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ORIGINAL RESEARCH

Cross-discipline teaching and learning of cardiology through an augmented reality application

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ABSTRACT

Introduction:
Undergraduate health sciences and health professional degree programmes introduce students to common heart diseases and associated treatments, including atrial fibrillation (AF). Our students, second-year biomedical science and pharmacy students, through formal and informal feedback on their learning experience with cardiology, noted AF as the most difficult to comprehend. The learning challenges include electrophysiology and pharmacology aspects of AF. This study, therefore, aims to investigate the potential use of augmented reality (AR) to enhance students' engagement and understanding of AF.

Methods:
Based upon students' feedback, and guided by the learning outcomes of our degree programmes, we developed an AR application (App) to teach AF, covering general as well as discipline-specific learning content. The development was done through an iterative process, grounded in the constructivist learning theories. A survey consisting of 13 Likert-scale questions and an open-ended question formulated around user interface principles was conducted to gather students' feedback of the App.

Results:
Thirteen per cent of pharmacy students (n = 21) and 22% of biomedical science students (n = 27) responded to the anonymous and voluntary survey. Student responses to the survey were largely positive, including the areas related to engagement, novelty, realism, learning and enjoyment.

Discussion:
This study shows that AR technology has enhanced students' engagement as well as perception of understanding of AF, specifically in the areas that students find difficult. This authentic learning tool has successfully addressed some of the learning challenges raised by students of both disciplines. Students' positive feedback suggests that a carefully designed AR App, guided by learning theories, is a suitable and viable option to improve students' understanding of complex subjects, apart from making learning immersive and engaging.

What this study adds

- An augmented reality (AR) application (App) for the teaching and learning of complex subjects.
- An authentic AR App for cross-discipline teaching and learning.
- A learning theories- and students' voice-guided AR App development.

Introduction

Cardiology is a branch of medicine covering various heart diseases and their treatments. A common heart disease, arrhythmia, is an abnormal heart rate or rhythm causing the heart to pump irregularly. Atrial fibrillation (AF) is the most common arrhythmia encountered in the clinical setting affecting around 30 million people worldwide [1]. Characterized by disorganized and rapid atrial electrical activity, AF results in an irregular heartbeat that increases the risk of blood clots and subsequent embolic events such as stroke [2]. AF is caused by several mechanisms that are not well understood, and because of this, the underlying cause of AF varies among AF patients [2]. These factors increase the challenges of both teaching and learning of AF, including associated pathophysiology, diagnosis and clinical management. Undergraduate students of health sciences and health professional degree programmes who learned cardiology have similarly acknowledged the challenge of learning AF.

A student perception survey involving year-2 biomedical science students at the University of Warwick was undertaken to identify pedagogical issues in the delivery and understanding of cardiovascular-related content. The content is delivered as part of the blood and circulation core module which draws roughly upon three areas: fluid homeostasis, haematology and the cardiovascular system. Teaching of the module consists of 12 one-hour lectures and an electrocardiogram (ECG) workshop. Likert-scale questions were used to ascertain the level of engagement by the student, difficulty of a topic, and external learning resources used. Single-answer questions were used to determine how much time students spent studying the cardiovascular system lectures when compared to other topics in the module. Single-answer questions were also used to determine whether students had previously used augmented reality (AR) or virtual reality. Multiple-answer questions were used to establish which types of media students preferred. Text entry questions were used to gather general feedback [3].

The results of the survey demonstrated that students find the pharmacology and electrophysiology aspects of the cardiovascular system lectures amongst the two most difficult topics. Specific reference was made to the structure of different cardiac ion channels, how they are targeted by anti-arrhythmic agents and how they are responsible for different phases of the cardiac action potential. Other difficulties relate to ECG interpretation [3]. The current delivery of this content is via a series of didactic lectures which are viewed as unstimulating and requiring more learning effort by students in comparison to other topics. Whilst lecturing is one of the most widely used undergraduate teaching methods for the delivery of medical-related content, it does not promote thinking and deep learning [4]. The didactic lecture method is regarded as passive teaching and has been greatly criticized by various researchers, thus prompting the need for innovations in the teaching of medical education [5,6].

