Wireless Communications Engineering Education via Augmented Reality

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***Abstract*—The widespread adoption of wireless devices in all aspects of the public's daily lives and the growing demand for professionals in the wireless communications field demonstrate the need for in-depth wireless engineering education. This increased demand triggered many academic institutions to start offering courses and programs in this area. As a part of our previous work, we provided a platform for students to keep up with the improvements in the wireless communications field and gain hands-on experience using Software Defined Radios (SDR). However, existing coursework and curricula in wireless networking is challenged by the fact that it is difficult to intuitively visualize how the nodes in the network are operating in a way that is linked to the everyday world. In this paper, we introduce visualizations of wireless lab exercises using an Augmented Reality (AR) mobile app. The AR app is designed and built for a wide selection of wireless communications courses, where we are able to visualize links between wireless nodes, antenna radiation patterns, and data throughput. In this paper, we experimentally assess and present the benefits of introducing AR-based visualization tools into wireless communications courses at both the undergraduate and graduate level in terms of student interest and change in skill level.**

Keywords*—*engineering education; augmented reality; wireless communications education

I. Introduction

The convenience offered by online applications greatly improves the daily lives of the general public. More and more people are chosing to conduct their daily transactions on the Internet rather than face-to-face visits. Google reports about 3.5 billion online searches are performed every day on average [1]. The wide adoption of smart wireless devices is one of the biggest contributors in this exponentially increasing number. The popularity of wireless networks and the need for wireless infrastructure and protocol improvements to support the increasing user demand, presents opportunities for new models for wireless engineering education.

In addition to game-based learning techniques, other options have also gained attention in recent years. The use of flipped classrooms offers a new approach to the way student learning and assessment is conducted, where students are given *take home* lectures and are asked to complete their assignments in class with the presence of an instructor [2], [3]. More and more educators choose student-centric learning techniques rather than teacher-centric teaching [4], [5]. Our previous work in this area also shows increased student learning gains when educators follow a student-centric approach, especially in a course related to technology [6].

In the past, we developed wireless communications courses, which leverage current research not found in textbooks to enhance topics covered and to provide up-to-date learning experiences for students [7]. Students enrolled in our course did appreciate such teaching style. In this paper, we further identify a way of improving wireless communications and engineering courses by means of an augmented reality (AR) mobile application (app), where a student or an educator can use the camera on their smartphone to visualize concepts covered in the course [8]. AR apps have been gaining popularity in the past decade with their use in classroom. There have been AR implementations for visual arts [9], math and geometry [10], and chemistry [11] courses.

Although there is a wide range of opportunities, wireless communications education have mainly relied on virtual reality (VR) tools to enhance the course experience for students [12]. There have been AR tools developed for wireless communication research such as monitoring wireless sensor networks [13], [14], 3D visualization of wireless networks [15], and Internet-of-Things [16]. However, there has been a lack of an AR tool for wireless communications education that can interact with the experiment and/or item being observed, hence opening doors for a student-centric hands-on experience.

In this paper, we discuss our novel augmented reality visualization tool that brings many of the benefits from student-centric, visual, game-based learning tools together and encourages student-based learning in wireless communications courses. We also present our study where effectiveness in increasing undergraduate and graduate student learning and interest in the field of wireless communications education is measured. We structure our paper as follows: In the next section, we introduce our AR tool, go into details of its design, and also discuss some of the challenges in wireless communications. Section III then offers a visualization solution using our AR app as a case study. Section IV introduces the survey we developed to measure the effectiveness of our AR tool in wireless communications courses. We then discuss our study, results, and future work in Sections V, VI, and VII respectively and finally conclude this paper in Section VIII.

II. Augmented Reality Visualization Tool

A. Wireless Communications Education Challenges

A significant barrier to the comprehension of wireless communications education lies in the fact that radio frequency (RF) electromagnetic signals are invisible and therefore hard to visualize. Although wireless equipment exists that can provide

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students with hands-on experience, it might not be readily available due to its cost or it might require a complicated setup, which might deter students from such courses and/or fields. While the novelty of our wireless communication education enhancements can be described in words, it can be unintuitive to the student audience who lacks extensive RF training. We integrate an AR application framework into our software-defined radio (SDR) [1] network testbed to enable a physically intuitive way to visualize signals as they propagate through the wireless medium. The radios provide runtime inputs describing their current states, including active radiation directions, antenna modes, real-time achieved up- and downlink throughputs to the AR cloud backend. This reporting can be accomplished using USB serial communication through an Internet-connected gateway, or directly over Ethernet if the radio node has Internet access. Our AR mobile application takes these inputs from the cloud backend and annotates them in an intuitive way directly next to the target radios on mobile screens of educators and students in a classroom. The entire process incurs negligible time lag in visualization while tremendously enhancing the students' comprehension of wireless network activities.

