Augmented Reality for Enhancing Life Science Education

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***Abstract*— Augmented Reality (AR) has the opportunity to be a disruptive technology in the delivery of educational materials at all levels, from public outreach activities to expert level teaching at undergraduate and postgraduate levels. The attractiveness of AR as a teaching tool is its ability to deliver a blended learning experience created from the mixing of the virtual and real environments or materials in the classroom. This allows students to learn in a variety of ways to mix didactic, experiential and kinaesthetic learning. We have developed, and are in the process of developing, AR applications that aim to transform the learning space into one that is highly interactive, so this paper will discuss the potential impact of such teaching interventions on higher education.**

Keywords- Augmented reality; education; visualisation.

I. INTRODUCTION

One contemporary paradigm in higher education is the tailoring of educational resources towards a so-called "digitally native" audience who, for the most part, have grown up surrounded by digital technology. The students entering higher education today are demanding a high standard of education that incorporates the digital world in which they live. There is sometimes a tendency to aspire to incorporate digital technologies into everything that is carried out in a higher education institution, but it is not digital natives rather digitally aware students that we should be developing [1]. Furthermore, students require an ability to be prepared for the future, especially in a fast-paced, ever changing world were digital literacy, and skills associated with it are seen as essential [2]. Further to this, the life sciences are one such area where this requirement for a digital skill set is a necessity as much of the current research relies on digitalisation of data. For example, this could be in the form of genomic data or population statistics of various patient sub-groups [3]. This paper will discuss the development and testing of an augmented reality (AR) app for teaching metabolism, especially glucose metabolism and insulin signalling. Section II discusses the background to the project; Section III describes the implementation of the AR app; Section IV shows results from testing; and Section V discusses the conclusions of this work.

A. VR/AR in Education

As a consequence of the required skills set a life science undergraduate needs and the inherent requirement to develop digitally-driven approaches to delivering a high quality education, the use of augmented reality and virtual reality has become an emerging theme. A simple literature search in the PubMed (The National Center for Biotechnology Information) database for the terms virtual reality and augmented reality in education shows the rapid growth of both areas (Figure 1).

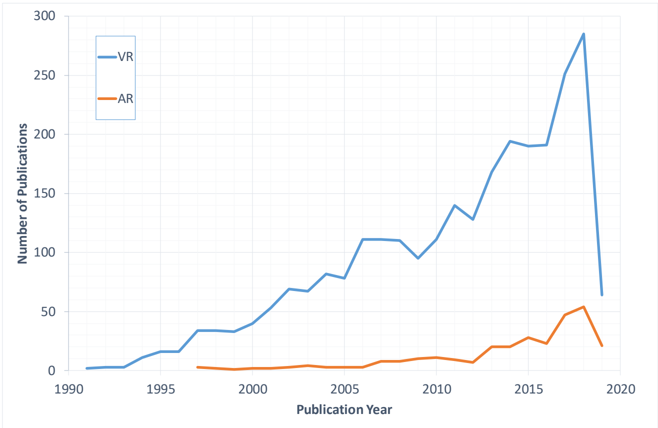


Figure 1. PubMed results by year for virtual and augmented reality publications.

Search terms of "virtual reality AND education" and "augmented reality AND education" were used to identify the total number of publications in each year from the first year that a publication appeared in the PubMed database. VR (blue line), virtual reality; AR (red line), augmented reality. Note – there was one publication for augmented reality dated 1989, which is excluded from the data shown.

B. Aims

This paper will describe the results of a consultation on the use of digital visualisation technologies in the teaching of life science subjects and the creation and testing of an AR application to aid in the teaching of metabolism, specifically linked to glucose and insulin signalling.

C. Study Methods

The present study was conducted in the School of Medicine, Medical Sciences and Nutrition at the University of Aberdeen. Ninety participants were self-selected by completing a survey as part of a second year undergraduate biochemistry course that forms part of the core curriculum for most life science degree programmes. Of the ninety questionnaire participants, eight were randomly selected to take part in a focus group and seven volunteered to test an AR application linked to the teaching of metabolism.

The questionnaire aimed to identify student preferences in the teaching structure-function relationships in the life science subject areas. The focus group aimed to question participants on their preference for digital technology and how it can integrate with their teaching. The testing of the AR application aimed to identify their views of AR in education having been exposed for the first time to this kind of technology in the classroom.