At Monash University, year-2 pharmacy students learn about various heart diseases, including AF, through the cardiovascular therapeutic unit. Students learn about AF through eight one-hour interactive lectures and two knowledge application, case-based learning workshops, supported by self-directed learning material accessible through the unit learning management system (Moodle). However, students commented in the University's formal student evaluation of teaching and unit (SETU) that the pathophysiology of irregular heart rhythms, the pharmacology of anti-arrhythmic agents and the clinical management of AF are more complex than other types of heart diseases. This feedback, together with the comments made by biomedical science students, indicated that we needed an innovative approach to improve the effectiveness of the teaching and learning of AF.

The emergence of mobile learning technology has changed the education landscape, offering opportunities to enhance student outcomes. One of the most recent advancements in mobile technology is AR – a digital tool that combines computer-generated virtual objects with the users' environment in real time, thus offering an immersive and more enriching learning experience than visualizing a heart model through computer, printed or physical objects. An App can be easily installed on mobile devices, such as a smartphone, thereby increasing accessibility as well as flexibility in learning, in line with the growing trend of using technology-based learning methods in higher education.

From a pedagogical perspective, constructivism is one of the education theories found to be particularly relevant for the design of learner-generated AR content [7]. Constructivism underpins a pedagogical approach to engage students in the learning process including how students interact with each other or with a learning environment during knowledge attainment and construction. Importantly, from a cognitive and social perspective, a constructivism framework encompasses experiential, situated, collaborative and game-based learning theories – all pertinent to learning in a technology-based setting [8]. Indeed, AR is an interactive technology that provides experiential learning opportunities to users with visual, auditory and, in some cases, tactile input. Experiential learning is the process of learning through experience and requires the learners' personal involvement; it addresses both the needs and wants of the learners and is both self-initiated and self-evaluated and is a well-established education theory [9]. A purposefully designed technological intervention that is supported by learning theories stemming from constructivism is able to improve student engagement in the learning of complex subjects [10]. We, therefore, asked the following research questions:

1) Can AR improve students' engagement in the learning of AF?
2) Can AR improve students' understanding of AF, specifically the learning challenges raised by students?

Methods

Overview of the study

Grounded in the constructivist learning theories, the development of the AR App for AF learning was completed through an iterative process. A pilot study was initially conducted on the beta version of the App in 2020, where a short survey was carried out with pharmacy students to gauge students' expectations of the App. Students' feedbacks of the App were subsequently incorporated into the revised version of the App. A full-scale survey with the revised App version was conducted in 2021. The survey questions were formulated around user interface principles [11,12], based on the following criteria: usability, engagement, novelty, immersion, realism, learning and enjoyment.

Participants

In 2020, the year-2 pharmacy cohort of 109 students was invited to participate in a six-item survey consisting of five Likert-scale questions and one open question. In 2021, 156 year-2 pharmacy students were invited to respond to the full-scale, 14-item survey. In both surveys, students were invited via Google Invite, and given the links to access the questionnaire and explanatory statement of the research during the invite. The explanatory statement explained to students that consent was implied when they responded to the survey, and that participation was voluntary. Data were collected between October and November 2020, and from August to September 2021, respectively. The study was approved by the Monash University Human Research Ethics Committee (MUHREC), project ID 19232.

At the University of Warwick, the pilot study was not conducted on the beta version of the App in the year 2020 due to COVID-19 restrictions. However, in 2021, 122 year-2 biomedical science students were approached. These students were invited to participate via Moodle Forum messages and the same questionnaire and implied consent information were given for the voluntary study. These data were collected in September 2021. This aspect of the study was approved by the University of Warwick's Biological Sciences Research Ethics Committee (BSREC), project REGO-SLS-39.