B. Mobile Application Implementation

Noticing a need for visualization tools for use in wireless communications engineering education, we began the development of our augmented reality mobile application by initially working on the native iOS platform. We then quickly realized it was a better decision to continue with a more diverse platform to ensure a wider reach of audience. We settled on the Vuforia plug-in for Unity3D [17], [18] as our final selection for development. The Vuforia plug-in for Unity3D platform is a lot more popular than the native iOS SDK since it has a lot more documentation, and, from Unity3D, the application can easily be ported to multiple end-user devices (iOS, Android, Desktops, Oculus Rift, and more). Our design, as shown in Figure 1, allows for the AR app to communicate with the test equipment such as retreiving experimental setup information from wireless nodes and customizing its visual outputs, which has not been demonstrated in the context of educational tools before. The experimental setup is loosely defined and could be any setup applicable to topics covered in the course that can send information to the AR app. The information retrieved could include reconfigurable antenna mode selection (i.e. the direction in which the antenna is radiating [19]), and data throughput statistics. The app does require image markers to be placed on the experiment setup to identify individual wireless node with their correct identity (e.g. transmitter vs. receiver).

Our final app design, BeamViewer, has been released for popular mobile platforms (iOS and Android). Additional information can be found at *www.beamviewer.io* including a video demonstration of our tool. The intended operation of BeamViewer is part of an experimental bundle, which includes a experiment server to parse and service queries from the app, and an SDR implementation. Each of these components is further explained in the following subsections.

C. Experiment Server Operations

The wireless SDR nodes communicate with BeamViewer running on the mobile devices through Parse API, which provides cloud based back-end tools to be able to store and retrieve data in the cloud along with log-in handling, push notifications and running code on the cloud. Python scripts run locally on the host PC connected to the radio nodes and poll for any information requested as a part of the experimental setup, such as antenna configurations and calculated uplink and downlink throughput, through its serial COM ports. This information is then pushed and updated into the Parse cloud for the AR application to retrieve.

[1]highly customizable wireless development platform

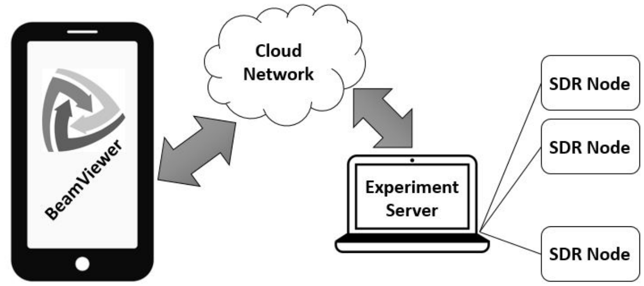


Fig. 1: Data flow for BeamViewer operations.

D. SDR Implementation

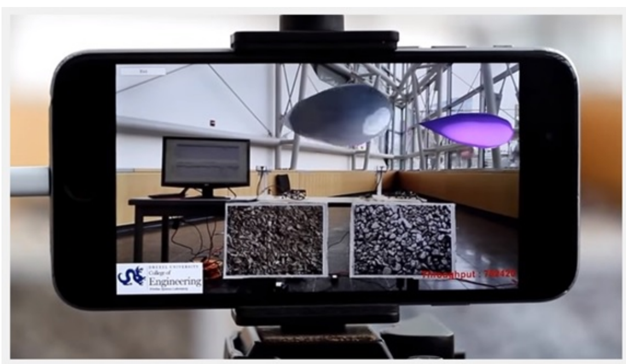
To facilitate students' understanding of the wireless communication topics, we design and develop an experimental SDR testbed that can be used to demonstrate various concepts such as data throughput. This testbed, building upon the Wireless open-Access Research Platform (WARP) [20], can be used to prototype real-time communication networks with multiple base stations and clients. Our implementation leverages WARP's real-time 802.11 physical layer together with a custom-built Time Division Multiple Access (TDMA). Using this platform, we can provide a wide range of network services, such as network time synchronization, resource scheduling, and handoffs. More importantly, we can conduct several experiments that leverage directional antennas and an algorithm that optimizes data throughput and signal strength based on the antenna direction selection. All of our demonstrations are conducted on an experimental SDR-based radio network in a relatively quiet, unused WiFi channel: 802.11 channel 14 at 2.484 GHz.