II. BACKGROUND

Virtual and augmented realities (VR and AR respectively) allow immersive and visual experiences for the user. In VR, this will be via the use of a head-mounted display that is either a standalone device or a device tethered to a computer that drives the visualisation hardware. VR can also be delivered using smartphone technology and a headset viewer that allows the user to display a VR image on the smartphone screen. When using tethered or standalone VR headsets, there is a requirement for high-end computer hardware to run the software, but for smartphone VR the requirement for accelerated hardware is less so and the headset smartphone holders are also relatively inexpensive or can even be created by the user (e.g., Google Cardboard). In AR, the experience is different from VR as it allows the user to overlay digital content in the real-world environment and interact with that content. This offers some distinct advantages over VR as it allows the user experience to be shared amongst groups rather than being a single-user experience, and it also provides an opportunity for users to mix learning styles when the AR is combined with more traditional forms of teaching materials such as texts or lecture slides. This mixed approach could provide a powerful tool that satisfies many learner styles, allows collaborative learning, and provides increased scope to bring subjects to life in a way that has not been possible before.

A. VR/AR in Educational Context

In an educational context, VR offers some distinct advantages over standard teaching practices in that it can allow students to simulate scenarios, such as surgical training of medical students [4], or allow students to understand abstract concepts that are not visible like protein structure and function [5]. AR also offers advantages as it can allow the delivery of mixed methods teaching were students have traditional learning from written materials coupled with visualisations of the processes involved [6], or provide interactions between real-world objects and the digital visualisations [7].

In many education settings where budgets are often constrained or limited, the use of smartphone technology to deliver VR or AR experiences becomes a more attractive proposition. This also ties in with more and more students having their own devices that are capable of delivering high quality digital experiences as smartphone technology becomes increasingly more powerful. Moreover, students are required in many higher education institutions to use their own devices to record attendance, interact with classes through online voting systems and other institutional resources such as timetables and virtual learning environments. This means there is a real opportunity to develop classroom activities that make use of the 'bring your own device' (BYOD) model. It does also present challenges as BYOD means there will be variable technologies in circulation in any given student cohort. Operating systems, hardware specifications and graphics capabilities will vary widely, so careful consideration may need to be given if students were to use their own devices for VR or AR applications.

B. A TPACK Model of AR Education

There is growing evidence that digital visualisations help students understand abstract concepts, which can be viewed through the lens of the technological pedagogical content knowledge (TPACK) framework [8]. This framework (see Figure 2) highlights the importance of the interplay between technology, discipline knowledge and teaching practice to deliver a modern and relevant programme of study, especially in the life sciences were digital technology is crucial in virtually all research areas. In higher education institutions, the expectation is that subject-specific knowledge and expertise is provided by academic staff alongside effective teaching practices. The one area where there is perhaps some variation is in the ability of the academic to embed technology into the classroom and provide students with a modern curriculum that integrates technology into their learning. AR offers just such an opportunity without changing traditional curricula significantly, as it allows the blending of instructive teaching with digital visualisations.

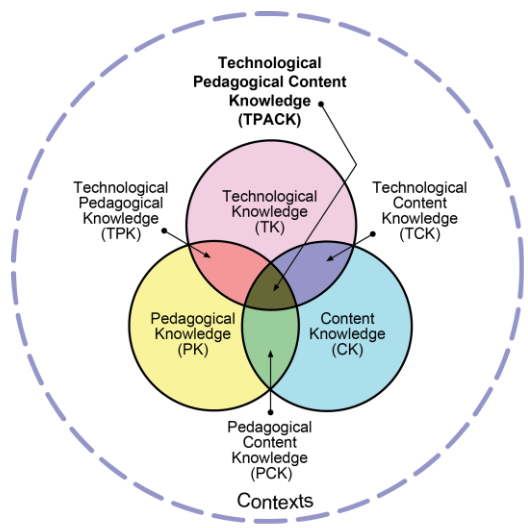


Figure 2. Technological Pedagogical Content Knowledge Framework [9].

C. 3D Literacy and AR in Life Sciences Teaching

The ability to understand three-dimensional structures is crucial in virtually all life science disciplines, from a gross anatomical level to the sub-cellular and molecular levels. One could describe this skill set as a '3D literacy' [10] that plays a pivotal role in a full appreciation of the concepts that underpin biological processes and functionality. Traditional teaching methods in the life sciences will often be didactic in practice, with possible inclusion of models to highlight structural aspects of how processes work. In anatomy and physiology disciplines, this will often take the form of physical cadaveric specimens, but where this is not possible, teaching will rely on physical models to highlight structure-function relationships in the human body. In the molecular life science disciplines, this concept of structure and function is just as valid, and as such, various physical chemical structure models will often be used to explain the processes involved at a sub-cellular level. The use of models coupled with some functionality can teach molecular concepts well, with two examples being the concept of polarity of water molecules or structure-function relationships in proteins [11][12].