Questionnaire

As the universities were closed to all on-campus student engagement in 2020 and 2021 due to the COVID-19 pandemic, on-site exposure to the App was not possible. As a solution, a video that illustrated the App features as well as demonstrating the use of the App was made and shared with students through either the Google platform or Moodle. Students were able to review the video as many times as they liked, to allow them to evaluate the App and respond to the questionnaire.

The full-scale questionnaire contained 13 multiple-choice questions that conformed to a five-point Likert-scale format that ranged from 'Strongly agree' to 'Strongly disagree' and one open-ended question. Student responses to the survey were anonymous.

Data analysis

Student acceptance of the App was analysed based on the user interface principles previously mentioned. The themes that emerged from the students' responses to the open-ended question were analysed.

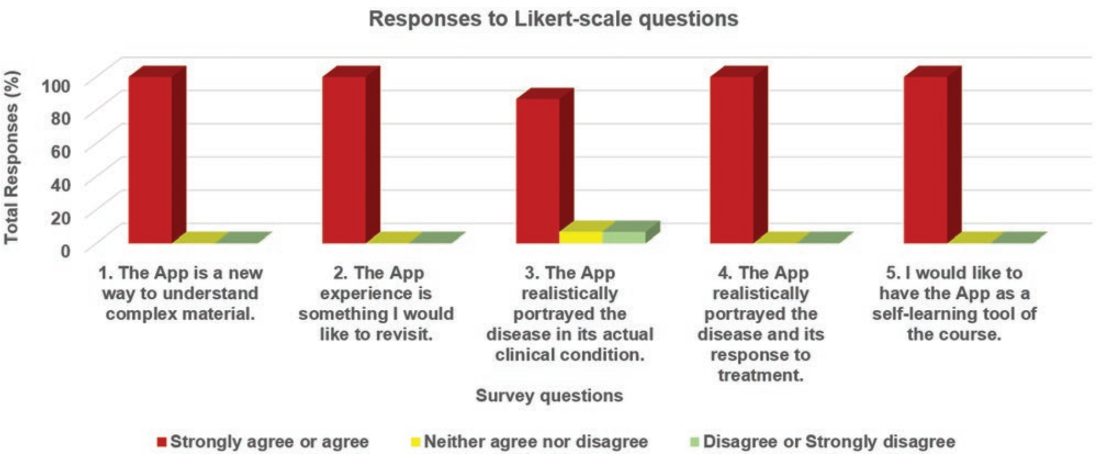
Results

Participation

Fifteen per cent of the pharmacy students (*n* = 16) participated in the pilot study. Figure 1 shows students' responses to the Likert-scale questions. All students strongly agreed or agreed to four of the five questions asked. One student either disagreed or was neutral when asked if the App realistically portrayed the disease in its actual clinical condition. In students' responses to the open question 'Is there any aspect of the App or any other feedback related to this tool that you would like to give to the researchers?', one student did not provide any comment; one student indicated 'not applicable' and two students indicated 'none' (data not shown). The survey suggested that students were satisfied with the App requiring no further improvement although there were some long answers from highly enthusiastic students specifying changes they thought were needed, which were subsequently acted upon.

From the preliminary qualitative questionnaire leading to the development of the final App version, it was important to

Figure 1: Pharmacy students' responses (15%) to the beta version of the AR App in 2020



consider and capture the students' voice in the development and use of the technology within both the pharmacy and biomedical science cohorts. We, therefore, collected students' feedback on the revised beta version of the App using the full-scale questionnaire.

Approximately 13.5% of pharmacy students (n = 21) responded to the survey. The lack of opportunity for physical experience with the App may have contributed to the low participation rate. Nevertheless, students' responses to the survey were largely positive allowing us to draw a conclusion from their responses. In comparison, 22% of the biomedical science students (n = 27) responded to the survey again with many positive responses. The response rate was consistent with other online questionnaire requests to the Warwick students' year cohort.