The research components of our demonstrations, while remaining outside the scope of standard coursework, are also presented to the students to illustrate open problems and novel approaches in wireless communications research. Specifically, we introduce the students to the concepts of *directionality* and *dynamic radiation patterns*, both of which mean focusing electromagnetic signal energy in certain directions dynamically to boost efficiency. Our SDR testbed achieves this capability using reconfigurable antennas - compact antennas that can change their radiation patterns on the fly [19].

III. AR Case Study: Antenna Radiation Pattern Visualizations

It has been shown that it is easier for students to maximize their learning when they can see "things" and interact with them [21]. As a case study to anchor our initial implementation

(a) Classroom experience of our Augmented Reality app. Students can be seen with their devices observing the experiment being discussed. Image markers and SDR nodes can be seen on top of the cart.



(b) A sample screenshot of the device screen while an experiment is being observed.

Fig. 2: Classroom-use scenario of BeamViewer.

of BeamViewer on, we've selected antenna radiation pattern visualizations. Visualizing such patterns presents a challenge in wireless communications courses. We describe the concepts behind our focus point and how they integrate with our AR app below. Later sections of the paper will describe the details on our study for measuring the effectiveness of antenna radiation pattern visualization using our AR app in undergraduate and graduate level wireless communications courses.

A typical method of introducing antenna concepts in a wireless communications course involves introducing equations for calculating and plotting the pattern on a polar graph. These plots unfortunately cannot display the full 3D radiation pattern easily. Therefore, many educators choose to visualize 2D cross-sections of these patterns instead and expect students to be able to merge them in their head to reach the 3D solution. For one of the experimental setups for use with our AR app, we use two wireless SDR nodes equipped with directional reconfigurable antennas. These antennas are capable of electrically changing their radiation patterns. One advantage of switching directions using such antennas is to be able to optimize received signal power to maximize received wireless packets (measured as data throughput). A traditional way of displaying results for this experimental setup would be using graphs on a computer screen that may or may not be real-time. With our AR app, we create information flow between the SDR nodes (experimental setup) and the mobile devices (students/educators running our AR app). As the experimental setup runs algorithms to find the optimal radiation pattern for the antennas, the students can observe a visual change on their devices, which would normally be invisible to human eye. The information (radiation patterns and data throughput) displayed on the mobile device screen provides a real-time experience for students and educators as seen in Figure 2b.

Figure 2a shows how students interact with the experiment setup using their mobile devices. They can be seen standing up from their seats and getting closer to the experiment being discussed. Each student can see the SDR nodes and the image markers being used as a part of the setup. Each image marker represents a different wireless node (i.e. transmitter or receiver). Upon launching the BeamViewer app on their mobile devices and pointing its camera towards to image markers, the students can see the antenna radiation patterns being displayed on their mobile devices. These patterns are scaled and oriented based on the location of the student with respect to the markers.

IV. Student Learning Assessment

A. Survey Design

To assess the effectiveness of the augmented reality tool in the context of an undergraduate and a graduate course, we developed a survey to ask students about their interests and learning gains after seeing the AR demonstration showing antenna radiation patterns and data throughput between wireless nodes as described in Section III(A). We asked students: 1) to rank their current interest in particular course topics or activities; 2) how their interest in these topics or activities has changed after participating in the augmented reality demonstration; 3) how much they gained in skills and understanding in the relevant course; 4) what course related activities or assignments allowed them to make the greatest learning gains. Interest and gains in learning were assessed on a five point Likert style scale. Change in interest was assessed on a three point scale. For each question on the survey, we included one item that was not relevant to the goal of the augmented reality demonstration to ensure reliability of the responses. The goal of this tool was to gather data on student interest and learning gains after implementation of the augmented reality demonstration, to assess whether students make similar learning gains using this tool in different course contexts.

