Student-Centered Learning Using Augmented Reality in Anatomy and Physiology Education

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***Abstract*—This research-to-practice paper described how a student-centered learning pedagogy and AR techniques are used to enhance Anatomy and Physiology undergraduate education. Throughout the evolution of biomedical and engineering education, teachers and students have experimented with various forms of learning platforms and techniques in hopes of enhancing the learning experience. However, these efforts have not always been interactive, leading to student burnout, disengagement, decreased knowledge retention, and lower grades. To tackle this issue, We propose a method to improve both Anatomy and Physiology education. Students can learn biomedical science as well as other engineering educational topics with a more interactive experience using our proposed method via AR device, i.e., HoloLens 2. This project used an exploratory method, which involves conducting user studies using HoloLens 2 as a medium to teach students course-related topics. This method is based on a Student-Centered Learning pedagogy and allows students to walk through course materials with different paths and paces based on the students' preferences, allowing us to investigate the relationship between information retention and the AR platform. Said user studies are conducted to collect qualitative data about students' learning outcomes and their opinions on our proposed method. Through user studies, we recruited 30 students to take part in the lesson plans created and curated by professors in the associated university. Students are given quizzes before taking part to test knowledge of the subjects that they have not been introduced to before and then are allowed to tackle modules at their own pace. They are then given the option to attempt modules at their discretion. This is due to the lesson plan being designed as a tree structure, with multiple pathways that can be navigated either upward or downwards depending on whether they have completed the prerequisite module. After studying the lessons provided, they are given a quiz in a virtual environment to test the knowledge that they have gained while using the device. When calculating the averages of both assessments, students on average had an improvement of 10 percent in scores after using our proposed method compared to the quiz scores collected before using the device. They were also given a survey on their thoughts concerning using the HoloLens 2 device after finishing the study where 96 percent of students believe that the tools and techniques from augmented reality are both exciting and would find it useful in the study of other disciplines. 90 percent of students also found that both listening and conversational skills are frequently utilized while using Augmented Reality.**

***Index Terms*—Biomedical, Engineering, Undergraduate Course Development**

I. Introduction

Biomedical education has, over many years, been on a journey of various pedagogical innovations and enhancement [1]. Instructors and students have navigated through instructional strategies, methodologies, and technologies to improve the learning experience for biomedical students. Through this journey, students have seen many types of instructional material from traditional lectures to modern digital learning environments. Each method is aimed at improving the understanding, critical thinking, and competency of biomedical students.

However, while these innovations have taken place, there are still challenges that are apparent between interactivity in the classroom and the learning process [2]. Despite the number of tools and resources instructors and teachers have access to, there is still a divide between engagement and the learning experience. This divide threatens student participation and academic success.

When the educational experience lacks interactivity, students may experience burnout due to the passive nature of instruction [2]. The lack of opportunities for active participation and engagement can lead to disinterest from the student [3]. In addition, the passive learning approach often results in superficial understanding and limited knowledge retention of the material, which in turn, hinders the students' ability to apply concepts from the classroom into real-world practice [4].

To address the lack of interactivity, we propose a method designed to splinter away from conventional instructional methods. Our approach embraces the integration of the engineering curriculum with traditional education subjects, encouraging a comprehensive educational experience. Central to our methodology is the utilization of augmented reality (AR) technology [5], specifically using the capabilities of the HoloLens 2 device [6]. By using this technology, we aim to cultivate an interactive learning environment that surpasses the limitations of traditional pedagogical approaches [7].

Our proposed method is designed to be an alternative to the conventional instructional methods. Our method involves the integration of engineering techniques with traditional biomedical education subjects, to create a comprehensive learning experience. Crucial to our methodology is the utilization of augmented reality (AR) technology, by using the HoloLens 2 device. With this technology, we aim to create an interactive learning environment that improves upon the traditional pedagogical approach and its limitations [8]. Besides this, we also apply a personalized learning pedagogy that prioritizes students' needs and contrasting learning styles, enhancing student autonomy [4].

To test our method, we conducted quantitative and qualitative user studies with over 30 undergraduate anatomy and physiology students. During each user study we would collect scores based on pre-assessments and post-assessments where students would use our HoloTeach application to learn material that they had no prior experience and measure the changes from before and after. After the assessments, students are then given qualitative surveys where they can give their opinion on the device and the learning experience. From these surveys, the students overall gave positive feedback.