Students' responses to the full-scale survey

The App received favourable feedback from pharmacy students (Figure 2). In terms of usability, the majority of pharmacy students strongly agreed or agreed that the App was easy to use (81%), the information presented was easy to navigate (95%), and that the App interface was fun and engaging (86%). With the latter, biomedical science students similarly agreed (83%) (Figure 3). But all the students neither agreed nor disagreed that the App was easy to use, and only 56% agreed regarding the navigation of information. Sixty-seven per cent of pharmacy students felt that they stayed focused on the content while exploring the App, while the remaining 23.8% and 9.5%, respectively, were neutral and disagreed on this aspect. Contrastingly, only 39% of biomedical science students felt they stayed focused on the content while the remaining 28% were neutral and 33% disagreed.

Regarding satisfaction with the tool, most of the pharmacy students found the App more engaging than other interactive learning tools that they have used in the pharmacy course (86%), similarly with the biomedical science students (82%). In both cohorts, there was a strong indication that the App experience is something that they would like to revisit (pharmacy 90%, biomedical science 94%).

There are various benefits of the App that students perceive. These include stimulating interest, knowledge and confidence. The majority of students in both cohorts strongly agreed or agreed that the App is a new way to understand complex materials effectively (pharmacy 95%, biomedical science 83%), they would like to have the App as a self-learning tool (pharmacy 95%, biomedical science 100%), and that they would recommend to their friends that the App would help their learning in the course content (pharmacy 90%, biomedical science 87.5%). In terms of knowledge, almost all pharmacy students strongly agreed or agreed (95%) that the App realistically portrayed the disease in its actual clinical condition while 82% of biomedical science students came to this conclusion. The majority of pharmacy and biomedical science students felt that the App realistically portrayed the disease and the response to treatment (pharmacy 95%, biomedical science 87.5%), and moreover, has improved their understanding of the disease and treatment (pharmacy 95%, biomedical science 87.5%). Students largely agreed (pharmacy 76%, biomedical science 59%) that they are more confident now than before in discussing the topic with their peers and lecturers.

Likert-scale responses themed against the user interface principles

The mean of students' agreement levels of the questions categorized under each of the criteria, expressed in percentage, was calculated and shown in Table 1. There were high levels of agreement from pharmacy students for most criteria that were associated with the user interface principles. Except for Immersion, other criteria recorded agreement levels that ranging from 85% to 95%. The agreement levels from biomedical science students on these criteria were generally high, ranged from 82% to 94% for four out of the seven criteria. However, there was a relatively low level of agreement on Learning (73.5%) as compared to other criteria, which was contributed by the low level of agreement for question 11 (59%). Similar to pharmacy students, there was a lower level of agreement on Immersion (66.5%) due to only a small number of students agreeing on question 6 (39%). Biomedical science students have the lowest agreement level on the App usability (46.3%), specifically critical on the ease of use as well as navigation.

Students' responses to the open-ended question

The four themes that emerged from students' responses are presented in Table 2. These include engaging, improved

Figure 2: Pharmacy students' responses (13.5%) to the revised version of the AR App in 2021