This survey was administered through Qualtrics (*www.qualtrics.com*) within one week of having the students participate in the augmented reality app demonstration. Fifteen students completed the survey from the graduate course out of a possible 20 participants, and nine students completed the survey from the undergraduate course out of a possible 15 participants. Responses to these surveys were anonymous.

To determine statistical significance of Likert style data, we used unpaired t-tests and corrected for multiple comparisons using the Holm-Sidak method. Items that were determined to be statistically significant had an alpha value of 0.05. Results of this study are presented in the later sections of this paper.

B. Survey Flow and Questions

In order to ensure all students were fully informed of the purpose of the study and how the final data will be used, the design of our survey started with an introduction paragraph explaining such information. We specifically made sure to tell them the data will not be seen by their instructor or their teaching assistant and to answer as honestly as possible. The following questions were asked during the survey:

1) Rate your current INTEREST in each of the following topics or activities. (Multiple choice)
2) Compared to last week, how has your interest in these topics or activities CHANGED after seeing the augmented reality (AR) demonstration: (Multiple choice)
3) How much did you GAIN in the following areas as a result of the course, thus far? (Multiple choice)
4) Did you make other gains from this augmented reality simulation that we didn't mention here? If so, please briefly describe these. (Short answer)
5) In your view, what course related activities or assignments allowed you to make the greatest learning GAINS relating to each of the following topics? (Multiple choice)

Each question asked students to provide a rating or a choice in the following topics that are related to wireless networks. The below options were selected based on discussions with the instructor and the teaching assistant for the courses identified.

- Sectoring
- Directional antennas
- Experiments using TIMS modules (undergrad course) or Experiments using MATLAB simulations (grad course) – control question
- Large-scale fading (shadowing, path loss) – control question
- Cognitive radio and adaptive sectoring

For questions 1-3, a number scale was used for answers. Question 4, a short answer textbox was provided for students to include any additional areas that were not originally included in the survey. The last question, gave students options between labs, lectures, homework assignments, and AR demonstration they have seen and asked which of them contributed the most to their learning gains.

V. Experiment Methodology

A. Student Demographics

The students involved in our study were either enrolled in ECES 306 Analog & Digital Communications or ECET 512 Wireless Systems courses. While both these courses are offered under the Electrical & Computer Engineering Department, ECES 306 is an undergraduate course and ECET 512 is a graduate level course. There were 15 students in the undergraduate course, all of whom were male students. Of the 20 students in the graduate course, 17 were male and 3 were female. The students in ECES 306 were third and fourth year undergraduate students in the electrical and computer engineering department. The students in ECET 512 consisted of 2 undergraduate students, 15 Masters students and 3 PhD students. No country of origin or race information was collected for the purposes of this study.

B. Course Logistics and Flow

ECES 306 is an introductory communication systems course at undergraduate level covering both analog and digital systems. The course begins with a review of signal and system analysis and introduces analog modulation techniques such as amplitude, phase and frequency modulation. Then sampling, quantization, line encoding pulse shaping and digital modulation techniques are covered. This is followed by modulation performance analysis, and a brief introduction to source coding and information theory. This course has a lecture portion that meets twice a week for 80 minutes on Tuesdays and Thursdays. Additionally, there is also a laboratory component that meets on Fridays for 110 minutes. The lectures are typical of most small engineering classes where the course instructor presents the material using the white board. The teaching assistant is responsible for running the laboratory portion, which usually begins with a short quiz on the material presented in lecture that week and is followed by laboratory assignment. The laboratory assignments consist of building and analyzing models of communication systems using modular hardware designed for communications modeling. In addition to the laboratory assignments, there are also weekly homework assignments.

ECET 512 is a more advanced, graduate-level, communications course focusing on wireless communications systems. After first introducing the cellular system fundamentals, this course presents the principles of large scale and small scale mobile radio propagation. Then multiple access schemes and cellular architectures are discussed. Finally emerging technologies in wireless communications are presented. This course meets twice a week for 80 minutes and does not have a laboratory component. As part of the course, students have to do eight programming assignments and a course project.