The contributions of this project include the integration of personalized learning pedagogy with biomedical education, AR app development, and user study results. This approach aims to not only enhance the educational experience, but also provide insight into the practical applications and effectiveness of AR in biomedical training.

The remaining sections of this paper review related work on augmented reality and student-centered pedagogy, present our proposed method using student-centered pedagogy and the augmented reality application, present the results of our assessments during the user studies and the given feedback by students after taking part, and a summarization of our work.

II. Related Work

A. Student-Centered Learning

One potential avenue for educating students involves exploring educational computer games as a platform. This would give the change of passive learning to active, allowing students to have a more hands-on experience. Through this study [4], undergraduate students were separated randomly into groups to participate in one of the student-centered learning methods, game-based versus traditional lecture. They were tested in three scenarios, prior knowledge which was done before the method was applied, short-term knowledge, and finally long-term knowledge. The results of the learning methods had seen that the gaming-based method performed better in the post assessment while the lecture-based method performed as well as gaming in long-term knowledge. Comparing this method of educating, our students are given the ability to learn any subject at their own speed, separate from other students. This allows for less stress for the student, giving them the ability to spend more time on tougher students while reinforcing the subjects they already know. The use of AR compared to a computer game-based learning method allows for an even more interactive experience for students to test their abilities with 3D objects in a virtual environment [9]. As well as giving a more interactive experience, the augmented reality platform allows students to be introduced into a student-centered pedagogy, where while they work in a classroom or lab, they learn about anatomy and physiology on their own but asking questions to a teacher or teacher's assistant if having any trouble.

While creating a student-centered pedagogy using AR, multiple applications have been made to see what would work best in a classroom. One study uses an application called VesARlius when teaching students [10], allowing them to look at a 3D view of thorax, abdomen, and pelvis. The study would take 16 first-year medical students and split them into a control group that used traditional learning methods, which were notes and lectures, versus the AR application listed above. There would be 15-minute breaks for each group where they would have group assignments as well as having group learning session where each group is given learning objectives to learn in said session. To test the results both a pre-test and post-test were given to each group to compare the improvements of both methods. The quantitative outcome of the study showed small differences in the test results with the students using AR application doing slightly better than the control group who used traditional learning. The qualitative outcome was much different, where students were more optimistic when it came to AR and its uses compared to traditional learning. Both their study and mine are aimed at having a student-centered pedagogy. The major difference is the ability for a student to be completely independent in their introduction and study of materials, there is at no point where both teachers and teacher assistants give objectives on what to learn while in the classroom other than a topic tree. This means that multiple branching paths are available to students to learn topics based on what they have decided to learn. All the materials are given to the student, and they can decide what they would like to learn first. They are also not set by any time-limit as they are in the study above, allowing them to interact and learn at their own pace. Finally, while most of their quizzes are still given on paper, students are allowed to test their own abilities through the application whenever they feel like they are comfortable with the material.

In both studies referenced above, the learning experience has increased, even subtly, increasing in post-assessment test scores as well as qualitative responses from surveys conducted being more positive compared to traditional learning. These studies as well as other works believe that increasing students' autonomy can enhance their motivation and engagement [11]. Giving the students the resources to learn topics pertaining to anatomy and physiology while allowing them to learn said and foster the retainment of new subject matter. Our study, unlike the ones above, uses a topic, or dependency, tree that students would follow while choosing topics, which branches that students choose to follow are entirely up to the said student's preference and background. We create an atmosphere that is hands-off, allowing students the reins to learn at their own pace while only interacting with teachers or teaching assistants to ask questions that they may still have about the subject matter that they have learned on their own time.

B. *Augmented Reality*

The use of augmented reality in medical education is rapidly evolving, where most anatomical education has relied on cadavers, lectures, and books, augmented reality allows access to these tools in a virtual format, which can be both cheap and allow personal experimentation and learning on person-to-person learning speeds. Medical students also prefer the AR devices due to it's ability to be used hands-free, where some exercises require them to use their hands while they can use the device as a visual "helper," and with the funding of medical schools, they are able to afford the state-of-the-art devices for their education. The experiment in the paper uses a similar form of 3D models of human organ to help students interact with and investigate the complicated structures that a book or lecture doesn't allow [12]. The point of the social experiences that AR allows is expanded upon, where it is possible to create an environment that supports the social situations in an environment that is looked over by a teacher or teaching assistant. Some of these environments that are created in our application and can be used in others can even include forms of multiplayer, where multiple students can work together through complex situations that demand more than one person in a work environment [5]. But due to the lack of training that focuses on social skills in a classroom, there is not much literature or statistics that can evaluate this form of interpersonal interactions between students. This can be measured through using applications such as mine, where we have created modules and quizzes that are easily modified to fit any situation and learning material needed. When doing case studies, students are given the freedom to investigate any topic they want to learn as well as communicate with other students, allowing for questions and cooperation that is not seen during lectures.

