Journal of Health Science & Education
An open access journal
eSciRes
JHSE-1-121
Research Article

Using Mobile Augmented Reality to Enhance Health Professional Practice Education

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Abstract

The use of augmented reality (AR) as a new multimedia networking technology is increasing. An investigation was made of the value of using AR as a tool to support the teaching of clinical practice skills. A series of mobile AR resources were created for use on tablet computers and smartphones to supplement clinical skills teaching in the laboratory (using image recognition), and clinical practice (using geolocation). Undergraduate students in nursing, physiotherapy, and occupational therapy tested these resources in lab sessions, a location based campus exercise, and during clinical practice experiences. Following this, a post-exposure web survey and focus group interviews were undertaken to appraise the value of these tools. Results demonstrated that the potential for students to use technologies they already possess in AR based m-learning may offer significant advantages, and offer a practical technique to engage learners. However, these technologies remain in an early stage of development and more robust implementations and sustainable platforms are required for mainstream educational use.

Introduction

Evidence of the impact of Augmented Reality (AR) on society is already accumulating. We see examples of the use of AR in navigation, sightseeing, the military, medical and patient education, gaming, marketing, the mainstream media, high-tech manufacturing industries, and others. All have embraced AR as a means of delivering additional content on-demand, at the point of encounter with an object in the physical world. AR is now deriving substantial financial support from investors and corporations alike [1]. Examples of AR infiltrating several global retail marketing campaign initiatives, include technology that allows consumers to try on clothes virtually, to IKEA's "AR Catalogue" which enables potential buyers to see how furniture looks inside their own homes. These applications are impressive early phase testaments of AR's potential to expand conventional media. As education represents an enterprise that has hugely capitalized on information technologies and new media, exploration of the potential of AR for educational purposes is now also occurring [2].

AR is a set of new mobile technologies where simultaneous views of real world objects or environments are enhanced by computer-generated media such as graphical, video, sound or web-based content [3,4]. AR currently uses image recognition or geo-positioning (location recognition) technologies to identify physical objects or places in the real world, and overlays digital information about them visually on a digital display in-situ. These digital augmented elements are superimposed on the real world through head-mounted eyewear, a glass transparent screen or a camera display such as a smartphone or tablet computer screen. Unlike virtual reality, AR does not attempt to create a fully digital world that users can interact with, relying instead on the blending of digital and physical domains.

As many students in universities now own smartphone devices [5,6] and commercial AR services using smartphone cameras are developing rapidly [7], these developments have now brought these technologies within the reach of both students and educators, and new possibilities and opportunities for mobile learning (m-learning) using AR are now arising. This project was designed to explore if mobile AR technologies have the potential to enhance the learning of practice skills in the lab, and support practice-based learning during clinical practicums for healthcare professional students in three professions, as part of their practice education.

In contemporary healthcare professional education, there has been increasing emphasis on constructivist learning with students taking an active role in the process where learners are seen to construct new knowledge and skills in relationship to their existing knowledge and build knowledge within their personal environments. Research has suggested this approach improves student confidence and fosters development of critical thinking skills [8-10]. AR promotes active engagement with the users' physical environment, but overall it is still considered a novelty and most implementations to date have lacked an explicit pedagogic framework [2,11]. Structured mobile learning (or m-learning as it has been called) offers a constructivist approach where educators can provide AR activities using heuristic learning strategies for students to provide alternative ways of engaging with content, promoting more active learning, and enhancing the learning experience. M-learning is focused on learning across multiple contexts through social and content interactions using personal electronic devices [3,12,13]. The idea of using mobile digital devices to support learning is actually long-standing. Alan

Kay's Dynabook, developed at the Xerox Paolo-Alto Research Labs from the 1970s, represented the first serious attempt to design a computer-mediated mobile learning platform [14] and had its roots in constructivist learning theory [15]. There was an emphasis on heuristic and exploratory learning, and the ideas of situated cognition, in that we question our ideas and knowledge of the world as we learn in-situ, and that all knowledge is situated in activity bound to social, cultural and physical contexts [15]. Although the constructivist roots of m-learning have been questioned [16], together with humanism it remains a highly prevalent conceptual model for employing m-learning within modern professional education.