C. Experiment Setup

For both courses, ECET 512 and ECES 306, the instructor and the teaching assistant were notified of our intent to administer this study in their courses. The teaching assistant helped with distributing the survey link to the class for the study. The experimental setup for the AR demo was arranged on a cart and the cart was brought into the classroom at the beginning of the class meeting time. For ECET 512, the study was conducted during the beginning of the lecture period. The lab session was selected for ECES 306 to be more suitable for this study rather than the lecture period due to time constraints. In both cases, a *third-party team* provided the AR demonstration, which lasted about 10-15 minutes and also involved description of what's happening and student questions. Students were also encouraged to download the app to their personal devices but this was not required. The study team also provided devices that students could pass around. Participation in survey was also encouraged but not required.

TABLE I: Student Interest after Augmented Reality Experience. Responses are on a scale of 1 (very uninterested) to 5 (very interested).

	Graduate Course		Undergraduate Course	
Rate your current interest in each of the following topics or activities	**Mean**	**SD**	**Mean**	**SD**
Sectoring	4.40	0.74	4.22	0.67
Directional antennas	4.40	0.63	4.22	0.44
Large-scale fading (shadowing, path loss)	3.80	0.68	4.00	1.00
Cognitive radio and adaptive sectoring	4.07	0.80	4.11	0.93

TABLE II: Perceived Change in Student Interest after Augmented Reality Experience. Responses are on a scale of 1 (I am now less interested) to 3 (I am now more interested)

	Graduate Course		Undergraduate Course	
Compared to last week, how has your interest in these topics or activities changed?	**Mean**	**SD**	**Mean**	**SD**
Sectoring	2.27	0.46	2.44	0.53
Directional antennas	2.53	0.52	2.67	0.50
Large-scale fading (shadowing, path loss)	2.20	0.56	2.33	0.50
Cognitive radio and adaptive sectoring	2.40	0.74	2.56	0.50

VI. Survey Results and Discussion

After all surveys were completed, all the results were analyzed. In the context of both the graduate and undergraduate course, students expressed more interest in topics that were relevant to the augmented reality demonstration as shown in Table I. While sectoring, directional antennas and cognitive radio and adaptive sectoring were topics that were relevant to the augmented reality demonstration, large-scale fading was not relevant. For the topics relevant to the augmented reality demonstration, on average both graduate and undergraduate students expressed that they were interested in these topics. There were no significant differences between the interest levels between graduate and undergraduate students, suggesting that both groups expressed an equivalent level of interest in relevant topics.

It is possible that the interest in these topics was intrinsic to the students, and is not attributed to the augmented reality simulation. Therefore, we further asked students about their perceived change in interest after observing the augmented reality demonstration as displayed on Table II. On average, students reported being at least as interested, trending towards being more interested, in the topics relevant to the augmented reality demonstration. Of note, there were no significant differences observed between perceived change in student interest amongst graduate and undergraduate students. This suggests that both groups can gain interest in course topics after exposure to supplementary visual learning tools such as our augmented reality demonstration.

In terms of learning gains, on average, students in the graduate course reported higher learning gains than students in the undergraduate course on the topics studied, with statistically significant differences seen for understanding the benefits of cell sectoring, and being able to integrate directional antennas for cell sectoring (Table III). These differences could

TABLE III: Learning Gains. Responses are on a scale of 1 (no gains) to 5 (great gain).

	Graduate Course		Undergraduate Course	
How much did you gain in the following areas as a result of the course, thus far?	**Mean**	**SD**	**Mean**	**SD**
Understanding the benefits of cell sectoring	3.80*	1.15	2.44	1.33
Being able to integrate directional antennas for cell sectoring	3.60*	1.06	2.44	1.42
Demonstrating the effects of large-scale fading in mobile networks	3.60	1.24	3.00	1.12
Cognitive radio and adaptive sectoring	3.00	1.41	2.78	1.30

* P values were less than 0.05 in comparing Graduate to Undergraduate course responses.

be attributed to various student backgrounds in terms of their education, where graduate students may have already seen some of the topics during their undergraduate education and/or during their reserach as a part of their graduate work. Although visual learning tools seem to contribute to increased learning gains, undergraduate students in a communications systems classes might require additional steps to maximize their learning, such as supplementary reading. With that said, both groups did indicate, on average, making moderate gains in learning in all areas studied. This allows us to categorize the use of AR visual tools as a valid addition to wireless communications courses.

