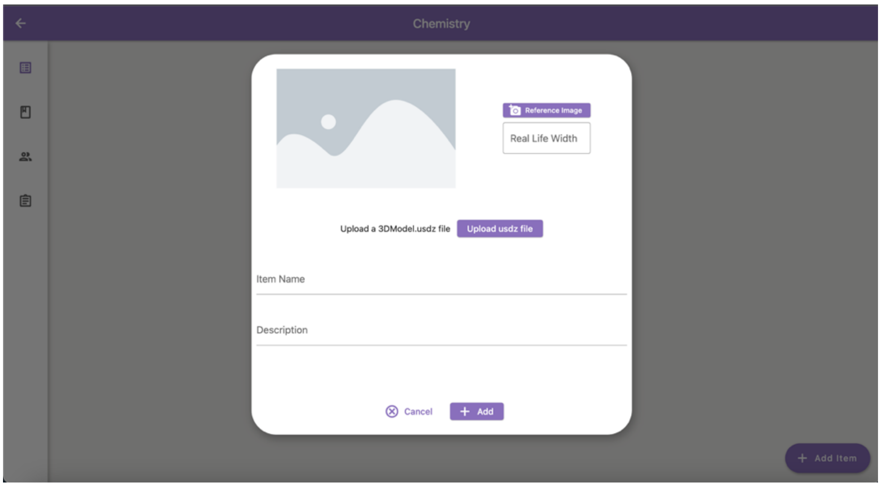

Fig. 2. Add Items via Web Interface

Often, data does not come instantly to the application and requires time to be retrieved from the database, and this is especially true for files. During data retrieval from the database, the UI should not freeze and display an indication that something is currently downloading to not give the impression to the user that the application has crashed or that their interaction with the UI elements was not registered. This process of retrieving data from the database and updating it on the main thread after completion is achieved via asynchronous operations. With the interaction of async await in Swift, the async processes can be written synchronously via tasks. Whenever a view appears, a task containing an async function is called, and on completion, the UI is updated correspondingly. Our platform uses the async-await feature of SwiftUI while downloading the 3D models from Cloud Storage. When the item view is presented, an async function is called to download the corresponding 3D model into memory. While the model downloads into the local storage, the placement buttons for the AR view are disabled, indicating to the user that the model has not been downloaded yet. When the task is completed, the buttons are enabled, indicating to the user that they can now interact with them. Similarly, Dart has an async-await feature that allows writing asynchronous functions, also known as a “Future.” Our platform allows us to present a loading indicator while the files are uploaded to the cloud.

2.2 Conforming to Design Principles

Interface design is a critical factor in quality software. An interface with a simple yet expressive design can help the user interact with it much more manageable. For example, having a big title and expressive icons are some approaches to having an expressive UI.

Platform-Specific Design Principles. Since the application is multi-platform, the color pallet, shape design, and general components should be developed similarly, mainly in case the professor wants to interact with the app's mobile version. This helps the application's learning curve, as the professor does not have to learn two different UIs'. However, platform-specific elements should also be respected, precisely the difference in screen real estate between a web application and a mobile phone. Thus, our platform has the same color pallet for both applications and components, such as “class” icons, which are identical on both platforms.

In contrast, each device's layout is created to take advantage of the entire real estate of the screen. For example, on the iPhone, the application presents the list of classes in a scrollable list format, while on the web application, it displays a scrollable grid format, which adapts to the screen's width. Moreover, each application uses intuitive icons and labels, while the iOS version also respects the built-in native icons. Furthermore, the iOS application also adapts to the user’s environment, considering the device theme, dark or light mode, and automatically changing the color pallet. The similarity in design, colors, and platform-specific adaptability can be seen in Fig. 3.