Although laptops and personal digital assistants (PDAs) became available in the 1990's and have been used in a variety of educational contexts, it was not really until the advent of ultra-mobile computers: UMPCs, tablet PCs, small form-factor laptops and smartphone technologies in the last decade that m-learning approaches have attempted to embrace the use of students' personal devices. This has become a driving focus of m-learning research and practice in more recent years despite issues with standardization [17]. Today students utilize an increasing array of mobile technologies that have the potential to support learning anytime or anywhere and increase flexibility of learning [12]. Therefore, the addition of AR appears to have potential as an additional resource in the modern m-learning toolkit.

The Development of augmented reality

Overall, AR represents a form of intermediated reality [18], in which a view of the real world is modified by a computer in some way (enhanced or simplified). As a result, the technology functions to change our current perception of reality in some way. A simple example would be night-vision goggles that filter and amplify infrared radiation images and then display the enhanced image in eyewear. AR represents a development of this concept, adding the power of modern digital information technologies to provide even more information to the user within their environment. Ranked as an emerging technology by the Horizon Report in 2014 [7]. AR represents a new technology that turns mobile devices into mobile multimedia networked reference devices.

Tom Caudell at Boeing first used the term "augmented reality" to describe a digital display used by aircraft electricians to blend computer graphics onto a physical reality in 1990. This enabled Boeing workers to view wiring schematics over a plywood layup board so they could create aircraft wiring looms more efficiently [19]. In 1992, two other teams were developing similar technologies. Louis Rosenberg created what is widely recognised as the first functioning AR system for the US Air Force known as Virtual Fixtures. Here the user performed the remote manipulation of an object using mechanical manipulators and a headset projecting an image, and fixtures were superimposed as cues to help guide the user in their tasks. For example, a virtual ruler to help the user draw a straight line. In this implementation, the user's movements were also controlled by the system to assist them drawing the line [20]. Another team made up of Steven Feiner, Blair MacIntyre and Doree Seligmann at Columbia University developed a three-dimensional (3D) graphics overlay imaging system to show people how to load and service a printer without having to refer to instructions [21]. Military applications of augmented systems were also being developed at this time with AR aircraft head-up displays. The National Aeronautical and Space Administration (NASA) tested an aircraft synthetic vision landing display on their X_{38} prototype re-entry vehicle in 2000 using a display showing video map overlays including runways and obstacles [19]. AR remained very much in the domain of research scientists involving very expensive, unwieldy equipment and complicated hardware and software until Hirokazu Kato of the Nara Institute of Science and Technology released an open source AR tool kit in 1999 that allowed video capture tracking of the real world to be combined with interactive virtual objects on any platform [22]. As this opened up the use of AR to a wider population, alternative implementations of AR began to appear. Bruce Thomas and researchers in the Wearable Computer Lab at the University of South Australia demonstrated the first outdoor mobile augmented reality computer game in 2000 with their ARQuake game [23]. In 2005, the German company Metaio released the first end-consumer AR application that allowed the user to put virtual furniture in an image of their living room. However, it was not until the development of more powerful smartphones from 2008 that widespread commercial uptake of AR technologies began to appear. The Austrian company Mobilizy brought its Wikitude smartphone application to Android phone users to view the world through their mobile phone cameras and see augmentations on their phone screen of real-world points of interest (POIs) in 2008. In 2009, the Dutch company Layar created a simple smartphone AR browser app that allowed users to locate POIs through image recognition and/or GPS location sensing and superimpose AR content over an image of the user's environment from their phone camera. These applications are now freely available to the public, and uptake of commercial AR resources is beginning to occur. Development of AR continues with major companies entering the field such as the forthcoming Google Glass, and the Microsoft Hololens products, and Apple purchasing the German Metaio AR company in 2016.

Methods

Setting, design and recruitment

The study was conducted at the University of British Columbia, Vancouver, Canada with nursing, occupational therapy and physical therapy students, and built and expanded on the work of an earlier study undertaken with nursing students [24]. Here a multiprofessional student population a geopositional AR experience was utilized. This study enhances our understanding of the applicability of AR in clinical labs to multiple health professions with a variety of different clinical skills and educational needs. An exploratory action-research based study design [25,26] was adopted to explore the potential value of AR applications in the lab, to identify deficiencies in the design and implementation of AR resources, and to refine techniques further. The approach is consistent with established exploratory action feedback approaches [27-29]. For evaluation, a combined mixed methods qualitative evaluation strategy using a phenomenological approach (concerned with the user's personal perception and meaning derived from the experience) was adopted in order to evaluate the student's experiences in using AR tools [26].