Another study would use a mobile AR application to learn about the heart's anatomy [13]. The study would take 60 students and divide them into two groups, a control group one that would learn using online lectures and handout notes and an experimental group that would use the AR application. Before the study, each group was given a pre-test of 21 items and 12 open-ended questions to assess what they knew before studying. After, each group were given a post-test with the same questions but in a different order. The outcome of the study suggests that students who utilized the AR application demonstrated higher performance and satisfaction. In contrast, those who relied on traditional notes and lectures showed comparatively lower levels of both. Comparing this application with mine, they use both 3D objects as well as 2D explanations, but the introduction of material is on different platforms. Our application is through a school-supplied HoloLens 2 rather than a smart phone device, allowing access to students who might not have access to the same technologies as other students in the classroom. Our application would also give multiple modules on different anatomy systems rather than the heart which the studies mobile AR application HeARt is based on. This allows for students to decide what part of the human anatomy they would like to learn rather than restricting them to one organ. Our application also gives access to quizzes to test their knowledge after each module and case study has been read, giving students the ability to test their knowledge at any time.

According to our literature review, AR technology is very promising to improve the learning experience for anatomy and physiology. This is proven by the related work presented where in both instances, the post assessment test scores of the AR groups were higher compared to the control groups that used lectures and handout notes. The satisfaction levels of those who used the AR applications were also higher than those that used the traditional method. The application allowed for multiple avenues when it came to student interaction, even including forms of multiplayer that allowed students to work together in different environments to bolster the social skills of students.

III. Proposed Method

A. *Student-Centered Personalized Learning Pedagogy*

A student-centered personalized learning pedagogy is proposed in the paper [7] and is employed to enhance medical education in this project. The reasoning behind using this pedagogy as the basis for our research is that it has been proposed in other classes with previous research and has worked [14]. This pedagogy emphasizes active involvement in each individual's learning process, prioritizing their needs, learning styles, and interests to foster an interactive learning environment. These aspects are particularly crucial in biomedical education, aligning with its philosophy [1]. By centering instruction around the student rather than the instructor, the pedagogy cultivates skills in critical thinking, problem-solving, and autonomous learning. Overall, this student-centered personalized learning pedagogy aligns well with biomedical education, addressing the evolving needs and challenges of modern professions and equipping future professionals with the necessary skills for success in their careers.

By conducting user studies, we study how students can learn Anatomy and Physiology using the student-centered personalized learning pedagogy [7]. By using the idea of a topic tree, shown in figure 1, we can build a plan that allows students to choose their own unique learning path based on dependencies created by domain experts. This also allows students to learn at their own pace, where the interaction with either teachers or teaching assistants is for clarifications for questions that they may have.

As shown in figure 1, a student would start with the introductory module or topic shown as color blue where

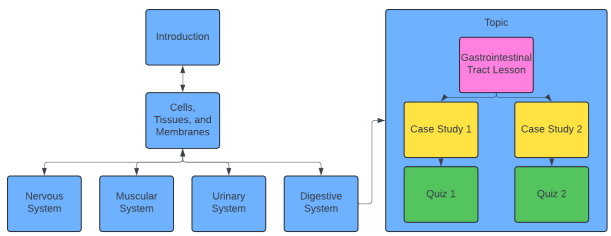

Fig. 1. An example topic tree used for the Anatomy and Physiology course. The topics, or modules, are colored blue, the lessons are colored pink, the case studies are colored yellow, and the quizzes are colored green. Created using Lucidchart [15].

they would learn about start material and/or notes. This will then lead to a branching module, i.e., Cells, Tissues, and membranes, which can then lead into Digestive System which students will be introduced to lessons about the gastrointestinal tract. When finished with a lesson, shown as color pink in figure 1, the students will read over two case studies, as shown as color yellow, to get a real-world scenario that pertains to the lesson. After completing both case studies, students may then take quizzes, as shown as color green, associated with the lesson to test their knowledge, once passed they may go onto any module that the previous topic was a dependency for. While going down the tree, a student may choose diverging branches to follow which is possible if the previous module is completed. This also gives the option to go back to a previous branch to complete modules that they have skipped. The way the application is formatted allows for it to be used across other courses, it is not hard coded for an anatomy and physiology course.

