iOS Augmented Reality Application for Immersive Structural Biology Education

Sabrina Chow
sabrina8chow@gmail.com
Cornell University
Ithaca, New York, USA

Kendra Krueger
kkrueger@gc.cuny.edu
The Advanced Science Research Center at the CUNY Graduate Center
City University of New York
New York, New York, USA

Oyewole Oyekoya
oo700@hunter.cuny.edu
Hunter College
City University of New York
New York, New York, USA

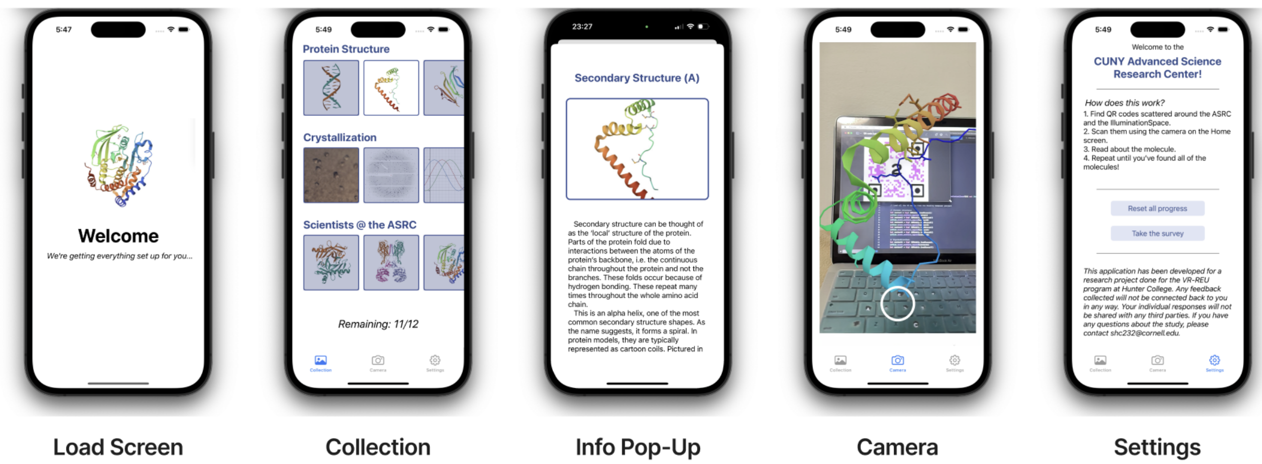

Figure 1: All of the screens of the application.

ABSTRACT

In this day and age, there is a need for more tools in education that take advantage of the new frontiers of technology. Students have grown up in a digital world and can quickly adapt to new methods of learning. XR, or extended reality, involves the use of technology to upgrade the physical world. Augmented reality (AR), in particular, has a nice balance of enhancing the physical world with digital models while also remaining convenient and accessible since it can be done through a smartphone. This study looked at whether an AR iOS application could be an effective and engaging learning tool. The application was designed to be an augmented reality game and exergame by being a scavenger hunt that accompanied a tour. Preliminary results reveal that participants enjoyed the game and found that it made the tour more educational and slightly more engaging.

ISS Companion '23, November 05–08, 2023, Pittsburgh, PA, USA

ACM ISBN 979-8-4007-0425-3/23/11...$15.00
https://doi.org/10.1145/3626485.3626532

CCS CONCEPTS

• **Human-centered computing** → **Mixed / augmented reality**; **Scientific visualization**.

KEYWORDS

Augmented Reality, iOS Application Development, STEM Education, Structural Biology

ACM Reference Format:
Sabrina Chow, Kendra Krueger, and Oyewole Oyekoya. 2023. iOS Augmented Reality Application for Immersive Structural Biology Education. In *Companion Proceedings of the Conference on Interactive Surfaces and Spaces (ISS Companion '23), November 05–08, 2023, Pittsburgh, PA, USA*. ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3626485.3626532

1 INTRODUCTION

Augmented Reality (AR) is the overlay of digital media on the real world as perceived through a screen. This new technology has most often been applied to the realm of gaming, leading to the creation of Augmented Reality Games (ARGs). These ARGs have many new possible applications in the field of education.

The goal of this project was to create a curriculum for middle school, high school, and undergraduate students to learn about the basics of structural biology through an ARG. The location of focus was the IlluminationSpace in the CUNY Advanced Science

Research Center (ASRC). The outreach program works with students to introduce them to the work of their scientists and inspire them in their STEM careers. This research tests whether an iOS application can support this mission and be an effective learning tool for structural biology.