A convenience non-probability sample of 253 students (120 undergraduate first-year nursing students undertaking a foundational clinical skills course, 81 second-year physical therapy students in a clinical practice course and 52 first-year occupational therapy students in a practice skills course) were invited to participate in the use and evaluation of a broad range of AR resources in the 2015-16 academic year. The Behavioural Research Ethics Board at the University of British Columbia undertook an ethical review and approved the proposal prior to data collection.

Materials

Students were given access to AR resources to encourage them to explore educational resources and make conceptual links from multimedia resources to physical equipment, using interactively hyperlinked material, and to reflect on their practice during their supervised labs and for unsupervised practice sessions. The use of AR enabled additional educational resources to be made available on-demand, at the point of interaction with a new piece of equipment, and allowed student revision of content at will. These affordances of the technology encourage more active learning by students, potentially enhancing learning outcomes. After an environment scan for suitable AR service providers, the Junaio application and associated Metaio backend service were selected as an AR platform for use in this project due to cost, multiple device support, image recognition and geopositional recognition functionality, simplicity and ready availability.

Image recognition AR content

A broad range of equipment in the clinical skills laboratories in the three professional programs was selected by instructors. Equipment varied according to discipline, ranging from a water-sealed chest-tube drain and wall oxygen, to a ceiling lift or button hook, to a TENS or Interferential Current device. The total number of AR resources available across the three programs was 126. Equipment was tagged for AR image recognition, using either a digital photograph of the item or a Quick Response (QR) visual digital code attached to the item. As an example, for the nursing students this equipment included: Pleural drainage equipment, syringes and needles, sharps containers, oxygen delivery, catheter bags, and tracheostomy equipment as well as hand-washing and infection control posters. Each piece of lab equipment that had associated AR content was labelled with a decal to indicate it had AR resources available to view.

Multimedia instructional materials that demonstrated the principles of use, practical application and problem-solving techniques for the equipment were obtained or created in-house, and then hosted on a University web-server. For example, web-based instructional videos showed how to perform clinical hand washing, how to control a TENS device, how to safely operate a ceiling lift, or how to undertake respiratory auscultation and select appropriate oxygenation equipment following a respiratory assessment. Videos were then linked to the appropriate pieces of equipment using the web-based AR backend service (Metaio). Rather than provide simple checklists of actions (as with more traditional skills reinforcement techniques), a range of multimedia resources concerning the equipment/skill being practiced were selected to maximize appeal to multi-modal learners [30]. Students undertaking supervised and unsupervised lab practice could then scan the equipment on their smartphones or tablet computers using the freely available AR application (Junaio). When scanned, embedded AR calls to action appeared on the student's device screen, linking directly to the different resources available for the students to explore (Figure 1).

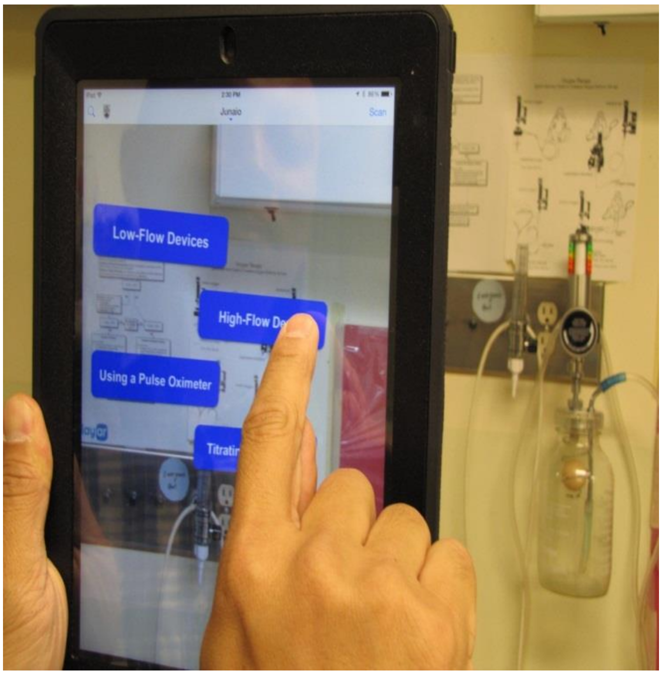

Figure 1: A student views AR call to action buttons augmenting oxygen equipment on a tablet computer screen.

