Collaborative VR Simulation for Radiation Therapy Education

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Abstract Cancer is the cause of over 16% of deaths globally. A common form of cancer treatment is radiation therapy, however, students learning radiation therapy have limited access to practical training opportunities due to the high demand upon equipment. Simulation of radiation therapy can provide an effective training solution without requiring expensive and in demand equipment. We have developed LINACVR, a Virtual Reality radiation (VR) therapy simulation prototype that provides an immersive training solution. We evaluated LINACVR with 15 radiation therapy students and educators. The results indicated that LINACVR would be effective in radiation therapy training and was more effective than existing simulators. The implication of our design is that VR simulation could help to improve the education process of learning about domain specific health areas such as radiation therapy.

1 Introduction

Cancer was responsible for an estimated 9.6 million deaths in 2018, accounting for about 16% of all deaths globally [36], and it is estimated that 40% of people will have cancer at some stage of their life [28]. Radiation therapy is a common form of treatment and is in high demand. The Royal College of Radiologists found that the average wait time from diagnosis of cancer to the beginning of radiation treatment in the UK was 51 days, with some waiting as long as 379 days [9]. Radiation therapy

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requires highly trained operators, however these operators have limited access to practical training due to the cost of, and demand for, specialized equipment.

Medical Linear Particle Accelerator (LINAC) machines (Figure 1) are used by radiation therapists to deliver targeted radiation to tumors for the treatment of cancers. For this procedure a patient is positioned on a motorized platform called a treatment couch, and once the patient is in place radiation is delivered from a part of the machine called the gantry [27]. These two pieces of radiation equipment are important for therapists to learn to position correctly.

Patients undergoing radiation therapy treatment often experience severe psychosocial stress [25] and psychological distress [26]. Rainey [23] found that radiation therapy patients who had undergone a patient education program providing them with more information about the upcoming procedure experienced significantly less emotional distress from the procedure. They found that 85% of patients reported that they would like to learn more about radiation therapy.

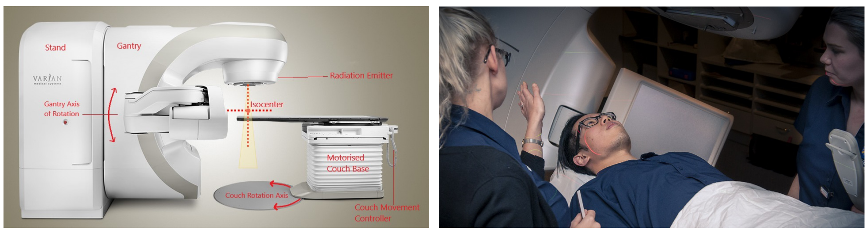
Carlson [5] discusses six reported errors during radiation therapy. Five errors involved delivering radiation to the wrong area, and one used considerably higher levels of radiation than the treatment plan listed. Events like these can put patients at risk of serious harm. They found that an important way to minimize the risk of incidents such as these is to have clear procedures that the therapists are thoroughly trained in. Kaczur [15] reported that the medical radiation accidents with most severe consequences, such as severe burns or internal damage, were related to mis-calibration of radiation therapy equipment. Similarly to Carlson, Kaczur found that the cause of these accidents was usually poor radiation education and training.

Radiation therapy students must train extensively in the use of Medical LINAC equipment. A LINAC machine can cost several million dollars (USD) to purchase and up to a half million dollars in annual operational costs, with a lifespan of approximately 10 years [12]. This makes it financially infeasible for an educational facility to have a dedicated LINAC machine for students to train with. It is vital, however, that students are able to train sufficiently before they interact with real equipment or assist with the treatment of real patients. Students typically gain their first experiences with LINAC machines during observational placements within the hospital, and later through practical placements. Opportunities for inexperienced students to actually practice with real equipment are limited due to the high demand for radiation therapy treatment. A training simulation in which inexperienced students can familiarize themselves with LINAC machine operation would enable them to go into the work force with a more comprehensive understanding of the equipment and environment. This would allow them to gain practical experience earlier. Additionally, a virtual simulation can allow students to experience, and to train in dealing with, negative scenarios such as errors causing mis-calibration and misalignment [3]. An effective simulation would also allow experienced students to further develop their skills in a risk free environment.