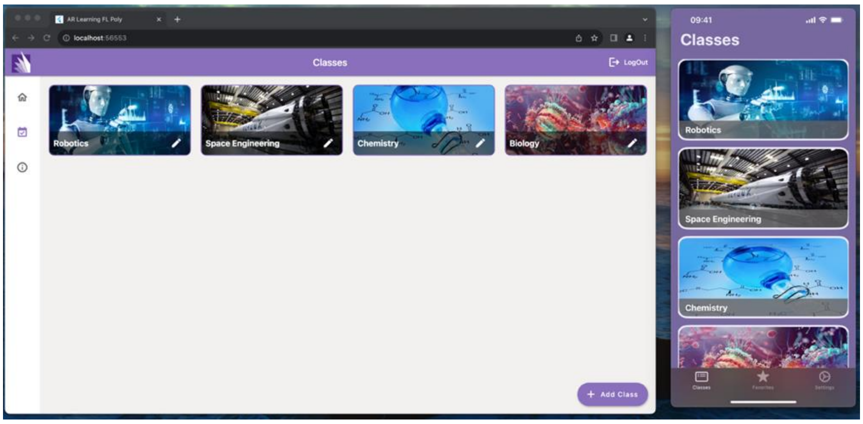

Fig. 3. Class Menu on both Web and iOS

AR Interface Design Principles. While developing an AR application interface guidelines must be implemented. Firstly, the iOS application uses as much screen real estate as possible by even taking advantage of the safe area of the phone. Secondly, only necessary buttons are placed on the AR View so the user can close the view, open the menu for adding objects, and take a screenshot in the assignment section. Furthermore, it is also a good practice to display only relevant text, thus, we display only the molecular formula for both chemistry labs. In contrast, for the ion lab, we also display the charge, ratio, and molecule name above each placed object. This results in the screen not being too cluttered and displaying only essential information to the user so that he will not get overwhelmed. Additionally, object movement is enabled, which allows users to move, resize, and delete each object. Fig. 4 depicts the good practices of human interfaces presented above. Guiding the user in an AR View experience via a coaching overlay is a good practice for guiding the user to move the phone to analyze their surroundings, as seen in Fig. 5.

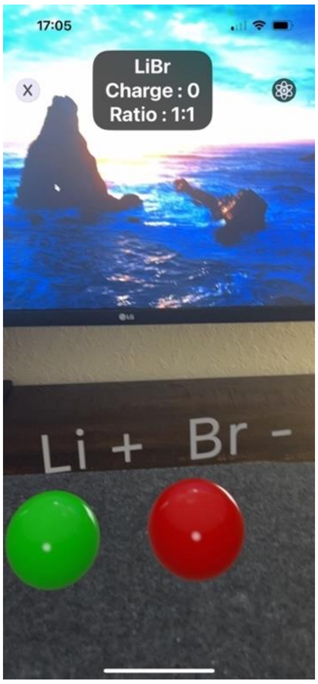

Fig. 4. ION Lab

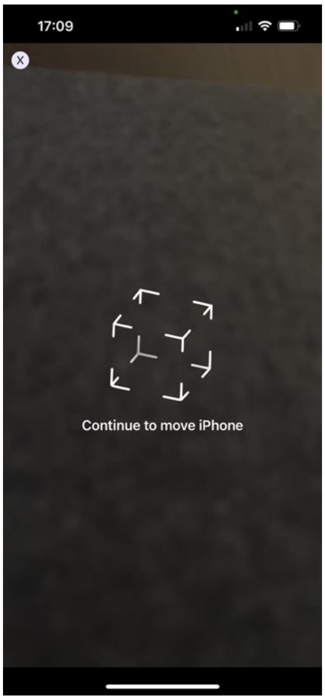

Fig. 5. Coaching overlay

2.3 Case Study: Implementing Chemistry Labs

Our platform aims to have an interdisciplinary approach by giving professors access to add any type of class and relevant 3D models, whether it is a physics class, robotics, or even space engineering. While the platform has this versatility, it also focuses on Chemistry by having two labs for students to interact with and learn two key aspects: chemical compounds and ion charges. The application also has a shared AR experience to promote teamwork during the labs. This section will discuss the implementation and data collection for the labs.

Application Programming Interface (API). APIs act as a translator between two or more software programs. It is usually used to obtain a JSON or XML response, which developers use to decode data in their applications. Our application uses external APIs to obtain essential information in the field of Chemistry.

Firstly, the “periodic table” API is used to obtain data in JSON format about all the elements in the periodic table so that the students can visualize and add the 3D models of it via the ARView. The data parsed from the previously mentioned API includes element name, symbol, atomic mass, and group block. After the data is obtained, it is processed by the application and displayed to the user in a visual format, as seen in Fig. 6.