Instructors teaching clinical lab skills were briefed on the availability of AR resources and shown how they could integrate them into their lab teaching sessions as additional resources for students to use. The resources were then implemented with students in five different clinical skills courses during 2015-16 where students used their own smartphones (or department iPads) to access relevant AR resources whilst they were learning and practicing new clinical skills.

By scanning specific tagged equipment using Junaio on a smartphone or on a tablet computer, students could gain immediate access to digital multimedia showing how the equipment worked, the theoretical context of use, and how to use the equipment. Multimedia content appeared on their devices by simply tapping a button that appeared on the smartphone or tablet screen. Additionally, the Junaio application automatically bookmarked links to resources from the items scanned by the students. These could be accessed from a history tab in the application at the student's convenience later.

Geopositional AR content

Included in this study was the integration of a set of AR resources that used geopositional location (latitude, longitude and altitude) rather than image recognition to trigger calls to action. Scanning the area around them with the Junaio AR app using their device camera, students would see call to action data overlaid on the screen showing the distance and direction to locations relevant to their program. These locations could also be viewed superimposed on a 2-dimensional map of their surrounding area. Geopositional resources were created for student orientation to new locations; when these flags on the screen were tapped they provided further data about the point of interest (Figure 2).

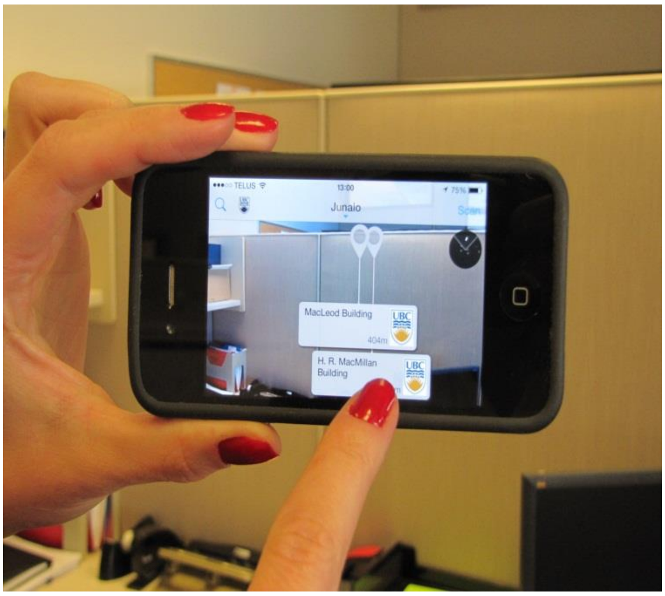

Figure 2: A student taps on a geopositional tag showing direction to access resources about the location.

For example, for nursing students undertaking clinical placements, AR resources were created for a number of clinical sites around the city and uploaded to the Metaio hosting server. The uploaded resources included descriptions of the clinical units, key staff members' contact information (e-mail and telephone), changing and parking facilities available, and transportation options to the site, including a live link for Google Maps © route planning (from the user's current location to the clinical site). These materials were used in one clinical course for the nursing cohort, and students were briefed on how to access the material on their first day. Additional geopositional content was also created for multiple on-campus locations during an orientation week multi-professional student mixer activity, involving 1100 students new to health professions education.

Data collection and analysis

To evaluate the student's perceptions of the educational value of the AR tools a web survey and follow-up focus group activity were implemented:

1. The survey explored student's levels of satisfaction with the AR resources they had available to support learning. Specifically, a) goal and focus of the resources, b) quality of the resources, c) practical usage of the AR resources and d) overall perceived educational value [31]. Additionally, two survey questions about the geolocation application were added into the survey evaluating the new to health professions student orientation. The surveys used Likert Scale questions and also included open-ended questions to elicit qualitative comments about user's experiences with the AR resources. An incentive of a movie gift voucher was used to encourage participation.
2. Participants in the survey were also invited to take part in a terminal focus group interview. An interview of 40 minutes was undertaken with seven volunteers to elicit further data regarding their perceptions of the value of this approach in their learning [32,33] An incentive of a $25 gift voucher was included for participation in the focus group.