The course content used in the study includes information for the gastrointestinal tract and the microscopic anatomy of the kidney. The lesson of the gastrointestinal tract includes information about the esophagus, gastroesophageal junction, stomach, duodenum, and colon. It also includes two case studies with real-life applications to help understand the system more and ends with two quizzes about each case study. The microscopic anatomy of the kidney lesson includes collecting ducts, distal convoluted tubule, loop of Henle, proximal convoluted tubules, and the renal corpuscle. As well as the previous lesson, this one includes both two case studies and quizzes associated with each study to test the knowledge learned from the lessons.

The format of the topic trees enables flexibility, allowing adjustments when needed. It offers the opportunity for applying this method across other forms of biomedical and engineering education. It enables educators to refine the content to suit the changing needs of the class and individual student's learning styles and is a way to foster the continuous development to said pedagogies.

B. AR Application

While we have had previous research done with the student-centered personalized learning pedagogy, we wanted to build of that with the use of augmented reality, so we have created a Unity-based [16] AR application has been developed and implemented according to the topic dependency tree depicted in figure 1. The application created involves a network of QR codes and menus that map to the lessons of the module, as shown in figure 2. Due to how the mapping works, each QR code can be remapped to different lessons at any time, allowing for easy module creation and changes, while the menus navigate to different lists containing numbered case studies and quizzes for students to assess their knowledge retention.

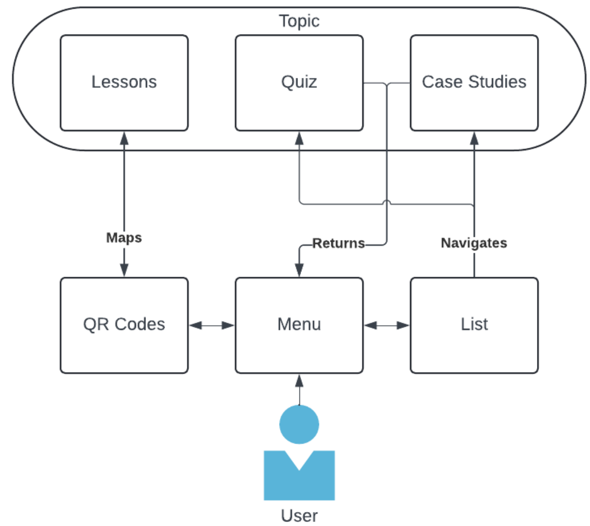

Fig. 2. Flowchart that shows how the user interacts with the lessons, case studies, and quizzes through the use of Menus, QR codes and lists. Created using Lucidchart [15].

The application consists of visuals including pictures and panels that hold information that students can access through menus and lists. These menus allow for an easy case studies and quizzes approach and the ability to start the lesson through real-world QR codes. The QR or quick response codes are images that can be scanned by the HoloLens 2 hardware to gain access to virtual buttons that will lead students through lessons of the overall module. HoloLens 2 is an AR device manufactured by Microsoft that also allows for image recognition, which is used by our application for the QR codes.

Some key components that differ from other AR applications include the use of QR codes, as said above. Through Vuforia [18], a software development kit used for augmented reality, we can load QR codes specific for each lesson. The use of real-life QR codes attached to body models in classrooms and labs allows students to have real-life visuals and microscopic images loaded into the application without carrying around textbooks. Our application also allows for built-in quizzes where scores are uploaded into a database after completion, this allows teachers to check on student's progress after each module's completion by connecting to the physical HoloLens 2 machine.

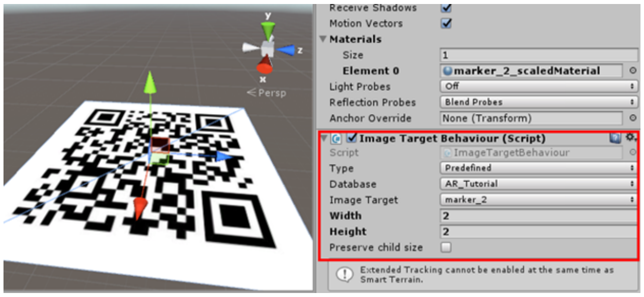

Fig. 3. Example of the functionality of Vuforia Engine in Unity, from The Knights of Unity [17].