2 RELATED WORK

2.1 Structural Biology

The focus of the application will be structural biology as to align with one of the ASRC's five initiatives. Specifically, the goal is to teach about molecule structure and crystallization.

Structural biologists aim to understand how the building blocks (i.e. molecules) are structured and interact with one another so that the processes of life can be understood [13].

2.2 Biochemistry in Mixed Reality

The use of AR aligns well with the educational aspect of this project. A key part of biochemistry and molecular biology as a whole is visualizing molecules and how they interact. For students with poor spatial abilities, this can be near impossible without any help, emphasizing the importance of using new methods and available technology to help students 'see' the molecules [16].

Students in this day and age have grown up in a world where technology is everywhere, making them particularly adaptable to new digital methods of learning [4]. Reeves at al. 2021 aimed to find whether AR could be used to aid with learning biochemical material since AR allows for object-based learning without the physical object and the molecules studied are much too small to be perceived with raw vision [14]. They had two education goals in mind: 1) how structure leads to function for proteins and 2) how genetic mutations can alter structure, which leads to disease. The authors found that the combination of lectures and AR had the best performance, indicating that AR is an effective tool for learning structural biology.

Given the general success with using AR in teaching biochemistry, many instructors would like to use these tools to teach, but they do not have the time or experience to develop their own [2]. That is why it is so important to develop new techniques and applications that at a minimum provide a framework that teachers can adapt to their purposes.

2.3 Exergames

Exergames are defined as video games that cause the player to exercise in the process of playing the game. An example of a popular exergame is the ARG Pokemon Go by Niantic Labs. Ruiz-Ariza et al. 2018 found that the game increased physical activity, thereby promoting cognitive performance and emotional intelligence [15]. When comparing cognitively engaging games with exergames, physical activity was determined to engage the mind the most [5]. Given that the IlluminationSpace is already an area dedicated entirely to learning, it made sense to take advantage of that space and encourage students to be active while learning.

One of the key issues with exergames and game design in general is making the game engaging so that users will want to keep playing [10]. XR is the perfect solution to this issue because its core principle is immersion. Although virtual reality is more immersive than augmented reality, AR provides enough physical and social context to create an immersive environment [16].

3 METHODOLOGY

An iOS application was built to display different items from structural biology topics. The application was built using Xcode in Swift and was designed for use through iPhones and iPads. The application specifically uses Apple's RealityKit to display these items as 3D through AR.

The subject material was split into three sections: protein structure, x-ray crystallography, and scientist spotlights. Altogether there were 8 different molecules used along with 4 2D images. The images used to describe the process of x-ray crystallography were provided courtesy of Dr. Eta Isiorho.

To display 3D models of molecules, .PDB files were used. Models were taken from RCSB PDB. Visible in Figure 1 are 1ZX3, 4R8O [17], 6B90 [9], 6M1D [18], 103D [8], and 6VNA [11]. Another two models were used but do not appear in the figure: 1S1Y [1] and 4IWM [7]. These files were loaded into ChimeraX to adjust the color then downloaded as .GLB files. These .GLB files were brought into Apple's RealityConverter and turned into .USDZ files. The .USDZ files were imported into Apple's RealityComposer to build the scene of the molecule model on top of a QR code.

In order to try to keep users active to stimulate the brain through physical activity, the application uses the format of a scavenger hunt through the ASRC space. The QR codes were printed and placed around the building, requiring users to go up and down the stairs and move throughout the space to find them. When users scan a code with their phone camera through the app, they are able to see the item in 3D through their screen. The model is stationary on the QR code, but the user can move around, allowing the user to see it from different perspectives.

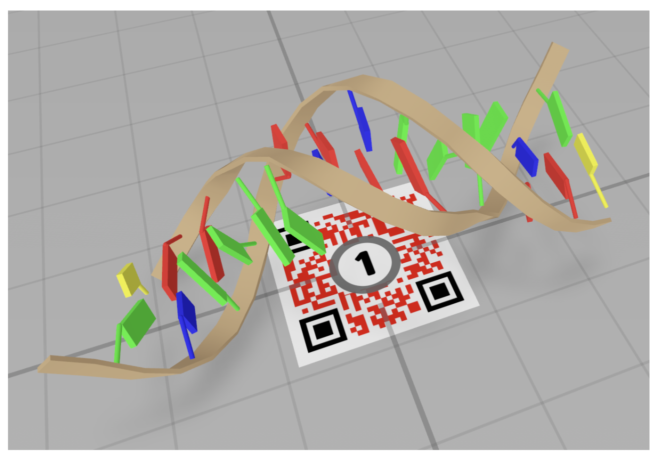

Figure 2: The 3D model of 103D on its QR code.