The data from the questionnaires and focus group were transcribed and analysed using descriptive statistics and a content analysis performed using NVivio 11 software to explore for substantive concepts and relationships arising. Two independent researchers undertook the initial coding and a final consensus of key issues was developed from this.

Results

Survey

Student perspectives on AR implementation and value: The online survey was completed by 76 of a total population of 253 students giving a response rate of 30%. The shorter geolocation questions were answered by 73 of the 120 participants (response rate=76%). The responses to the 5 point Likert Scale questions are presented in Table 1 with questions arranged from highest mean rating to lowest.

Overall, responses were positive. The first three questions listed demonstrate some agreement on statements relating to the AR content being relevant, at the right level, and contemporary. Questions exploring the technology in content delivery, such as ease of use, logical and consistent presentation of the material, and overall assistance in helping learn the skills were generally neutral. The negatively phrased questions (on the value of AR as a gimmick) were also responded to more neutrally.

Statement (n=76)	**Strongly Agree (5)**	**Agree (4)**	**Neutral (3)**	**Disagree (2)**	**Strongly Disagree (1)**	**Mean**
The AR resources were focused on relevant specific skills.	9(11.8%)	43(56.6%)	21(27.6%)	3(3.9%)	0	3.8
The level of the resources was appropriate (i.e., it was not too simple or too difficult).	8(10.5%)	38(50%)	24(31.6)	6(7.9%)	0(0%)	3.6
The AR resources provided reflected contemporary knowledge and practice.	6(8.2%)	40(54.8%)	18(24.7%)	7(9.6%)	2(2.7%)	3.6
The AR resources were easy to use.	11(14.6%)	29(38.6%)	17(22.7%)	13(17.3%)	5(6.7%)	3.4
The AR learning resources reflected high technical quality throughout.	3(3.9%)	29(38.1%)	30(39.5%)	12(15.7%)	2(2.6%)	3.3
The AR items were well organized in a consistent and logical fashion that was easy to use and follow	4(5.2%)	30(39.5%)	27(35.5%)	12(15.7%)	3(3.9%)	3.2
The AR resources helped me learn the skills and knowledge required.	4(5.3%)	31(40.1%)	20(26.3%)	17(22.4%)	4(5.3%)	3.2
The AR resources provided additional information in the lab that will help me in my practice.	3(3.9%)	28(36.8%)	25(32.9)	16(21.5%)	4(5.3%)	3.1
The AR resources were more of a gimmick and not really helpful to learn (n.b. negative question)	7(9.2%)	19(25%)	11(14.5%)	28(36.9%)	5(6.6%)	2.9
Statements about the geolocation application (n=73)						
The Junaio App was easy to use to find directions to my meeting locations.	4(6.25%)	10(15.6%)	36(56.3%)	9(14.1%)	5(7.8%)	2.9
The Junaio App direction-finding resources were a gimmick and not really helpful in finding my meeting locations. (n.b. negative question)	8(13.6%)	13(22%)	35(59.3%)	6(10.1%)	3(5.1%)	3.2
Mean of all scores (when all ranked positively)=3.32, SD=0.28						

Table 1: Student survey scaled question responses. Students were asked to respond on a five point Likert Scale of 1=Strongly Disagree to 5=Strongly Agree. Values represent the numbers responding in each category and percentage response is given in brackets. Mean rating values of the Likert scores are given in the final column. Note, not all students answered every question.

Students' preferred media

Students were asked to rank their preference for the media used in the AR resources (from 1 (most favoured) to 3 (least favoured). Video resources were clearly the favourite form of media (81% ranked top) whilst text and PDF resources were less preferred: (Figure 3). The sample sizes and approach did not support within-group analyses (such as for variations between cohorts).

Technical issues, training and replacement of demonstration

Several themes materialised in data from the open-ended questions in the surveys. These are summarized below in Table 2.