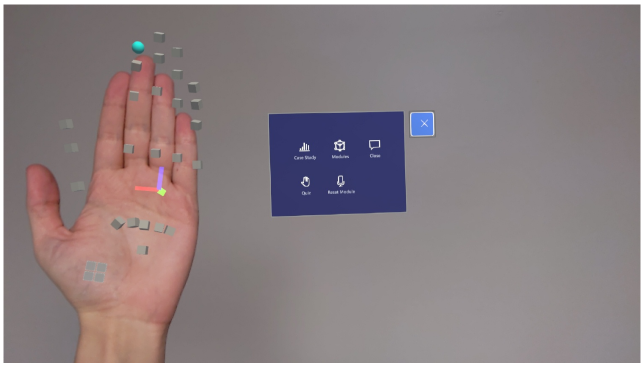

Fig. 4. Main menu panel scene when opening the application, tracked to the user's left hand.

The application's main menu is located to the right of the user's left hand. When the hand is lifted in front of the HoloLens 2 screen, the user will see five buttons in which they may press to continue onto the rest of the application, as shown in figure 4.

From left to right, the button labeled "Case Study" leads the user to a menu listing all case studies loaded onto the program. From there, the student may choose which case study they would like to look over before continuing onto the quizzes.

The next button labeled "Modules" allows for the QR codes to be scanned by the HoloLens 2 device. When scanned, the student may press on any code to be taken into a lesson. The third button on the top row labeled "Close" closes all panels that the student may have opened when navigating the menus. The left-most button on the second row labelled "Quiz" leads to another menu with the list of quizzes corresponding to the case studies in the previous menu list.

Finally, the last button on the second row is the "Reset Module" button, which is used to reset the location of all lesson panels to their original location if moved by the student. This is made for easy access if the student is finding it hard to locate where they last held the lesson panels.

The lessons in the application are accessed through the QR codes loaded through Vuforia development kit. When the codes are scanned and opened, the students will see a panel with the title of the system at the top and the lesson following. To the right of the main panel there are three buttons, one to "Close" the panel, one to "Read" the lesson, and an "Images" button to open pictures that correspond to the lesson the student is reading. When the "Images" button is pressed, another panel opens to the left of the main panel showing a close-up of the system being described, as shown below.

Each lesson is formatted in a way that allows students to read in short bursts. Allowing them time between each lesson to study both the topic and a visual of what they're reading. This contrasts with traditional lecture learning, where a student must learn at the same speed as fellow classmates who may be either slower or faster than them, giving said student more autonomy in their learning experience.

The case studies are aimed to give students a real-life situation in which they may experience the topics covered in each lesson. Each case study is laid out on a panel for the student to read at their own pace. Due to case studies being much longer than a single lesson, it has been given the functionality of eye-scrolling, where the application scans the user's eyes and see where they are while reading the case study. This gives students more accessibility when reading, not needing to use their hands to scroll through the document.

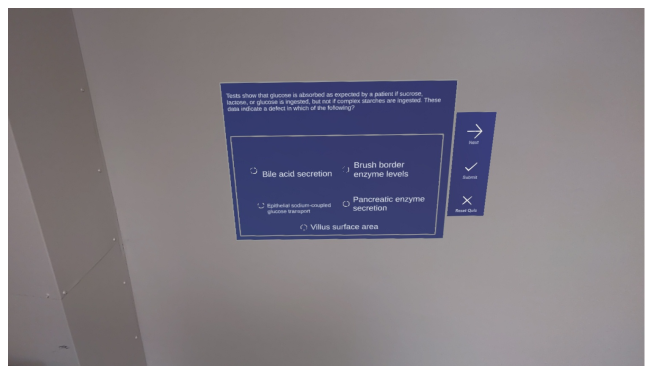

Fig. 5. Panel that contains an example quiz with it's five answer choices. The user may reset the quiz at any time.

Finally, there are the quizzes, or assessments, that students may access to test their knowledge after reading through the lessons and case studies, as shown in figure 5. When opened, they are given a panel that has a question, at least five answer choices, and three buttons that they may choose from to answer the question, go to the next question, or close and reset the quiz.

Once each quiz is finished, the score is then saved to a CSV file on the headset. For anonymity during the user study, names were not saved, but when introduced into the classroom, the quiz name, scores, name of student, and date the quiz was taken will be stored. This is then accessed by the instructor of the course to assess what the student understands and what needs to be changed in the module for them to get a better understanding.

If the student does well on the assessments for a module, they are then able to travel down the topic tree to the next module that was dependant on what they just learned.