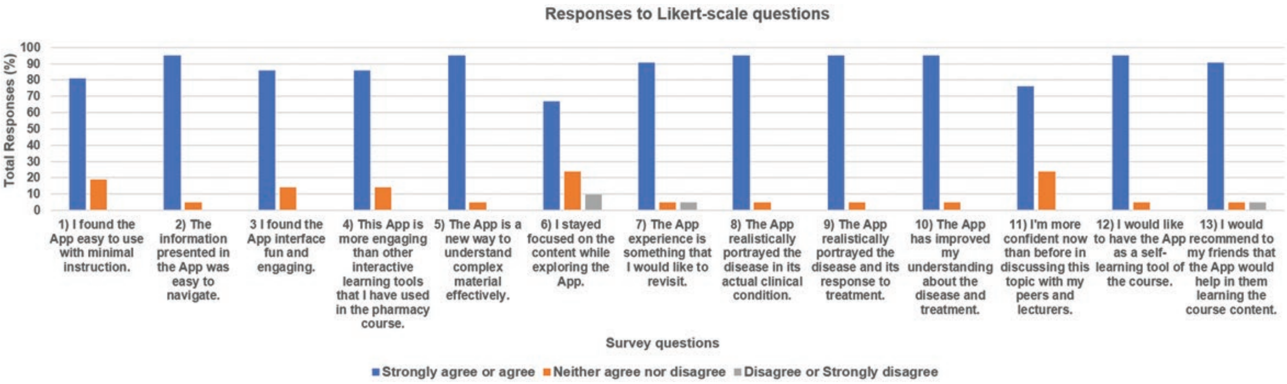


Figure 3: Biomedical science students' responses (22%) to the revised version of the AR App in 2021

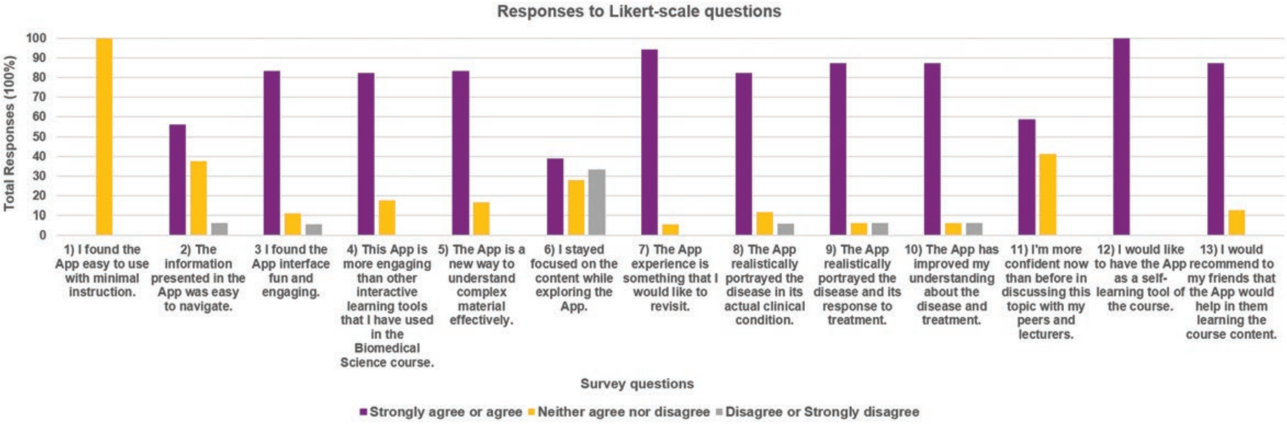


Table 1: The feedback of pharmacy and biomedical science students on the AR App according to the user interface principles

Criteria	Questions	Mean of the agreement level (%)	
		Pharmacy (*n* = 21)	Biomedical science (*n* = 27)
Usability	1–3	87.3	46.3
Engagement	3 and 4	85.7	82.5
Novelty	4 and 5	90.5	82.5
Immersion	6 and 7	78.5	66.5
Realism	8 and 9	95.2	85
Learning	10 and 11	85.5	73.5
Enjoyment	12 and 13	92.5	94

understanding, general content and discipline-specific content.

Discussion

User interface refers to how a user communicates his or her needs to the device, and how the device in turn provides the results of its computations and requirements to the user [11]. According to Blair-Early and Zender [12], an interface has two basic considerations, that is, users and content, and user interface means users interact with the content to accomplish some goals. Applying the user interface principles to the context of our development means students interact with the AR App by selecting the content about AF that they wish to explore further to learn more or better about AF. A properly designed interface would satisfy the user's needs and capabilities in the most effective way possible [11]. In this study, students' responses to the questions associated with Engagement, Realism and Learning suggest that the App has satisfied learning needs. The high agreement levels of Realism and Learning indicate that the App has improved students' perceived understanding of AF.