Question: What problems (if any) arose using the AR resources? **Responses:** 31 responses. **Significant themes** (response and number of responses in brackets) Difficulty scanning (20), Internet Connection issues (8), Instability of application (3). **Illustrative quotes:** *"Some just didn't scan, you ended up trying from all different angles."* *"It wouldn't connect for me one time, just kept getting the "no connection" message."*
Question: Do you have any other comments on the use of AR resources in the clinical skills lab? **Responses:** 16 responses. **Significant themes** (response and number of responses in backets): Should not replace demonstration (9). Supplemental to the instructor (7). **Illustrative quotes:** *"Allowing the professors to DEMONSTRATE IN the lab and teach us is the most helpful way of learning."* *"It should supplement hands-on teaching from instructor instead of replacing the role of the instructor in the lab."*
Question: What suggestions do you have to improve the use of AR resources in the lab? **Responses:** 22 responses. **Significant themes** (response and number of responses in brackets): More training to use it (14), Provide more AR resources/videos (8) **Illustrative quotes:** *"I think inclusion of a good orientation would have been helpful. I only found out what the thing was from other students.* *"More videos produced by instructors would be good."*

Table 2: Key open ended question responses.

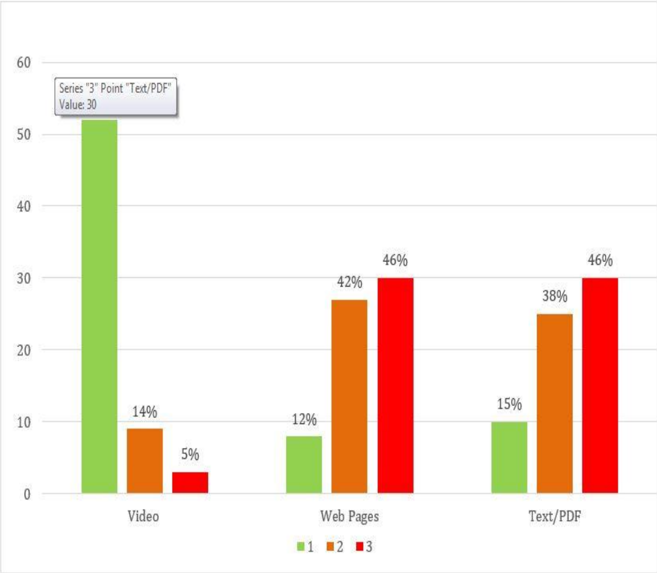

Figure 3: Student ranking of preferred media use (first, second or third) in AR applications.

Although responses were limited, one operational issue that was evident in these data concerned technical problems arising, as a number of students reported problems scanning objects and with Internet connectivity and slow times to download associated materials. Concerns were also expressed over the potential to replace actual skills lab demonstration by instructors with AR versions. Four students also commented that they would not want instructor demonstration replaced by video.

Focus group

Table three presents a summary of the results from the content analysis of the online focus group. Seven common themes emerged, representing aspects the students' responses: Access, content, future potential, orientation/training, pedagogy and technology. These appear to reinforce similar points identified through the online questionnaire survey. The identification of broad positive and negative commentary sub groups in table 3 illustrates the issues raised.

Broad Themes	**Sub-group (positive)**	**Sub group (negative)**
Technical	• Scanning flat objects worked best (6) • Good use of multifunctional smartphone technology (5) • Comfortable with the technology quickly (3)	• Scanning recognition difficulty (8) • Phone screens small (2) • Did not work on some devices (4) • Network speed slow (3)
Pedagogy	• Good supplemental resources (8) • Good for extra self-directed practice (5)	• Should not replace demonstration (6) • Inconsistent use of resources by instructors (6) • Not sure of added value (2) • Detracted from flow of practice (2) • Too many links on some items (2)
Content	• Videos were best (9) Videos created by our instructors most useful (6)	• Some videos were confusing (2) • Video was too long in some cases (4)
Mobile access	• Rapid access to information in situ (7) Review anywhere (5)	• -
Accessibility	• Able to use own devices (8)	• Frustration with limited access to devices (2) • Multiple students per screen (2)
Potential	• Use in clinical practice would be useful (3) • Geospatial metadata (geotagging) for practice site information (5)	-
Orientation/ Training	• Orientation was effective (2)	• Orientation was insufficient (6)

Table 3: Key themes arising from the focus group discussion (number of statements reflecting these issues in brackets).