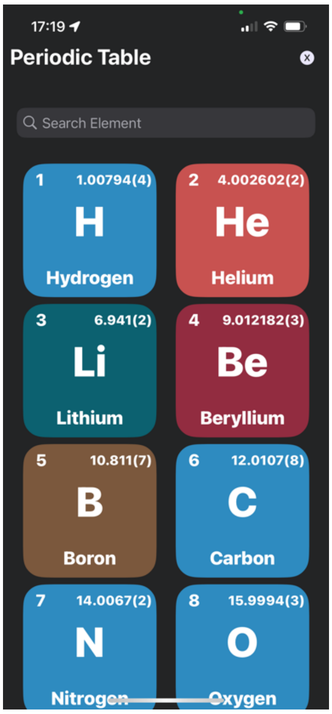

Fig. 6. Periodic Table

Secondly, the web application uses the PubChem API, which accesses the PubChem database [19], an open-source chemistry database provided by the National Institute of Health, to provide essential information for chemical compounds. The application requests information regarding compounds, which the professors can add as an assignment to students so that they can build the compound in 3D. The received information includes a 2D image of the compound, the molecular formula, a description, molecular weight, and SMILES of the compound. After the response data is parsed, it is presented on the web platform to the professor, as seen in Fig. 7, and if agreed, can be saved to the Firebase database and presented to the student in the assignment format, as seen in Fig. 8. The retrieved API information is essential in guiding the student to complete the assignment by presenting a 2D image of what they should build, hinting at how the molecular formula should look like, and expanding the student’s knowledge of each compound by describing it. Thus, this aligns with the application's goal to teach students different subjects in a more interactive and spatially engaging way, with a focus on chemistry.

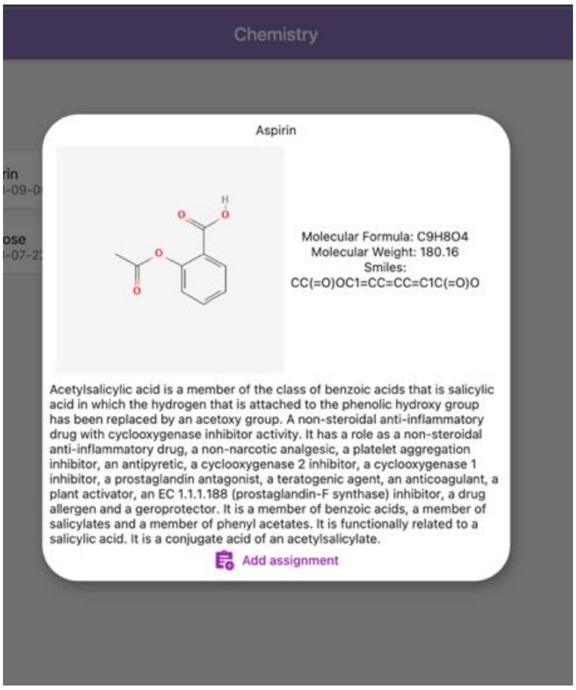

Fig. 7. PubChem Visual API Response

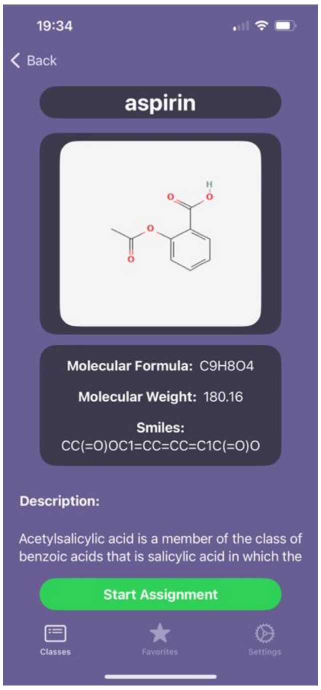

Fig. 8. Mobile Assignment View

Assignment-based Lab for Building Compounds. The compound lab uses an assignment approach to teach students the structure of a specific compound by making them build it in a 3D format based on a 2D image. This hands-on lab allows students to visualize a chemical compound further beyond the boundaries of a 2D image by bringing it into their environment, allowing them to interact with it, and receiving a grade based on their accuracy. After the students are familiarized with the 2D image of the compound, as well as gained knowledge about it, such as the molecular formula and a description, they can proceed to start the assignment and build the 3D model of the compound. Upon starting the assignment, the platform displays an AR view, allowing the students to place molecules from the given periodic table and form connections between the placed molecules. After the student is satisfied with the model he built for the given assignment, he can take a screenshot of the model and send it to the professor to grade it via the web platform. The screenshot and submit button can be seen in Fig. 9, while the professor's view can be seen in Fig. 10.