The best interface is the one that is not noticed, where users focus on the information and task at hand rather than the mechanisms used to present the information and perform the task [11]. This aspect may be represented

Table 2: The four emergent themes and representative comments of each theme

Theme	Representative comments
What works	
Engaging	The App looks very fun and informative Looking through the heart and the receptors was really cool This was really great – refreshing to have such app produced and linked to our course
Improved understanding	Really wanted to know about the drug and receptors and this works well The explanation of AF interventions from beta blockers to amiodarone and flecainide was much clearer than in the lectures More please – helps me understand by seeing in action
What has not worked	
General content	I'm still not sure about the action potential – perhaps more on that would be good I thought the ECG needed more explanation It would be helpful if there is a written version of the explanation
Discipline-specific content	I wanted something to explain the blood clotting Show how some of the medical procedures are conducted on the heart

by students' feedback on Usability and Immersion. While pharmacy students found the Usability was good, biomedical science students felt that they were not able to evaluate this aspect of the App, possibly due to the absence of hands-on experience. The same reason may explain the lower agreement level of biomedical science students than pharmacy students on Immersion. Despite this, students from both disciplines recorded high agreement level on Enjoyment, an indicator for general approval of an App design and development.

Students' qualitative feedback echoed their responses to the multiple-choice questions. Specifically, the presentation of the pharmacology aspect of AF was adequate and satisfactory, and has successfully addressed the learning challenge mentioned by students. However, further development is required for other contents. For example, we may need to show how aberrant action potentials are generated during AF and demonstrate the association between the action potential and abnormal ECG patterns. Further explanation on the mechanism of blood clotting and medical procedures may include the addition of 2D videos illustrating these processes to the App, but learning may become less immersive and interactive with this approach. Another suggestion was to include captions by the narrator – which shows individuals' preference to specific learning styles, possibly the aural and read/write learning style. While the provision of a full narrator's script to the users may not be ideal for an AR App, we may consider including brief notes in the App.

The survey results answered the research questions – the AR App has improved engagement in learning AF as well as students' perception of understanding of AF. The results demonstrate that the constructivism framework is a suitable reference for the design of AR content for teaching and learning purposes. Although there was a lack of opportunity for students to experience AR in-person, engagement was enhanced through watching a video that shows the function, use and content of the App. The video demonstrated elements of the experiential and situated learning theories. For example, the video generated observations and reflections, the latter allowed the formation of abstract concepts and creation of new experiences [13]. Learning was situated because students created their own knowledge from the experience of watching the video, which was accessible through the Google platform or Moodle.

Limitations

The main limitation of the study was that students did not have the opportunity to experience the immersive features of the AR technology when responding to the surveys. This limitation may have reduced students' interest to participate in the surveys. Although the response rate was low, students' high level of acceptance and approval rating of the learning tool were clearly evidenced in the surveys. Another limitation of the study was that students' performance in the unit or module following this intervention was not measured. This is a potential area of future research, which may inform students' actual improvement in the understanding of AF.

Conclusion

An AR App has been successfully developed that enhances students' learning and understanding of AF supported by the positive responses by students to several aspects of their learning experience, including engagement, novelty, realism, learning and enjoyment. The development focused on addressing the learning challenges brought up by both pharmacy and biomedical science students. During the development activities, the learning objectives and learning outcomes of the unit or module of both degree programmes were repeatedly considered and addressed. This alignment process provided the notion that the AR App offers a valid level of authenticity, and that it complements the teaching and learning activities of the targeted degree programmes. The study indicates that AR may be considered an effective approach to the teaching and learning of complex subjects and a novel way to engage students.

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Declarations

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Competing interests

The authors have no relevant financial or non-financial interests to disclose.

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