Another place where we saw interesting differences was in student perception of our augmented reality demonstration. We asked students to choose the course related activities or assignments that allowed them to make the greatest learning gains in particular topics as shown in Table IV. Students in the undergraduate course were more likely than students in the graduate course to report the augmented reality demonstration as useful for achieving learning gains in the course. Interestingly, 56% of students responding to the survey from the undergraduate course indicated that the augmented reality demonstration was helpful in allowing them to make learning gains in large-scale fading. This is notable because this was not a topic that was taught using this demonstration, and therefore, it is unlikely that the students actually learned more about large-scale fading as a result of the augmented reality demonstration. This result may suggest that undergraduate students have an overall greater enthusiasm for this approach as a learning tool, such that they are attributing its usefulness in achieving irrelevant learning gains. Future work will focus on developing tools to directly assess student understanding of these topics, which can be administered pre- and post-administration of the augmented reality demonstration.

During the study, the instructor and the teaching assistant also reported their observations of their students. The students enrolled in the graduate-level course seemed to have a wide range of questions and were interested in learning about the inner details of the AR tool and the experiment system in addition to the specific topics that were being talked about (e.g. sectoring, directional antennas). On the other hand, the undergraduate cohort seemed more impressed in terms of being able to download the BeamViewer app to their own devices and actually interacting with the experiment. This group did

TABLE IV: Student Perception of Augmented Reality as a Mechanism to Assist their Learning.

Percentage of students who indicated that the augmented reality simulation was the course related activity that allowed them to make the greatest learning gains relating to each of the following topics	**Graduate Course**	**Undergraduate Course**
Sectoring	0%	33%
Directional antennas	13%	78%
Large-scale fading (shadowing, path loss)	0%	56%
Demonstrating the effects of large-scale fading in mobile networks	7%	44%
Cognitive radio and adaptive sectoring	47%	44%

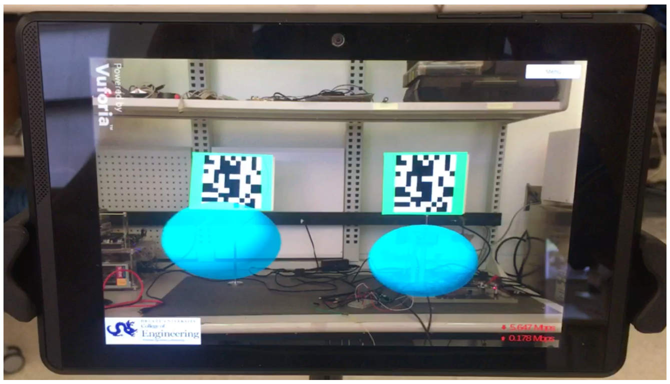


Fig. 3: Encryption keys can be visualized as barcodes for wireless cybersecurity courses.

not have as many questions as the ones in the graduate course.

Overall, the results from this pilot study suggest that this augmented reality demonstration can be useful in promoting student interest and learning gains in specific topics relating to wireless technology. As well, these results seem to suggest that this tool is useful for teaching both undergraduate and graduate populations.

VII. Future Work

Our future goals include providing additional experimental setups that are supported by our BeamViewer app in order to support multiple different courses. A sample experimental setup that is soon to be supported is visualization of wireless Physical (PHY) layer encryption keys as a part of wireless cybersecurity courses. Figure 3 shows an idea of how this can be accomplished. Barcode-like pictures are created on-the-fly by BeamViewer and is displayed over the image marker associated with the node (due to the highly dynamic nature of the wireless environment, the keys might not be symmetric at all times; hence, the need for two barcodes.). Our future work also includes allowing for user interactions with the experiment setup for a fully immersive learning experience.

VIII. Conclusion

In conclusion, we have developed and presented an augmented reality based visualization tool that is suitiable for wireless communications education. We assessed the effectiveness of our AR tool by designing and conducting a survey in two wireless engineering courses, one at graduate level and one at undergraduate level. Although some differences were observed between the responses from the two cohorts, overall, students have shown an increased interest and reported learning gains in areas related to the demonstration they saw. We have also noticed that introduction of a new visualization tool into classrooms increased the general enthusiasm of students in other unrelated areas. This also makes our AR app an effective tool that can be used for student recruitment activities such as wireless communications engineering.

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