In order to increase the effectiveness and reduce the cost of radiation therapy training we have developed *LINACVR* which is able to simulate a LINAC machine and environment in VR. The application involves two simulation scenarios. The first simulation allows radiation therapists to learn and practice the operation of a LINAC machine. The second simulation shows the experience of the radiation treatment procedure from the perspective of a patient.

2 Background

Medical LINACs treat cancer by delivering targeted high precision ionizing radiation to the tumor. This is done across multiple regular treatment sessions which vary depending on the cancer being treated, but is often between 10-40 sessions. Figure 1(a) shows a labeled Vairan TrueBeam LINAC machine [33], the same model of machine that is common in radiation therapy departments at hospitals. The machine being operated in Figure 1(b) is also a Varian TrueBeam.



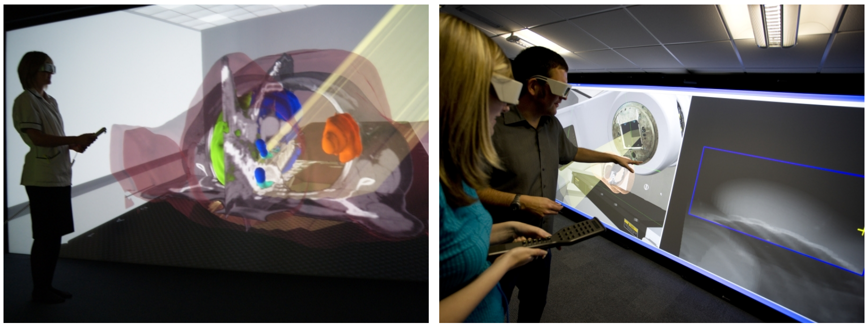
(a) An annotated image of a Varian TrueBeam LINAC machine [33].

(b) Radiation therapy students positioning a patient in a LINAC environment.

Fig. 1 Medical Linear Particle Accelerator (LINAC) for radiation therapy.

The radiation is generated within either the stand or the gantry, and is directed out of the emitting collimator head of the gantry and through the patient [22]. The exact path and shape of the radiation can be finely tuned by the radiation therapist based on a treatment plan specific to each patient. In Figure 1(a), the yellow diverging triangle coming out of the gantry head represents the radiation. The isocentre is the intersection of the center of the radiation and the horizontal axis of the gantry. This is where the center of the tumor must be in order for the radiation to properly irradiate the cancerous cells. Indicators of the location of the tumor are marked with tattoos externally on the body of the patient. These tattoos are placed based on a digitized plan created using a 3D scan of the patient, and are used by the radiation therapists to triangulate the internal location of the tumor. The tattoos are lined up with a laser grid projected onto the patient, allowing correct repeatable positioning of a tumour in the isocentre. While radiation is being emitted, the gantry rotates around the horizontal axis, passing through the space under the end of the couch. Ensuring that the gantry does not collide with the couch is vital.

To position the patient so that the tumor is at the radiation isocenter, the treatment couch can be moved. This is done with a couch movement controller, known as the "pendant", where the student on the right of Figure 1(b) is using one. The couch on a modern treatment couch is motorized and can move and rotate in almost all directions, although some older designs support less of these. The couch is able to both move and tilt up, down, left and right. It can also rotate around a circular path on the ground, labeled as “Couch Rotation Axis” in Figure 1(a).



(a) Educator exploring digital anatomy. (b) Students exploring a virtual LINAC.

Fig. 2 VERT simulation of radiation therapy [2, 21, 34, 35].

In order to allow students to learn and practice LINAC operations without access to an actual machine they must initially be trained using simulation. VERT (Figure 2) is the only available training simulation for radiation therapy [2, 21, 34, 35]. VERT involves projecting imagery onto a large screen in front of a student to represent the 3D LINAC environment, and a controller resembling those used for controlling a treatment couch. To provide depth perception to the imagery 3D glasses are worn. This means that users cannot interact with the simulation as though they are present in the treatment room. Due to this, students cannot practice manually positioning the patient by hand, an important skill to learn. Instead they are limited to performing alignment by moving the treatment couch. VERT only supports one user at a time, but typically there are at least two radiation therapists working together. A simulation that supports collaborative operation by multiple simultaneous users would allow students to practice in a way that more closely resembles the actual environment, and develop more relevant operational and communication skills. VERT can cost up to $1,000,000 (NZD) which makes it very expensive for teaching institutions. VERT is not fully immersive so students may not be able to fully experience a realistic environment, and may therefore have difficulty applying what they have learned to a real life treatment. A fully immersive low cost VR simulation would give students a more affordable and easier way to familiarize themselves with LINAC operation in a way that is more directly applicable to the real world, which is what we propose with LINACVR.