IV. Experiment Results and Discussion

Through this research we would like to find if introducing a previously successful student-centered learning method, but with the use of augmented reality, in a classroom will increase interactivity and knowledge retention, while lowering disengagement.

A. *Experimental Design*

The experimental setup used in this study aimed to investigate the effect of applying a student-centered pedagogical approach to learning through augmented reality. To evaluate this approach, we recruited 30 biomedical students to take part in user study where we created a module, with the help of the instructor of the course, for them to read through and then assess the knowledge they gained in a quiz format. The information in the module was curated by a professor in the associated university to make sure that students at the undergraduate level had not seen in lectures at their level of education. Before using the application, students would be given a pre-assessment to test the knowledge on the subject they already have. Students were then given the HoloLens 2 headset to take part in the module, in which they were given as much time as they wanted to read through the lessons and case studies. When a student is looking over the module, they are given a post-assessment to calculate the gain and retainment of knowledge. Once the post-assessment is finished, they are asked to take part in a survey to give feedback on augmented reality and its prospects in the classroom.

The student recruitment yielded a diverse group in various demographic aspects, all being recruited from anatomy and physiology courses and without prior knowledge of the material. Gender distribution consisted of 22 female and 8 male students. Regarding academic levels, there were two first-years, 11 second-years, 11 third-years, three fourth-years, and three fifth-years. In terms of grades, seven students predominantly achieved A's, 19 attained mostly A's and B's, while four maintained mostly B's and C's. Racial diversity encompassed 19 White students, three Asians, three Black/African Americans, two Hispanic/Latinos/Latinas, two Biracial/Multiracial individuals, and one from another racial background. First-generation representation included seven students, while 23 were not first-generation. Parental educational backgrounds varied, with 23 students having a parent holding a four-year or advanced degree, one with a parent possessing a two-year degree, two with some college experience, three with parents who are high school graduates, and one with a parent having less than a high school degree.

The majority of volunteers self-identified as female. Most who took part were in their second or third year of college and had mostly A's and B's in their course. Of these 30 students, a majority self-identified as white. A majority of students are not first-generation and a majority of their parent or guardian has at least a four-year or advanced degree.

To collect pre-assessment data, we used Qualtrics [19] to distribute the quiz. The same site was used for survey feedback. For the post-assessment, the application creates and stores the scores into a CSV file to later be extracted.

B. *Results*

Comparing the pre-assessment scores, with post-assessment, there has been a 10 percent increase in knowledge retainment after using the the augmented reality device and application.

When conducting a paired T-test on the data, due to the anonymity, we paired scores based on the time taken when receiving the results of both the pre-assessment and post-assessment. The P-value reported at this time is .187 and due to $P > .05$, it shows the results are insignificant but approaching near marginal significance. In other words, students' learning outcomes are not significantly increased. In the future, we would like to improve the graphical user interface design of our application and enhance the course content to improve learning outcomes further.

The feedback survey was split into nine sections including:

- Interest in augmented reality (AR)
- Perceived usefulness of augmented reality
- Professional perceptions of augmented reality
- General evaluation
- Demo materials
- Self Determination Theory (SDT) course evaluations
- What specific things about the demo that helped you support your learning?
- What changes would you suggest improving the AR demo for future students?
- We would like to learn more about your experience using augmented reality. Please share some feedback about the application, particularly things that you liked and things that you would like to see improved.

The feedback scores were based on a scale from disagree to agree. They are also able to skip sections if they don't feel comfortable answering.

C. *Discussion*

Based on the feedback from the students, using augmented reality in a student-centered pedagogical environment worked well.

Student's interest in augmented reality varied where over 90 percent of students agreed that augmented reality is exciting, and 75 percent either hope to see it in the future or are neutral to using it. 75 percent of students would voluntarily take a course if it involved using augmented reality with over the same amount believing they can usually figure out the new technology. 85 percent of students find the challenge of augmented reality motivating. This is a counter to 53 percent of students finding textbooks and slides as a better choice compared to augmented reality.