More recently, it has been possible to create models using 3D printing. The advantages of this technology are that the teacher can create models of virtually any kind of structure to aid in their teaching, but it does have drawbacks as it can be time consuming and technically difficult to create certain structures (e.g., very thin or overhanging structures) due to constraints in the 3D printing process. There are a huge variety of examples that utilise 3D printing and as with traditional models used in teaching they have been used in all areas of the life sciences were structure-function relationships are important for understanding [13][14]. All of the above teaching examples have several drawbacks, be that expense, time to create models, lack of functionality or movement in the models or that these models do not allow for mass participation in larger class sizes due to the limited number of models available.

AR has the possibility of addressing some of the issues with more traditional forms of structure-function teaching. If we follow the design principles set out by Dunleavy [15] then AR has the possibility to: 1. Enable and then challenge; 2. Drive by gamified story; and 3. See the unseen. All three of these principles can be relatively easily achieved using AR. There are many areas were AR has been implemented with varying degrees of success, but it holds most promise in those subjects were an appreciation of three dimensional space and structure is crucial for a full understanding of the subject. It has therefore been most successfully employed in subjects such as anatomy were it is crucial that students understand the spatial arrangements of tissues and organs, and were cadaveric material is not always available [16]. AR has also been used in more abstract subjects such as structural biology were students will understand molecular and sub-cellular processes much better if they can appreciate how the structure of molecules often dictate their function [17].

III. IMPLEMENTATION

The implementation of the AR application presented in this research was a three-stage process, involving 1) Modelling the different 3D assets; 2) Texturing and setting up the game-engine mechanics and 3) AR implementation.

A. Modelling

Nine different 3D models were created for the application. These are presented in Table I.

TABLE I. SCENE MODELS AND THEIR ROLES.

Model	**Role**
Character	Core element, in the application produced in high detail (73k polygons), as displayed in Figure 3.
Chocolate bar	Minor model, present to demonstrate eating.
Intestines and Gut	Core component for the application. Created in detail to show overall gut/digestive system construction.
Veins/Arteries	Core component for demonstrating the biological processes taking place, but with low poly (300 polygons).
Blood Vessels	Low poly (50 polygons each), animated objects in the scene to demonstrate blood flow and scale.
Cells	The cells are prominent in the application. They are very low poly, with the details being added through the texturing.
Muscle Cells	The muscle cells, again are low poly, and are the recipients of the glucose and insulin molecules.
Glucose & Insulin Molecules	Low poly, small objects in the scene but core to demonstrating the biology.

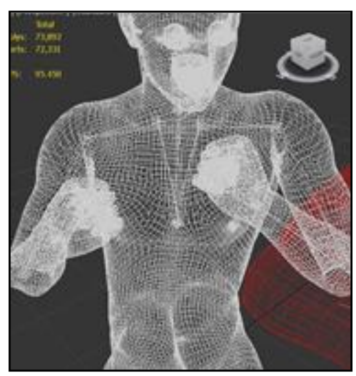


Figure 3. 3D Character Mesh.

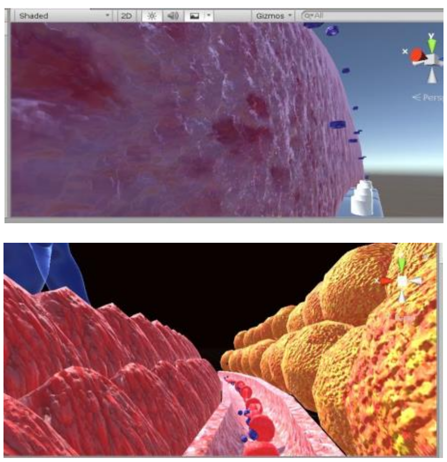
Following the modelling process, textures were added within the game-engine environment directly. By texturing within the game engine, it allowed for the inclusion of shaders on the models; resulting in a higher quality of texturing and realism.

B. Texturing and Game Engine Mechanics

The texturing process was crucial for adding detail to the 3D modelling process and creating a relatability for the students when operating the AR application. An effective texturing process also ensured that the models maintained a low poly count, as the detail was generated by the textures rather than the 3D models themselves. A low poly count is necessary to ensure that the AR application runs smoothly on hand held devices (i.e., tablets and smart phones), which have a limited processing and graphics capability in comparison with a PC/Laptop.