Fig. 9. Compound Submission

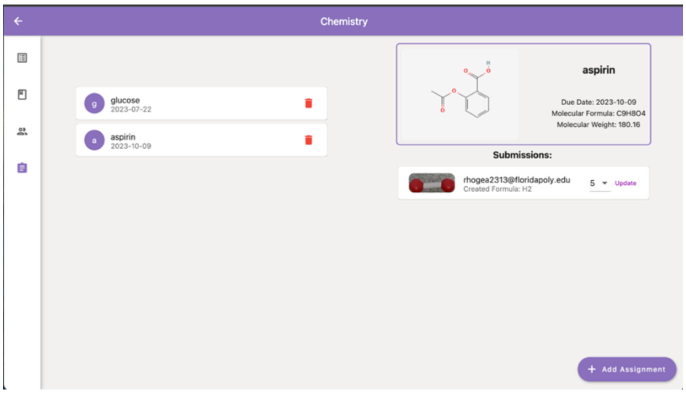

Fig. 10. Submissions List

Additionally, upon completing the assignment, the student receives a partial grade based on the molecular formula he built. The application achieves this by comparing the student's formula with the formula provided by the API response. Subsequently, the professor will update the grade based on the correctness of the connections via the web platform. Furthermore, the student can see the status, current grade, and overall assignment submission via the iOS application. The submission view in its final state, after the professor also assigned a grade, can be seen in Fig. 11.

Ion Lab. The second Chemistry lab aims to teach students how different ions combine to have a neutral charge. From an algorithmic point of view, this lab respects several chemistry rules: no more than two different molecules can be added, the positively charged ion always comes first in the formula, and the ratio is always reduced to its lowest value. The ratio is reduced using the most significant common devisor of both molecules. For example, if the user adds two molecules of lithium (Li^+) and two molecules of bromine (Br^-), the formula is LiBr, having a ratio of 1:1 instead of Li_2Br_2 and a ratio of 2:2, thus respecting the laws of chemistry. The charge in the previously mentioned example is 0, indicating to the user that what they built so far is correct, and when they try to add a different molecule, they will be prompted with an alert that it is incorrect. The mentioned example is shown in Fig. 12.

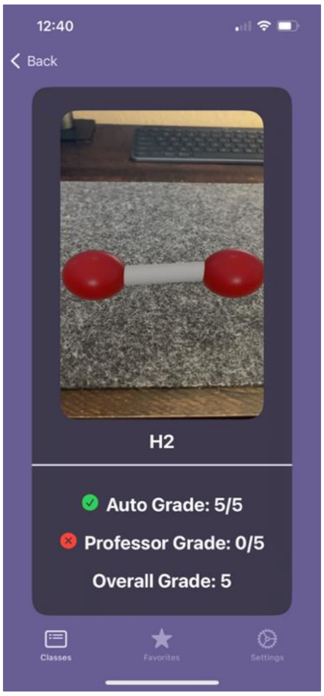

Fig. 11. Submission View

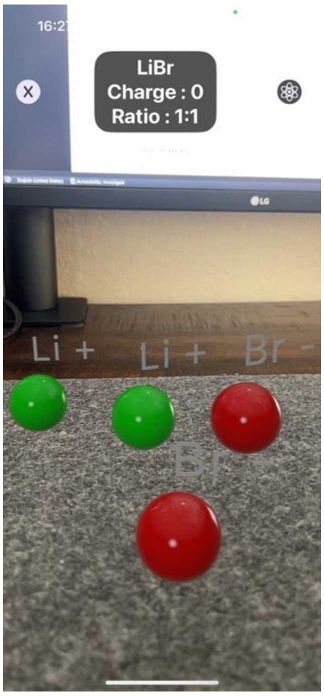

Fig. 12. LiBr example in the ion lab

Creating a Shared AR Experience. ARKit uses the device camera to gather and process the user's environment, and by enabling collaboration, the data can be sent to nearby devices connected to the same network, thus offering a multi-user AR experience. The framework uses multipeer connectivity by importing the “MultipeerConnectivity” package to transfer data from an advertiser to a receiver and vice versa. The package uses an MCNAdvertiser and MCNBrowser to create, advertise, and look for an available via network and offers the template for sending and receiving data. After the package creates the connected session, it delegates the session to the AR session created by AR Kit, which enables anchor data transfers via the model’s implemented methods for sending and receiving data to and from the connected peers.

In short, when the AR View for shared experience is enabled, the application notifies all nearby devices that a session is available to join. After two devices are connected by being close to each other, the advertiser sends all the AR anchors placed and their respective IDs. After the receiver gets the anchors, it places them in their allocated space and, based on their ID (i.e., “Bromine”), assigns a 3D entity to each anchor. The advertiser also assigns 3D entities to its anchors based on their ID, which in turn is assigned when a user selects an element from the periodic table. The interaction between an advertiser and a receiver can be seen in Fig. 13. For our application, collaboration is essential for the chemistry lab, such that students can interact with the elements of the periodic table together, thus encouraging social interaction and teamwork. Each student with an iOS device can join a session with a different iOS device and, via the provided periodic table, can place molecules in the environment of both users. The collaborative session can be seen in Fig. 14.