Kane [17] conducted a review of the current state, effectiveness, and usage of VERT. He found that VERT is the only widely used training solution, and is generally considered effective compared to traditional non-interactive media. A primary limitation is the inability to manually position a patient on the couch and is an important skill to learn. Kane [16] further explores the impact that VERT has had upon the the radiation therapy teaching program at Otago University and found that the integration of VERT as a training tool had difficulties but the simulation in the training of radiation therapy had significant potential. Leong et al. [18] studied the effects of using VERT in the training of the planning of treatment, and found that it increased the perceived conceptual understanding of the procedure for students.

Collaboration is important in radiation therapy and various studies have examined this aspect in virtual environments. Cai et al. [4] developed a multi-user application to simulate the planning of radiation therapy. In their application, physicians in remote locations were able to collaboratively perform a radiation treatment planning procedure. This allowed them to successfully collaboratively develop patient treatment plans without requiring the actual physical equipment. While this application intended to develop treatment plans for patients rather than to train therapists for machine operation, this still demonstrates the advantage of collaborative simulation when access to radiation equipment is limited. Churchill and Snowdon [6] examined a range of designs for collaboration in a virtual environment. The primary focus is the affordance of communication. Real world collaboration involves large amounts of both implicit and explicit communication. In order to achieve this, a collaborative virtual environment should be designed in a way that allows many channels of communication. Fraser et al. [11] examined the differences between collaboration in VR and the real world. One example is the limited field of view in VR. Humans have a horizontal angle of vision of around 210 degrees including peripheral vision, whereas VR headsets are around 110 degrees. This can lead to confusion in communication in VR, as users will often think that another user can see something that is in fact outside of their vision. They suggest visually indicating the field of view of other users, in order to explicitly show users the limitations of the system.

Simulation training in healthcare has been widely adopted including the use of VR. Cook et al. [7] conducted a systematic review of 609 studies evaluating the effectiveness of simulation for the education of health professionals. They found that simulation training consistently provided participants with large positive effects in terms of knowledge, skills, and behaviours, and moderate positive effects for patients. Across this review, only four percent of the studies did not show any benefit. Mantovani et al. [19] reviewed and discussed the current state and usefulness of VR in the training of healthcare professionals. They found that VR provided significant benefits over traditional training and education methods such as print and film media. Many knee injuries can be treated through arthroscopic surgery, however most training tools have issues due to cost, maintenance or availability. Arthroscopy surgery involves using tools and sensors inserted through small incisions, and so the tools cannot be seen by the surgeon while they are using them. Hollands and Trowbridge [13] provided surgical training simulation for knee surgeries where they used 3D representations of the geometry of a knee to allow surgeons to practice the operation in VR. VR allowed these surgical tools to be made visible, so that the surgeon can learn the correlation between manipulation of these tools and how the knee moves internally. Davies et al. [8] evaluated the effectiveness of using VR simulation for clinical X-ray imaging with 17 healthcare students. The study found that most students were both more confident with being present for the X-ray procedure, and had a better understanding of where to stand during the procedure.

A recent state-of-the-art report by Schlachter et al [24] on visual computing in radiation therapy planning. They concluded that it is not easy to introduce new approaches in the clinic but with the exception of applications for training and education. They also stated that radiation therapy is a patient-oriented process and that visual computing and radiation therapy people need to collaborate more especially the interface between hospitals, universities and companies. Our work builds upon these areas by developing a novel VR system for radiation therapy education using the latest VR headset technology.