As Figure 4 displays, the character is semi-transparent, in order to allow the intestines and digestive system to be visible. Food is also animated travelling down the throat into the stomach, as the character bites the chocolate bar. An organic texturing was applied to the various cells and tissues as shown in Figure 5.

Figure 4. Character Texturing.



(a)

(b)

Figure 5. Organic Texturing with the Game Engine. (a) Cells, (b) Blood Vessel with Blood Cells (Centre), Muscle Cells Right) and Pancreas Cells (Left).

High-resolution texture images were used. With the model being AR, it is possible to zoom in and view the assets at close inspection. Bump map and height maps were also applied to the models so that they did not appear flat on projection. The other technical challenge involved the UVW mapping as many of the models are spherical in appearance. The final scene composition is displayed in Figure 6. The composition consists of a character, with food passing down the throat as an animation; a close up view of the digestive system enclosed in a box next to the character; and a close up view of the biological process taking place within the blood stream.

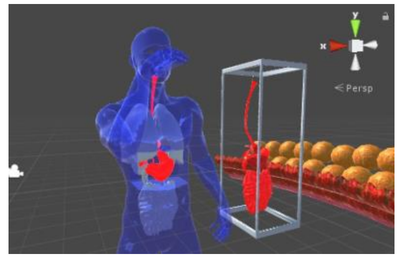
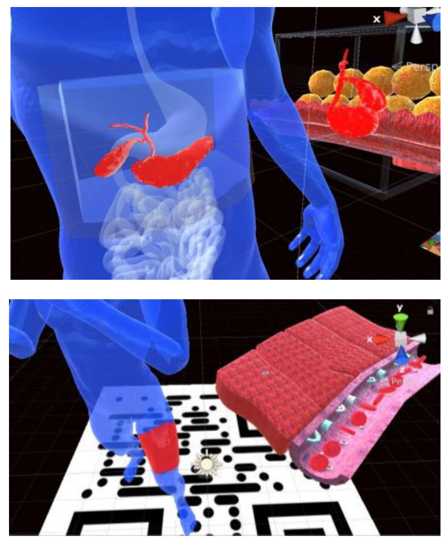


Figure 6. Final Composition.

C. *AR Setup*

The AR was set up using standard black and white QR code markers to project the models on (as shown in Figure 7b). However, under testing the models often ended up projecting with glitches or delays. The model project on QR is displayed in Figure 7.



(a)

(b)

Figure 7. Model Project in AR. (a) Up-close texturing (b) model projected on QR code in Game Engine.

Instead, advanced QR markers were used to improve the stability of the projection, as displayed in Figures 7a and 8. The app was then deployed on both Android and Windows tablets, as displayed in Figure 8.

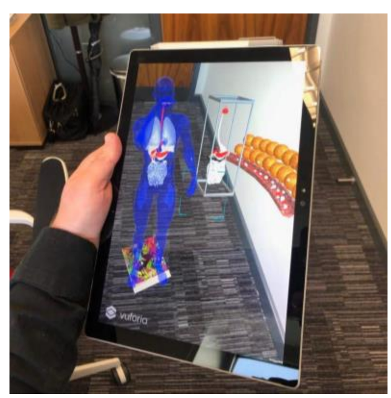


Figure 8. App Functioning on Windows Tablet.

Following the deployment of the app, it was then field-tested in a classroom environment at the University of Aberdeen.

IV. Results

Participants in the test completed an online questionnaire asking them to think about their views on gamification and the use of digital technology in their education as part of a second year undergraduate biochemistry course. 90 students (out of a class of 150) participated in the questionnaire and as a demographic, the vast majority (95%) were 19-24 years of age (i.e., an age group considered to be 'digital natives').

A. *Initial Questionnaire Findings*

When asked if they enjoy lectures, on a 5-point Likert scale, 40% enjoyed roughly half of their lectures and 49% enjoyed almost all lectures. 76% of participants agreed or strongly agreed that lecturers were good at explaining abstract concepts, suggesting that most students can understand and follow the lecture material being delivered, however only 22% strongly agreed so there is a large proportion who could have their learning enhanced at least partially. Similarly, a large proportion of the 90 participants agreed that lecturers made classes exciting and engaging with 63% agreeing or strongly agreeing to this statement, with 27% neutral showing that there is a decrease in student satisfaction compared to lecturers explaining abstract concepts well. 51% of participants agreed or strongly agreed that they make detailed lecture notes, with 25% disagreeing with this statement and 23% neutral, showing that approximately half of the students do not make detailed notes of the lecture material. 38% of participants were neutral and 19% agreed or strongly agreed that PowerPoint slides were boring, suggesting that there could be room to improve teaching provision away from standard teaching practices.