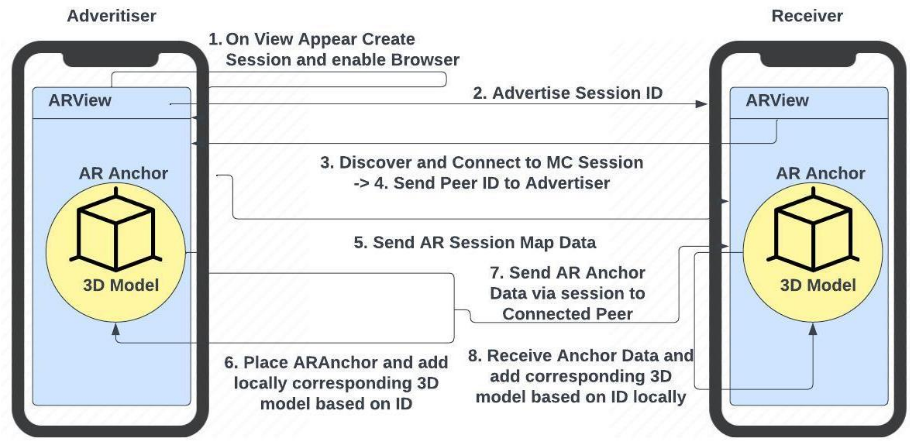

Fig. 13. Advertiser – Receiver Workflow Diagram

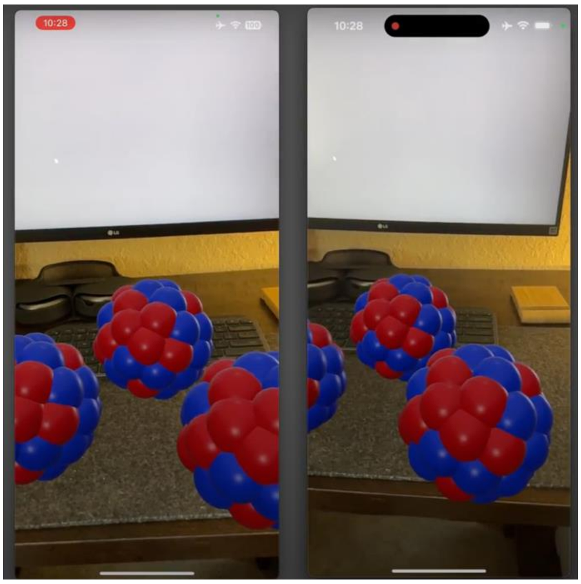

Fig. 14. Collaborative AR Experience

Data Collection. To accurately collect data and feedback for the mobile application, two questionnaires, video demos, and a hands-on experience of the application were conducted in five chemistry labs at Florida Polytechnic University to a total of sixty students. Before the students interacted with the application, a pre-demo questionnaire consisting of fourteen questions was provided. The questions consisted of nine Likert-like multiple-choice questions related to the student's prior experience with chemistry, their reasoning for taking a chemistry course, and their interest in chemistry. The remaining questions were also multiple-choice and related to the demographics of each user.

After each student completed the pre-demo questionnaire, a video demo of each lab was presented to the students. Next, they moved on with testing the application. Each student tested the application in three stages. At first, each student entered the ion lab and tried to create a neutral ion bond. Next, an assignment was created for each student, and they had to build the water compound using the periodic table. Some submissions made by students during testing can be seen in Fig. 15. Lastly, students were paired in two teams and asked to collaborate on a shared AR experience by interacting with different elements of the periodic table together.