With the perceived usefulness of augmented reality, over 90 percent of students perceive the usefulness of augmented reality in other disciplines and a majority finding that it relates to what they experience in the real world. While the opinion was split on the belief that augmented reality will help them earn a living, over 85 percent of them believe it is important for

TABLE I
SURVEY RESULTS ON AUGMENTED REALITY (AR)

Item		Disagree		Slightly Disagree		Neutral		Slightly Agree	Agree		N
I think augmented reality is exciting.	0.00%	0	0.00%	0	3.45%	1	24.14%	7	72.41%	21	29
I hope that my future career will require the use of augmented reality technology.	3.45%	1	20.69%	6	37.93%	11	17.24%	5	20.69%	6	29
I would voluntarily take an additional course if augmented reality was included given the opportunity.	6.90%	2	10.34%	3	3.45%	1	51.72%	15	27.59%	8	29
I can usually figure out my way around new technologies.	3.57%	1	17.86%	5	25.00%	7	35.71%	10	17.86%	5	28
I find the challenge of using augmented reality to learn about school subjects motivating.	0.00%	0	24.14%	7	20.69%	6	27.59%	8	27.59%	8	29
I would rather learn from textbooks and lectures instead of using augmented reality to learn the same topics.	3.57%	1	14.29%	4	28.57%	8	39.29%	11	14.29%	4	28
Tools and techniques from augmented reality can be useful in the study of other disciplines (e.g. biology, art, business).	0.00%	0	0.00%	0	3.45%	1	31.03%	9	65.52%	19	29
The subject of augmented reality relates to what I experience in the real world.	0.00%	0	13.79%	4	20.69%	6	34.48%	10	31.03%	9	29
Doing augmented reality simulations will help me earn a living.	6.90%	2	13.79%	4	41.38%	12	24.14%	7	13.79%	4	29
Augmented reality is a worthwhile and important technology for the future of learning.	3.45%	1	0.00%	0	6.90%	2	37.93%	11	51.72%	15	29
Taking a course that includes access to augmented reality is a good use of my time.	6.90%	2	3.45%	1	20.69%	6	27.59%	8	41.38%	12	29
In terms of my adult life, it is important for me to get access to augmented reality technologies in college.	3.45%	1	3.45%	1	20.69%	6	51.72%	15	20.69%	6	29
Like artists and musicians, professionals using AR are very creative in their work.	0.00%	0	6.90%	2	3.45%	1	34.48%	10	55.17%	16	29
A professional using AR must be able to talk with many different people.	0.00%	0	0.00%	0	13.79%	4	31.03%	9	55.17%	16	29
Those who work with AR must frequently use their listening skills.	0.00%	0	0.00%	0	10.34%	3	31.03%	9	58.62%	17	29
To work with AR, one needs good writing skills.	3.45%	1	20.69%	6	27.59%	8	24.14%	7	24.14%	7	29
I would recommend this technology to other students.	0.00%	0	3.57%	1	3.57%	1	46.43%	13	46.43%	13	28
I would recommend these modules to other students.	0.00%	0	3.70%	1	11.11%	3	40.74%	11	44.44%	12	27
How well do you expect to do on the quizzes?	25.00%	7	14.29%	4	25.00%	7	21.43%	6	14.29%	4	28
The demo was organized in a manner that helped me understand underlying concepts.	0.00%	0	7.41%	2	3.70%	1	37.04%	10	51.85%	14	27
The modules, case studies and quizzes complemented each other.	0.00%	0	0.00%	0	3.70%	1	33.33%	9	62.96%	17	27
The instructional materials (i.e., modules, case studies and quizzes, software) increased my knowledge and skills in the subject matter.	7.14%	2	10.71%	3	7.14%	2	32.14%	9	42.86%	12	28
I had a choice in the activities and assignments that I undertook in this demo.	7.14%	2	7.14%	2	7.14%	2	25.00%	7	53.57%	15	28
I was in control of my own learning in this demo.	0.00%	0	0.00%	0	7.14%	2	21.43%	6	71.43%	20	28
I got to learn about things that were of personal interest to me in this demo.	0.00%	0	7.14%	2	17.86%	5	28.57%	8	46.43%	13	28
The topics covered in this demo are interesting and relevant to my life.	3.57%	1	3.57%	1	7.14%	2	32.14%	9	53.57%	15	28
I successfully completed difficult tasks during this demo.	0.00%	0	3.57%	1	14.29%	4	25.00%	7	57.14%	16	28
I took on and mastered hard challenges in this demo.	3.57%	1	10.71%	3	3.57%	1	39.29%	11	42.86%	12	28
I did well, even on challenging quiz questions in this demo.	17.86%	5	14.29%	4	17.86%	5	25.00%	7	25.00%	7	28
I am making progress toward my goals by participating in this demo.	3.57%	1	10.71%	3	17.86%	5	39.29%	11	28.57%	8	28
I felt connected to other students during this demo.	7.14%	2	10.71%	3	14.29%	4	14.29%	4	53.57%	15	28

the future of learning. Finally, over 75 percent of the students believe the access to these technologies in the classroom is a good use of their time.