In answer to the statement that they prefer a hands-on approach to learning than being in lectures, 45% agreed or strongly agreed, 25% disagreed and 30% were neutral, showing the majority would possibly benefit from additional teaching methods. When asked the question of how lectures could be made more enjoyable, the free text responses were analysed, and the top 5 words identified in the responses were "interactive", "engaging", "examples", "videos" and "interaction". This is promising for the use of AR in the classroom as it shows that for engagement initiatives to be a success they should incorporate interactivity.

When asked if they consider themselves a "gamer", 42% and 19% strongly disagreed or disagreed respectively, and only 22% agreed or strongly agreed, which shows that any technology implemented into their learning should be adapted for the novice gamer audience and be easy to understand and interact with. Overall, 98% of participants own a smartphone (either Android or iOS), 93% have a laptop and 40% have a tablet, which means that only a very small percentage of the class do not have smartphones, so would minimise the cost if students were to use their own devices.

When asked if the use of games in class will help student learning, the majority (52%) agreed or strongly agreed that it would, and only a small fraction (15%) disagreed or strongly disagreed. This coupled with 92% agreeing or strongly agreeing that being able to "see" abstract concepts would help their learning, would strongly suggest that a highly visual and interactive AR approach would provide students with an excellent learning resource.

When asked the open-ended question of what they would like included in an educational app, the most common remarks were "keep it engaging", "abstract concepts", "3D structures" and "providing an interactive experience with more difficult theories". The results are plotted in a word cloud in Figure 9, where the larger the word, the more often is appeared in the feedback comments. Clear requirements for the application to be 'engaging' and 'interactive' are prominent in the feedback.

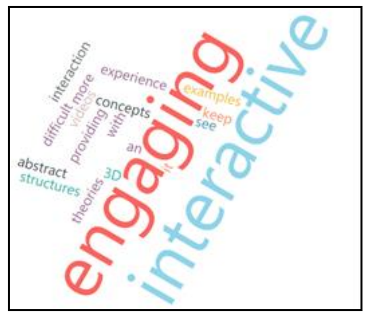


Figure 9. Pre-Survey Feedback Comments.

B. *Focus Group*

Based on the questionnaire feedback, we next organised a focus group made up of eight randomly chosen participants who indicated they wanted to take part in further discussions. The focus group was intended to gather views and opinions on the role that visualisation apps could play in teaching on the second year undergraduate biochemistry course. The following questions, which emerged from the questionnaire data, were used to encourage discussion: 1. Do you have difficulty visualising and learning abstract concepts? 2. How do you currently learn these difficult topics? 3. What would be the best use of gamification to teach lecture topics?

In summary, AR was favoured over VR and the participants would prefer any AR content to be used in a tutorial rather than lectures so that information from lectures could be consolidated rather than being taught for the first time. Several participants would also like to be able to pick up the AR app if required rather than it being a compulsory session that they must attend, which would allow them to use the additional visualisations if they required them to aid their learning. Accurate use of 3D models would be preferential over simplified models or models that do not resemble the actual structures being visualised.

C. *AR App Usage Feedback*

Following development of the AR app, it was tested with seven randomly selected participants (different individuals from those who participated in the focus group) to understand if students would prefer to use AR in their education. The AR app was developed to run alongside written materials that explained how three processes work in a specific metabolic process. 43% of participants strongly agreed and 57% agreed that the AR app motivated them to understand the processes being visualised, with nobody remaining neutral or disagreeing. 58% of participants strongly agreed or agreed that the AR app enhanced their learning and 42% where neutral. 57% strongly agreed and 43% agreed that the class was enjoyable and fun, and they rated the class overall with the same scores. When asked if they would like to see more AR in the classroom, 86% responded "absolutely" and 14% said they were not sure as it would depend on the class.

When asked which subject areas AR technology would be most useful for, the following subject areas: enzyme activity and protein structure, biochemistry, molecular biology, genetics, bioenergetics, immunology, physiology, neuroscience, enzyme activity and enzyme structure. Additionally, participants stated, "I think it's a great idea, and would definitely help information we're taught traditionally just from being able to visualise processes"; "it would be very useful to see how enzyme activity and protein conformation works"; "it's really cool and [would] be a great asset in classes and for learning concepts which are more abstract to understand.