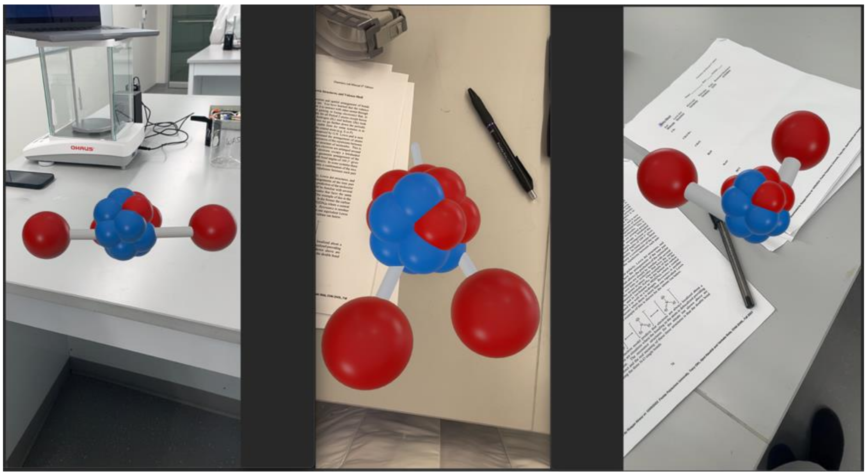

Fig. 15. Student Submissions of the Water Compound

Finally, after the hands-on tests, each student was asked to complete a post-test questionnaire formed by Likert-like multiple-choice questions. The Likert-like multiple choice questions were related to the likelihood of each student to prefer an AR lab rather than a real lab, how engaging the experience was, and their opinion on shared AR experiences.

3 Results

The study was conducted in five different chemistry labs at Florida Polytechnic, and as a result, 60 students responded to the post-questionnaire. Based on the results, over

70% of students consider AR an alternative to compound learning, with 60% considering it a tool that will help them understand the subject better. These results are reflected in Fig. 16 and 17.

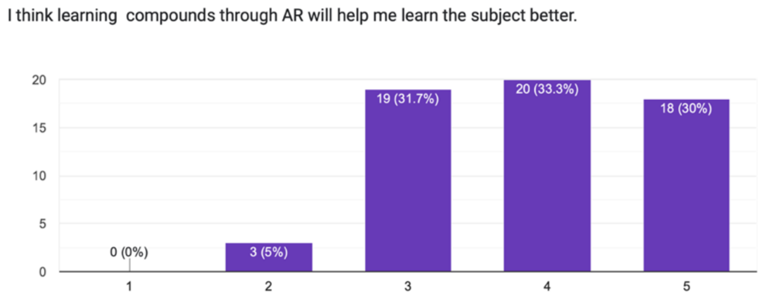

Fig. 16. Learning the Compounds Subject Better Through AR Questionnaire Results

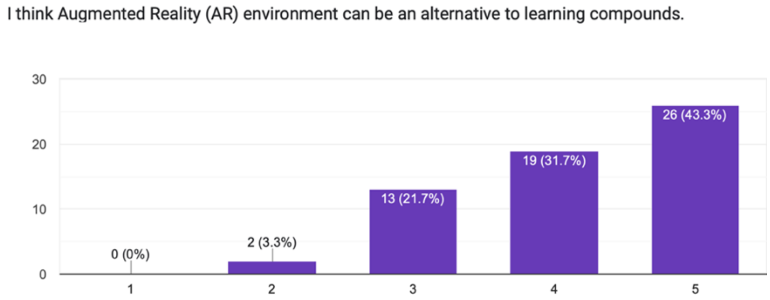

Fig. 17. AR as an Alternative for Learning Compounds Questionnaire Results

Similar results were obtained regarding the ion lab, with 40% of students strongly agreeing that AR can be an alternative to learning ions and 28.3% strongly agreeing that it would help them understand the subject better. The results can be seen in Fig.18 and 19.

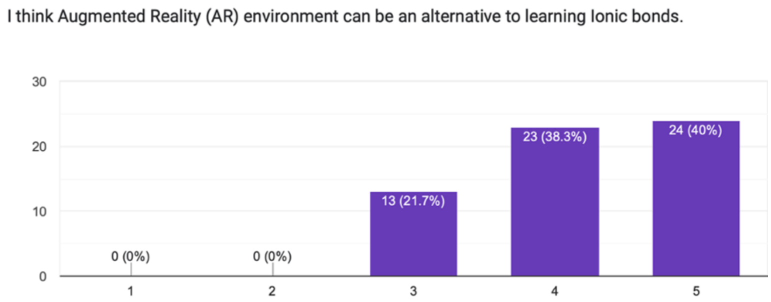

Fig. 18. AR as an Alternative for Learning Ionic Bonds Questionnaire Results

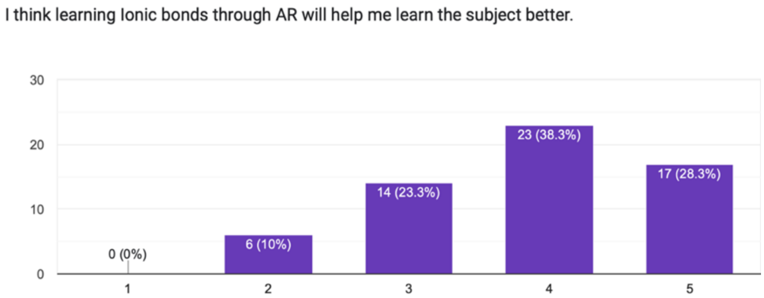

Fig. 19. Learning the Ionic Bonds Subject Better Through AR Questionnaire Results