To promote learning, once a user scans an item, they receive information on the item. If they want to review the information, they can go to the collection tab and tap on the item's image. To promote competitiveness and the game aspect of the application, the collection tab also indicates which items have not yet been collected and how many are left.

4 USER STUDY

In order to test the effects, user testing was done with a field trip group. No identifying information was collected– only feedback.

Due to Apple's limit to the number of devices that can run a developed iOS application, only two devices were able to download and run the app. Therefore, students were divided into two groups. Each group was given one of the iOS devices with the app and instructed to share the device. The students were shown how to use the app with one example QR code. Then, they were instructed to keep an eye out for similar QR codes around the building during the tour.

At the end of the field trip, all students were given the link to the same survey. The survey had two parts, a multiple choice section and a free response section. The multiple choice section used a Likert scale with feedback rankings on scale of 1- strongly disagree to 5- strongly agree [12]. Questions focused on three topics: usability, education, and fun. The usability questions were inspired by the System Usability Scale [6]. There were 11 questions total. This breaks down to 5 usability, 3 fun, and 3 education questions. The maximum possible score was 55. The free response section only asked two questions: "What did you like about the application/game?" and "What do you think could be improved about the application/game?"

5 RESULTS AND ANALYSIS

Out of 7 students who went on the tour, only 5 filled out the study survey afterwards. One user who filled out the survey later came back after submission saying that they filled out the multiple-choice portion wrong, switching the "Agree" choices with the "Disagree" choices. Their data for the multiple-choice section was therefore removed, although their written feedback was retained. The mean response was 50.75. The median response was 51.5.

All of the remaining users had positive reactions to the AR application. Most users seemed quite impressed with the AR content. User 3 specifically pointed out that "[they] liked how the visualization was experienced through the phone."

All the users gave some helpful advice about what could be improved about the application. Two of the users mentioned that it would have been nice to be able to access the 3D models again without having to find and scan the QR code again. Another couple of users wrote about how some of the displays were not clear. In the collection tab, semi-opaque screens were used to cover the molecules that were not yet unlocked, but the color was not dark enough in some cases, making it unclear the status of that item. Also the button on the camera tab made it seem like a picture was being taken and saved. In reality, the button just serves as a way to unlock a molecule.

6 DISCUSSION

Overall the results of the user study survey seem quite positive. If a respondent was completely neutral about everything, then their score would have been 33. Both the median and the mean were well above this level, indicating a more positive opinion of the application. If the median and mean were converted to a 100-point scale instead of a 55-point scale, their values would be approximately 92.7 and 92.3, respectively. Bangor et al. 2009 found that an adjective rating of "Excellent" had a mean score of 85.5 [3]. The converted mean and median are higher than the "Excellent" score. This suggests that the scores from the survey would be considered good.

Still, given the small sample size, neither the median nor the mean are particularly reliable metrics. Also, the survey was not entirely made up of the true SUS questions. Keeping that in mind, the survey questions can be broken down into their sections.

The iOS application was designed to test the feasibility of augmented reality as a learning device for structural biology. The trickiest part of structural biology is visualizing molecules, and the majority of participants agreed that seeing the 3D models through AR helped. 4 out of the 5 users declared that the game made them want to learn more and that they did actually learn something from the game. The positive findings of this pilot study confirms that AR can be an effective assistant in learning structural biology.

Furthermore, the generally high usability scores suggest that users were able to quickly adapt to the foreign application. This

	User			
	1	2	3	4
Usability of the application:				
The application was easy to use.	✓	✓	✓	✓
The application layout was intuitive.	✓	✓	✓	✓
I found the various functions in this system were well implemented.	✓	✓	✓	✓
I would imagine that most people would learn to use this application very quickly.	✓	✓	✓	✓
I am confident in my ability to use the application.	✓	✓	✓	✓
Motivation/fun:				
The game aspect made the experience more fun.	✓	✓	✓	✓
I feel like the game added something to the tour.	✓	✓	✓	✓
Having a scavenger hunt motivated me to pay closer attention.			✓	
Educational aspect:				
I learned something from the game.	✓	✓	✓	✓
Having a game made me want to learn about the subject material.	✓	✓	✓	✓
Seeing the 3D models made it easier to visualize the proteins.	✓	✓	✓	✓

Figure 3: The questions, sorted by subject matter, and the respondent's answers. A check mark indicates a positive score (4 for "Agree" or 5 for "Strongly Agree"), whereas a blank space indicates a negative or neutral score (1 for "Strongly Disagree," 2 for "Disagree," and 3 for "Neutral").

serves as a proof of concept for AR in STEM education as well as for other applications, such as engaging tours.