Figure 10. Post-Survey Feedback Comments.

It also helps people to gaze into the future and feel like they are part of…learning in a new direction". Again, the feedback was plotted in a word cloud as displayed in Figure 10. Key positive words, such as 'great', 'future', 'helps' are prominent in the feedback.

V. Conclusion and Future Work

In conclusion, the application proved successful with end-users and received primarily positive feedback. The deployment of the application on Android and Windows also meant the up-take of the application had a wide reach. In the future, we will investigate the deployment of the application on an iOS device.

There were some challenges with the initial model implementation as it did not show the correct processes, but this was overcome with clear communication between the development team and the scientists on the project.

There are also alternative approaches to delivering this kind of visualisation in class using VR, which will also be explored in the future, but as already described, the use of VR would change the class dynamics as it is a highly personalised experience even though it may be more immersive.

References

[1] M. Henderson, N. Selwyn, G. Finger, and R. Aston, "Students' everyday engagement with digital technology in university: exploring patterns of use and 'usefulness,'" J. High. Educ. Policy Manag., vol. 37, no. 3, pp. 308–319, May 2015.

[2] L. C. Larson and T. N. Miller, "21st Century Skills: Prepare Students for the Future," Kappa Delta Pi Rec., vol. 47, no. 3, pp. 121–123, Apr. 2011.

[3] V. Marx, "The big challenges of big data," Nature, vol. 498, no. 7453, pp. 255–260, Jun. 2013.

[4] N. E. Seymour et al., "Virtual Reality Training Improves Operating Room Performance: Results of a Randomized, Double-Blinded Study," Ann. Surg., vol. 236, no. 4, p. 458, 2002.

[5] M.-J. Garcia-Bonete, M. Jensen, and G. Katona, "A practical guide to developing virtual and augmented reality exercises for teaching structural biology," Biochem. Mol. Biol. Educ., vol. 47, no. 1, pp. 16–24, Jan. 2019.

[6] A. Sugiura, T. Kitama, M. Toyoura, and X. Mao, "The Use of Augmented Reality Technology in Medical Specimen Museum Tours," Anat. Sci. Educ., Nov. 2018.

[7] D. Behmke et al., "Augmented Reality Chemistry: Transforming 2-D Molecular Representations into Interactive 3-D Structures," Proc. Interdiscip. STEM Teach. Learn. Conf., vol. 2, no. 1, Jan. 2018.

[8] M. J. Koehler, P. Mishra, and W. Cain, "What is Technological Pedagogical Content Knowledge (TPACK)?," J. Educ., vol. 193, no. 3, pp. 13–19, Oct. 2013.

[9] Reproduced by permission of the publisher, © 2012 by tpack.org

[10] J. R. Roberts, E. Hagedorn, P. Dillenburg, M. Patrick, and T. Herman, "Physical models enhance molecular three-dimensional literacy in an introductory biochemistry course*," Biochem. Mol. Biol. Educ., vol. 33, no. 2, pp. 105–110, Nov. 2006.

[11] T. Herman et al., "Tactile teaching: Exploring protein structure/function using physical models," Biochem. Mol. Biol. Educ., vol. 34, no. 4, pp. 247–254, Jul. 2006.

[12] J. L. H. Johnson, S. H. Yalkowsky, and Ed Vitz, "A three-dimensional model for water," J. Chem. Educ., vol. 79, no. 9, p. 1088, Sep. 2002.

[13] S. C. Meyer, "3D Printing of Protein Models in an Undergraduate Laboratory: Leucine Zippers," J. Chem. Educ., vol. 92, no. 12, pp. 2120–2125, Dec. 2015.

[14] M. Vaccarezza and V. Papa, "3D printing: a valuable resource in human anatomy education," Anat. Sci. Int., vol. 90, no. 1, pp. 64–65, Jan. 2015.

[15] M. Dunleavy, "Design Principles for Augmented Reality Learning," TechTrends, vol. 58, no. 1, pp. 28–34, Jan. 2014.

[16] R. Barmaki et al., "Enhancement of Anatomical Education Using Augmented Reality: An Empirical Study of Body Painting," Anat. Sci. Educ., Jan. 2019.

[17] P. Safadel and D. White, "Facilitating Molecular Biology Teaching by Using Augmented Reality (AR) and Protein Data Bank (PDB)," TechTrends, pp. 1–6, Oct. 2018.