Although the labs with which the students interacted were focused on the field of chemistry, the application has multiple purposes, and the students were asked if they would consider AR as an alternative to a standard lecture. To the question, "I think learning through AR will be more engaging than a standard lecture," 53% of students strongly agreed that AR would make a standard lecture more engaging. Similarly, 40% of students agree, and 30% of students strongly agree that they would prefer the immersive AR learning experience to the learning experience of a standard lecture. These results can be seen in Fig. 20 and 21.

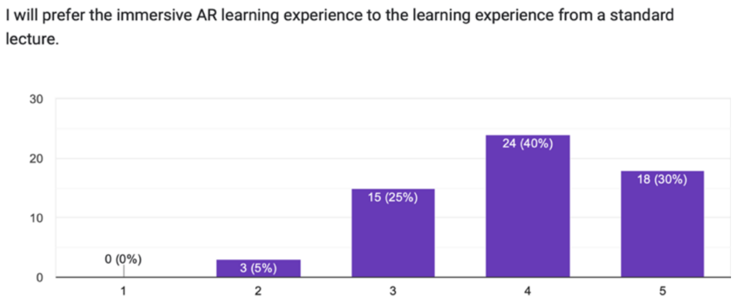

Fig. 20. Results for students who preferred an AR lecture to a standard lecture.

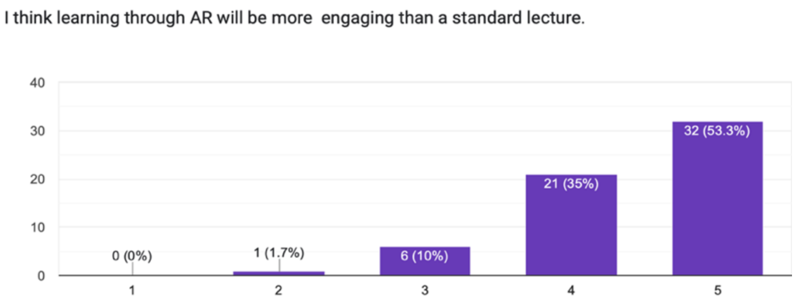

Fig. 21. Student's results for considering an AR lecture more engaging than a standard lecture.

The shared AR experience was implemented with the promotion of teamwork in mind, and it is an essential feature of the application. Thus, to get feedback regarding the importance of the experience for the platform, the following questions were asked: “I think learning in a shared AR experience is more engaging than an individual AR assignment experience” and “I think a shared AR experience is more engaging than an individual AR assignment experience”. As a result, 44.1% of students agreed that a shared AR experience is more engaging than an individual AR experience, and an additional 25.4% strongly agreed with the statement. Moreover, 39% of students agreed, and 37.3% strongly agreed that a shared AR experience would promote teamwork in a lab environment. These results can be seen in Fig. 22 and 23.

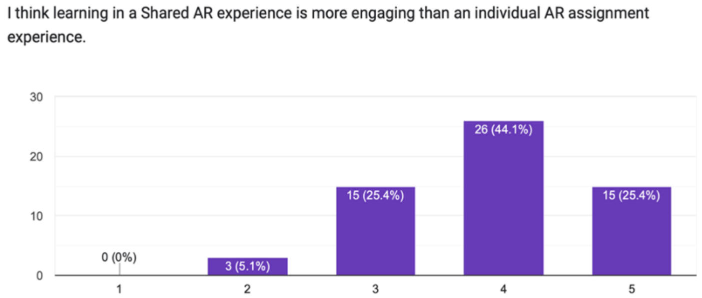

Fig. 22. Students Result on the engagement of a shared AR experience.

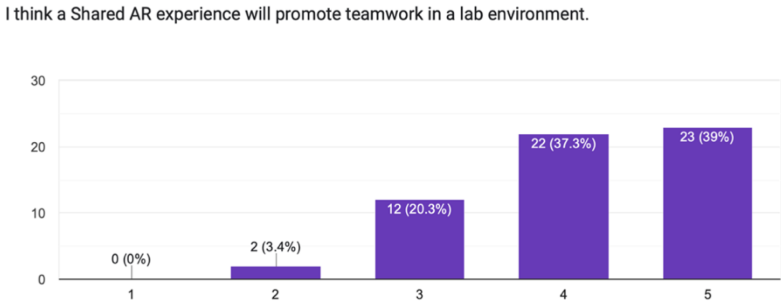

Fig. 23. Student's results on the promotion of teamwork in a lab via a shared AR experience.