Technical issues

The technical theme identified some positive aspects of the technology and some specific implementation issues. Participants noted that scanning two-dimensional (2D) objects worked very well, but 3D ones less so. Our data support the view that the technological approach can work effectively as a method of delivering targeted content, however, a number of significant technical issues were reported by participants. Notably, students reported scanning difficulties, as identified in the survey

"That's what I mean. I kept having to, like, re-log in, and nothing stayed on, even then scanning just didn't work sometimes" and *"Scanning some things didn't work but others worked really well."*

The way the AR technology made good use of multiple smartphone applications (camera, web-browser, and media player) was commented on positively by students and also one instructor. Several students reported that they felt comfortable with the technology quickly as they already used their smartphone, including the camera and browser: *"I use my smartphone all the time, and it was easy to add it."* Further work could benefit from identifying if those who do not experience technical problems respond differently to the AR technology compared with those who do, giving a sense of how significant these issues are in impacting the overall perceived value of AR.

Pedagogy

The next most evident thematic area was that of the pedagogic design of the sessions to incorporate the use of the AR resources. Students felt the resources could provide useful supplementary materials, and were especially useful for self-directed practice or review when learning new skills or techniques.

One student commented: "*Yeah, from a physio perspective we had a lot of equipment. We had like a dozen or so different pieces. So, it was nice to have the app to use on our own; but I wouldn't use it if there was an instructor around*." Another stated: "*It was good for individual review.*"
Negative perceptions of the pedagogic approach were also evident, with a number of students reporting concerns that this approach should not replace demonstration by the instructor: "It was useful for troubleshooting but it doesn't replace the instructor."

Some students felt that the use of the resources was inconsistent in the labs: "One thing that I noticed in our lab group was that our instructor often, umm, disagreed with the way that things were done in the video." and *"Most of us didn't even know what it was when we started our lab. Like, I don't even know if our clinical instructor showed us."* Two others felt the use of smartphones and scanning items did not add value and disrupted the flow of the labs. Two students also noted that they felt some of the AR items had too many links to resources: *"Some were confusing with a lot of different buttons on the screen."*

Content

The type of content preferred by the participants reflected the responses from the survey with video resources being highly preferred. Some students felt that the internally created videos were of most benefit: "What I liked about the videos that we got off those was that they're new – like, a lot of the stuff that they're linking to our modules for labs are videos from, like I swear to God, like 25 years ago." A couple of students reported the web videos (not in-house produced) as confusing: *"There are so many different ways to do everything, not sure the videos helped me."* The length of the video clips also created some commentary with a length of two to three minutes' maximum being identified as preferable by the students.

Mobile access

Another theme identified was the value of mobile access. Several students commented that it was valuable to access these resources in-situ in the lab, and others that they liked being able to review the content anywhere:
"As soon as they said, "Go, explore," we had time to use it."
"Being able to play the videos on my phone by the actual equipment was cool."

Accessibility

Another motif that arose reflected access to the technology. Several students identified that they liked being able to use their own smartphones, but some expressed concerns not all devices currently supported the app: "It didn't work on my phone." and one students noted: "We ended up crowding around a phone screen, as it didn't work for some phones."

Future potential

The future potential for this technology was also discussed in the focus group, including the potential to use GPS based geotagging. One student and one instructor noted that they felt educational AR resources would be useful to have available in clinical areas, such as for orientation information. One student commented: "*Yeah, when you used it, it would tell you how far away the area is; you can tap and get a bus route there, or Google Maps*."

Orientation

Finally, a last theme regarding the orientation of students to using AR arose. Of the students who commented on this area, two felt the orientation to using the Junaio resources was sufficient, six felt that is was not. Some instructors did not follow the AR briefing given or had forgotten. For example, one student noted *"There was eventually an orientation, but there was too much of a time gap. It was, like, here's this sheet of paper explaining this* *thing…"* and one student noted: *"Some instructors didn't know about it."*

Discussion

Key parallels between the survey and focus group findings emerged regarding the technical issues and pedagogic approach. Students were clearly comfortable with the technology and identified the ability to access resources to support self-directed learning and review of skills as positive attributes of using AR.

The results revealed that the use of smart phones and tablets allowed easy access to the resources. However, technical issues such as scanning problems, slow Internet response times and incompatible smartphones frustrated students, potentially having a negative impact on their learning. Technical problems with AR can quickly become an issue and an indicator of student dissatisfaction with the learning experience. Whilst new technologies can motivate and enhance student learning, making instructors comfortable with using new technologies is an essential aspect for gaining a positive impact on learning [34]. This highlights the need for effective faculty training and support to successfully integrate these new AR technologies in the lab [34,35].