The perceptions of augmented reality in a professional setting was also positive where a majority of the users see the creativity in AR. That those who use it must communicate with many people and have good listening skills. The belief in good writing skills for AR is varied.

The general evaluation of the user study included their belief on how they did as well as if they would recommend it to fellow students. In the case of the technology and modules, over 85 percent students would recommend it, but their belief in how well they would do on the quizzes varied, where 35 percent of students believe they would do well while 39 percent had the opposite opinion.

The opinion on the demo also had positive feedback. 88 percent of students believed the organization of the demo helped them understand the concepts presented and that the case studies, quizzes, and the module lesson complemented each other. 75 percent of the student believed that material increased their knowledge and skills in the subject.

The next section of questions involved the Self Determination Theory (SDT) [20]. These questions dealt with student autonomy and how the personalized learning approach helped them retain the knowledge during the user study. In the case of control, over 90 percent of the volunteers agreed that they had the autonomy to choose how they learned and 75 percent got to learn what they were personally interested in. Over 80 percent of the students mastered hard challenges during the demo and a majority agreed that they made progress towards their goals by participating.

To get an idea on the positives and negatives of this proposed method that weren't answered in the survey we provided, there were three sections at the end for students to bring up their thoughts as open-ended questions.

Some of the specific things about the demo that helped support their learning included the interaction of the application, the new atmosphere, the in-depth information about the subject, and definition of the terms. These qualities help give us an insight into the strengths of the application and demo.

Improvements that the students have made to improve the AR demo include changes to the interface, the formatting of the case studies, and sensitivity of the menus and their corresponding buttons. Outside the application, some worries had to do with accessibility for color blind students and providing an option for left-handed students. With these suggestions, we have made plans for changes that can be implemented in the future.

V. Conclusion and Future Work

A. Conclusion

In conclusion, our research highlights the unceasing evolution of biomedical and engineering education through the pursuit of pedagogical enhancements. Despite the number of innovations in instructional technologies, challenges continue to affect the gap between classroom interactivity and the learning process. This gap threatens engagement and leads to student burnout, hindering knowledge retention.

Recognizing these challenges, we propose a unique approach compared to traditional instructional methods. Aiming to integrate computer science principles into traditional education subjects, encouraging a personalized learning experience. Our approach adopts the capabilities of augmented reality (AR) technology, specifically the HoloLens 2 device, to cultivate a more interactive learning environment that traditional pedagogical approaches lack.

Finally, our approach emphasizes a personalized learning pedagogy that caters to individual student needs and diverse learning styles in hope to enhance student autonomy and engagement. To validate our method, we conducted user studies on undergraduate anatomy and physiology students, conducting both quantitative assessments and qualitative feedback. These studies have yielded favorable results, with students giving positive feedback of the device and having an increase in average scores after interacting with the modules given.

B. Limitations

Some limitations we ran into while completing this study was the sample size of student volunteers. There was an aim for more students to take part but due to time-restraints, we were only allowed half a year to conduct the user studies as well as only half an hour given per each user study. Another limitation was the access to educational documents to implement into the application. With help from multiple educators, we were able to collect enough resources for the experiment, but was not able to obtain more then two modules.

Difficulties in data collection involved missing data. We allowed students to not answer certain question in the feedback survey which resulted in most questions getting a few less responses then what was desired. We also aimed at anonymity so while the assessment scores have a time unique to each, we aren't able to correspond a specific pre-assessment score to a post-assessment score.

C. Future Work

Moving forward, our aspirations in this research involve furthering the development of the augmented reality application and how it interacts in a student-centered environment. The aim is to make these advancements accessible to a wide range of industries and educational settings, including software engineering classrooms. Additionally, our hope is to expand the application's functionality by creating additional computer graphic models that will bring a heightened level of interactivity to student learning experiences. These models will be designed to facilitate multiplayer functionality so that students can collaborate regardless of their physical location. We are also going to continue the study to see the long-term impact of the student's ability to retain the material using the device and while this is a tech-driven paper and it can possibly have high failure rate, we would like to study factors that can impact this high failure rate. It is also a hope to get external funding from both NSF IUSE and NSF REU to help us keep up with the emerging AR technologies, so we keep our software up to date with the current platforms.

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