To further test the results of our data and the credibility of our application, we performed a Spearman’s analysis on all the combinations of the questions from both the post-questionnaire and the pre-questionnaire. After that, we extracted all the significant large positive and negative relationships by picking the correlations with a Spearman’s coefficient value larger than 0.5 and a p-value<.001. A sample of the correlations can be seen in Fig. 24 and 25.

Question	Spearman's Coefficient	p-value
AR as an alternative to learning compounds vs. AR as an alternative to learning ionic bonds	0.767	9.09E-13
AR as an alternative to learning compounds vs. Learning compounds better with AR	0.539	8.72E-06
AR as an alternative to learning compounds vs. AR being more engaging than a standard lecture	0.581	1.12E-06
AR as an alternative to learning compounds vs. Prefering immtersive AR to a standard lecture	0.541	8.25E-06
AR as an alternative to learning compounds vs. Being open to learning with AR	0.51	3.09E-05
AR as an alternative to learning ionic compounds vs. AR being more engaging than a standard lecture	0.581	1.15E-06
AR as an alternative to learning ionic compounds vs. Prefering immtersive AR to a standard lecture	0.555	4.16E-06
AR as an alternative to learning ionic compounds vs. Being open to learning with AR	0.526	1.61E-05

Fig. 24. Spearman's Correlation Sample results for post-questionnaire questions.

Question	Spearman's Coefficient	p-value
Interested in learning chemistry vs. Enjoying learning through standard lectures	0.533	1.20E-05
Comfortable working in a chemistry lab vs. Being anxious about working in a chemistry lab	-0.547	6.10E-06
Enjoy learning through standard lectures vs. Liking their chemistry course	0.56	3.30E-06
Open to learning with AR vs. Considering AR as an alternative to learning ionic bonds	0.53	1.60E-05
Open to learning with AR vs. Considering AR as an alternative to learning compounds	0.51	3.10E-05
Liking their chemistry course vs Liking their chemistry lab	0.602	3.65E-07

Fig. 25. Spearman's Correlation results for pre-questionnaire questions.

We can conclude that AR is a good alternative to learning compounds to the same degree that AR is an excellent alternative to learning ionic bonds. Also, there is a significant positive correlation between the learning of compounds or ionic bonds and the engagement and immersion of an AR lab compared to a standard lecture. Additionally, students who consider that learning compounds or ionic bonds through AR is better, also consider an AR lab more engaging than a standard lecture. The students who consider the learning of compounds or ionic bonds through AR, also prefer the immersive shared AR experience, and agree that a shared AR experience will promote teamwork in the lab. The only negative significant relationship is between the students who feel anxious about working in a chemistry lab and the students who feel comfortable working in a chemistry lab. Overall, it can be concluded that students who are open to learning with AR also consider AR as an alternative to learning ionic bonds or compounds.

4 Conclusions

With the advancement of computer vision and phone hardware, AR became more accessible to the public. Having an impact on commercial use, gaming, and education, AR is being used more and more daily. In this study, we implemented an AR platform for your iPhone, with a companion web application, to demonstrate the potential use case and impact of AR in education. Although the web application allows the professors to add AR objects to any class, a more detailed implementation was applied for the chemistry lab to be able to perform a case study. In this study, we implemented three different AR chemistry labs for students to interact with and provide feedback via a questionnaire. Sixty students had to complete a compound assignment in which the goal was to build the water compound in AR, then build a neutrally charged ion bond, and finally place atoms in a shared AR experience.

In conclusion, for the chemistry case study, the general feedback on the application was positive overall, with an average of 29% of students strongly agreeing and 36% agreeing that they would use AR to learn compounds or ionic bonds to understand the subjects better. On average, 40% of students would strongly consider, and 35% would consider AR an alternative to a standard lecture to learn ionic bonds and compounds. To further conclude the study and the versatility of the application, 53% of students strongly agreed that AR would make a standard lecture more engaging, with 30% of students strongly agreeing that they would prefer an AR lecture over a standard lecture. Additionally, the application intends to promote teamwork, and the results conform with this idea, with 39% of students strongly agreeing that a shared AR experience would promote teamwork in a lab, and an additional 37% also agreeing to that statement. While 25% of students also strongly consider a shared AR experience more engaging than an individual AR experience, an additional 44% agree. Moreover, a large set of questions resulted in being highly correlated, thus proving the relevance of this case study.

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