6.1 Limitations

The study was only run with one group of undergraduate students. Only 7 students were able to try the app, and only 5 provided feedback through the survey. By sending a survey link and asking users to fill it out on their own time, volunteer bias was introduced. The ones who filled out the survey might be motivated to do so because they have stronger opinions.

In addition, the target age range for the IlluminationSpace includes middle school and high school students. While the preliminary results of this survey suggest that the AR could be a useful addition to the IlluminationSpace, there is no guarantee that the tour would be as effective with younger students.

Finally, the survey did not gather any information about the respondents. Demographic information certainly could have affected the way users perceived the application. For example, someone with a higher socioeconomic status would likely have more access to XR technology and better able to adjust to the application than someone who had no previous experience with AR.

6.2 Future Improvements

One of the main goals of developing this application was to create an immersive learning environment for students coming to the ASRC. While the AR aspect was fully implemented, users were limited to visual models that they could see from different perspectives. For a more immersive experience, users should be able to interact with the AR models. This would make the game more enjoyable because it gives the user more agency and maintains their attention on the application.

Another area where the application could be improved is the learning aspect. At the moment, the application has a collection screen where users can click on the items that they have unlocked to learn more. This method therefore depends entirely on the user to seek out more information. While the application is intended to act as support for the tour, it should still be more active in teaching users about the molecules. One possibility would be creating a popup for each time a molecule is unlocked, which would encourage users to read the captions for the image. Alternatively, unlocking the molecule could take the user directly to its caption. Furthermore, the user survey should also include some questions on the subject material in order to test how much was actually absorbed.

To improve usability, an in-app tutorial would be ideal. A demo was presented at the start of the tour, but given that the smartphone screen is small and there were multiple people, it was likely difficult for users to see everything that was going on.

As users suggested, the user interface could be improved. The color scheme could be clearer to indicate which molecules were locked and unlocked. In addition, badges on the items that were newly unlocked would draw more attention to the collection tab and draw users to to click on the items to read more. More efficient code would reduce loading times and stop the app freezing when the camera portion opens.

Finally, although the application was designed to be an exergame, physical activity was not monitored. Keeping track of the user's heartrate or a similar metric would lead to better analysis of whether the scavenger hunt was an effective game mode for learning.

7 CONCLUSION

This paper serves as a preliminary study on whether an iOS augmented reality exergame can be used as a learning device for STEM education. Although there were a limited number of participants, the positive feedback shows that users were able and wanted to use the application and got some structural biology knowledge out of the experience. This shows that an iOS application like this that uses RealityKit could be used to engage students and help them visualize 3D structures. In the future, this prototype could be expanded upon and generalized for classrooms worldwide.

ACKNOWLEDGMENTS

This work was supported in part by a grant from the National Science Foundation, Research Experience for Undergraduates program (Award No. 2050532, Principal Investigator - Oyewole Oyekoya).

REFERENCES

[1] Spencer Anderson, Vukica Srajer, Reinhard Pahl, Sudarshan Rajagopal, Friedrich Schotte, Philip Anfinrud, Michael Wulff, and Keith Moffat. 2004. Chromophore conformation and the evolution of tertiary structural changes in photoactive yellow protein. *Structure* 12, 6 (2004), 1039–1045.

[2] José M. Argüello and Robert E. Dempski. 2020. Fast, Simple, Student Generated Augmented Reality Approach for Protein Visualization in the Classroom and Home Study. *Journal of Chemical Education* 97, 8 (2020), 2327–2331. https://doi.org/10.1021/acs.jchemed.0c00323 arXiv:https://doi.org/10.1021/acs.jchemed.0c00323

[3] Aaron Bangor, Philip Kortum, and James Miller. 2009. Determining what individual SUS scores mean: Adding an adjective rating scale. *Journal of usability studies* 4, 3 (2009), 114–123.