Aside from providing support for the use of AR, pedagogic integration requires careful attention. A clear agreed pedagogic strategy for AR use across instructors in the labs is important to establish at the outset. The evaluative data suggest some positive impact of the AR tools on student learning, especially the value of mobile access to video resources to supplement learning and to support self-directed modes of learning. Concerns were expressed about replacing direct instructor-led demonstrations, but there are potential benefits to using standardized AR video content as supporting resources. In particular, having the option of reviewing video resources at the point of completing the hands-on practice of the skills was viewed as valuable. AR can improve access to learning resources, by making them easy to locate, relevant to the specific equipment being explored (at point of contact with equipment, rather than searching through a list), available on-demand, and provide easy transfer of the supporting resources away from the equipment for later review.

Overall, the importance of having clear goals in mind for using AR technologies is apparent, as the purpose and utility will be more evident to learners when they see the relevance and value in their learning process [36].

One other potential impact from AR, borne out by this study, is the ability to use AR to build capacity in lab sessions where the student to instructor ratio is high. In situations such as these, having AR-linked instructional resources can help to reduce student frustration at not getting help immediately from an instructor or teaching assistant.

Learning clinical skills is considered a developmental process where repeated practice leads to increased confidence and competence [37]. Creating an environment in which students can achieve rapid success in developing clinical skills leads to greater confidence, Promoting active learning in this context is necessary and finding a balance between teacher-guided and student self-directed learning and the fit of AR in this process is important. Using AR resources to supplement student learning and practice of skills does not remove the teacher from the learning process but enables the teacher to become a greater part of the whole learning environment that supports the learner. Albeit an important part, the teacher is not the centre of the learning experience and teachers using AR can support an active role in directing learning by providing access to resources when and where they will provide the most benefit to the student. Students supported this notion in their positive feedback regarding the value of mobile access and having the resources available "at the bedside" where they were practicing.

Limitations

This study has a number of limitations. First, the exploratory nature of the work, sample size and the non-probability purposeful sampling may mean results are not generalizable. Additionally, students self-selected for study participation. The technological immaturity of the applications is another limitation. We were able to draw some conclusions, but in a future study it would be advisable to further test AR interventions before the start of a larger research study, e.g. in a pilot.

Conclusions

This exploratory implementation of AR met with mixed results. Nevertheless, as AR technologies are now entering mainstream use their educational potential needs further exploration. Geographically situated (geolocation based) AR to support m-learning may prove useful to provide information related to specific spaces, such as orienting students to labs or clinical sites in-situ. Mobile device displays may also provide promise for learning technical skills, or manipulating clinical equipment. For example, becoming familiar with how to use a new physiological monitoring device. Exploring clinical learning AR applications in actual clinical settings is another area where work is needed.

The potential for students to use technologies they already possess in AR based m-learning may offer significant advantages, and offer a practical way to increase learner engagement. Educators need to continue to explore how to implement these developing technologies most effectively with careful attention to the technical solutions available and learner preferences. Carefully planned curriculum integration, incorporating systematic orientation of AR, is most likely to lead to successful outcomes.

The optimum pedagogic strategies for implementing AR into mainstream educational practice remains to be identified. Nevertheless, an important first step to the implementation of any pedagogic technology innovation is to understand its potential value and possible limitations, and the benefits of AR to supplement student learning in this case were evident. It appears that AR technologies do have some potential to enhance the learning of clinical skills in the lab, and augment clinical education in practice. But there remains a need for continued development of the tools with an educational focus.

In the case of learning clinical skills, where hands-on interaction on the part of the learner is critical in order to increase confidence and competence, using mobile teaching strategies such as AR seems to offer significant promise to facilitate m-learning in a cost-effective manner.

Acknowledgement

The authors would like to acknowledge the support of the University of British Columbia Teaching and Learning Enhancement Fund for funding this work.

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Received date: October 11, 2017; **Accepted date:** November 01, 2017; **Published date:** November 10, 2017

Citation: Garrett B, Anthony G, Jackson C (2017) Using Mobile Augmented Reality to Enhance Health Professional Practice Education. *J Health Sci Educ* 1(3): 121.