[4] John Barrow, Conor Forker, Andrew Sands, Darryl O'Hare, and William Hurst. 2019. Augmented Reality for Enhancing Life Science Education. In *Proceedings of VISUAL 2019 - The Fourth International Conference on Applications and Systems of Visual Paradigms*. https://www.iaria.org/conferences2019/VISUAL19.html

[5] John R Best. 2012. Exergaming immediately enhances children's executive function. *Developmental psychology* 48, 5 (2012), 1501.

[6] John Brooke. 1995. SUS: A quick and dirty usability scale. *Usability Eval. Ind.* 189 (11 1995).

[7] Sheng-Chia Chen, Chi-Hung Huang, Chia Shin Yang, Shu-Min Kuan, Ching-Ting Lin, Shan-Ho Chou, Yeh Chen, et al. 2014. Crystal structure of a conserved hypothetical protein MJ0927 from methanocaldococcus jannaschii reveals a novel quaternary assembly in the Nif3 family. *BioMed Research International* 2014 (2014), 171263.

[8] Shan-Ho Chou, Leiming Zhu, and Brian R Reid. 1994. The Unusual Structure of the Human Centromere (GGA) 2 Motif: Unpaired Guanosine Residues Stacked Between Sheared G· A Pairs. , 259–268 pages.

[9] Daniel A Keedy, Zachary B Hill, Justin T Biel, Emily Kang, T Justin Rettenmaier, Jose Brandao-Neto, Nicholas M Pearce, Frank von Delft, James A Wells, and James S Fraser. 2018. An expanded allosteric network in PTP1B by multitemperature crystallography, fragment screening, and covalent tethering. *Elife* 7 (2018), e36307.

[10] Teemu H. Laine and Hae Jung Suk. 2016. Designing Mobile Augmented Reality Exergames. *Games and Culture* 11, 5 (2016), 548–580. https://doi.org/10.1177/1555412015572006 arXiv:https://doi.org/10.1177/1555412015572006

[11] Shuxin Li, Eta A Isiorho, Victoria L Owens, Patrick H Donnan, Chidinma L Odili, and Steven O Mansoorabadi. 2021. A noncanonical heme oxygenase specific for the degradation of c-type heme. *Journal of Biological Chemistry* 296, C (1 2021), 100666. https://doi.org/10.1016/j.jbc.2021.100666

[12] R. Likert. 1932. A technique for the measurement of attitudes. *Archives of Psychology* 22 140 (1932), 55–55.

[13] Alexander McPherson. 2004. Introduction to protein crystallization. *Methods* 34, 3 (2004), 254–265. https://doi.org/10.1016/j.ymeth.2004.03.019 Macromolecular Crystallization.

[14] Laura Reeves, Edward Bolton, Matthew Bulpitt, Alex Scott, Ian Tomey, Micah Gates, and Robert A. Baldock. 2021. Use of augmented reality (AR) to aid bioscience education and enrich student experience. *Research in Learning Technology* 29 (Jan. 2021). https://doi.org/10.25304/rlt.v29.2572

[15] Alberto Ruiz-Ariza, Rafael Antonio Casuso, Sara Suarez-Manzano, and Emilio J. Martínez-López. 2018. Effect of augmented reality game Pokémon GO on cognitive performance and emotional intelligence in adolescent young. *Computers & Education* 116 (2018), 49–63. https://doi.org/10.1016/j.compedu.2017.09.002

[16] Parviz Safadel and David White. 2019. Facilitating molecular biology teaching by using Augmented Reality (AR) and Protein Data Bank (PDB). *TechTrends* 63, 2 (2019), 188–193.

[17] Qingping Xu, Matthew Biancalana, Joanna C Grant, Hsiu-Ju Chiu, Lukasz Jaroszewski, Mark W Knuth, Scott A Lesley, Adam Godzik, Marc-André Elsliger, Ashley M Deacon, et al. 2019. Structures of single-layer β-sheet proteins evolved from β-hairpin repeats. *Protein Science* 28, 9 (2019), 1676–1689.

[18] Renhong Yan, Yuanyuan Zhang, Yaning Li, Lu Xia, Yingying Guo, and Qiang Zhou. 2020. Structural basis for the recognition of SARS-CoV-2 by full-length human ACE2. *Science* 367, 6485 (2020), 1444–1448.

Received 2023-08-15; accepted 2023-09-15