3 LINACVR for Radiation Therapy Education

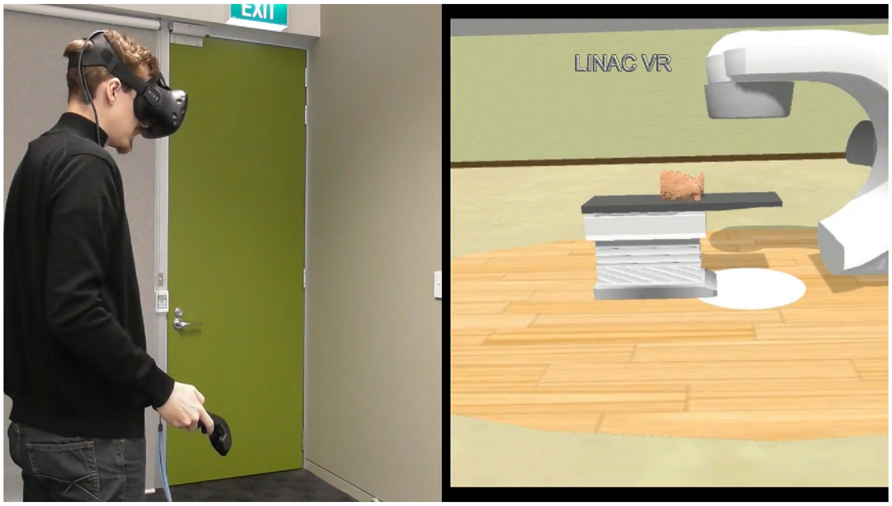
Simulation and VR simulation have shown to provide effective training benefits and transferable skills in healthcare education. We present *LINACVR* which is the first VR simulation radiation therapy treatment tool for both therapist training and patient education (Figure 3). LINACVR includes a multi-user simulation for both patient education and for therapist training, and a portable headset version for the patient perspective simulation.

3.1 User Interface

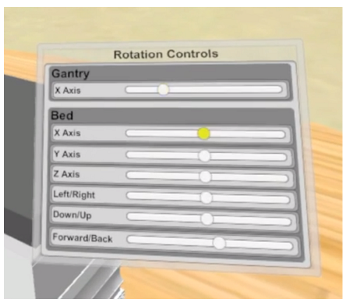
Figure 3(a) shows a user with the VR headset and controllers interacting with the patient and treatment couch. A 3D representation of a patient is constructed from Digital Imaging and Communications in Medicine (DICOM) data files. The patient model can be manually moved by interacting with it directly using the VR controllers. The treatment couch can be moved using a series of slider bars within a virtual menu panel (Figure 3(b)). The patient model and individual organs can be made transparent using similar slider bars in order to allow therapists to see the internal location of the isocenter. A projected laser grid indicating the location of the isocenter can also be activated.

When a user first loads the collaborative simulation and equips the headset, they find themselves in the LINAC treatment room facing a user interface, giving them the option to either host a session or join an existing one. Once an option is chosen, the user is placed closer to the equipment and patient model and can now interact with them. From here they can see other users who already joined or can wait for others to join the session. The users can then perform the LINAC procedure, with the actions of each also occurring in the simulations of the others.

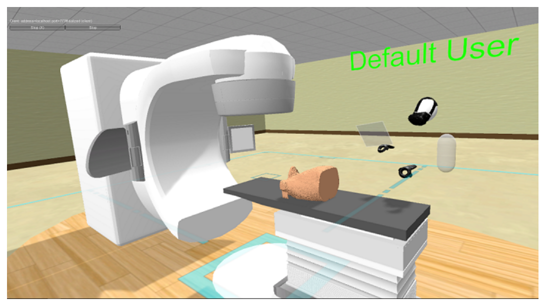
Figure 3(c) shows a remote user ("Default User" represented by controllers and headset) standing next to the LINAC equipment and using a menu as they appear to



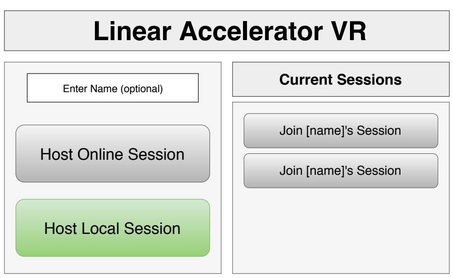
(a) User with VR headset (HTC Vive) and controllers viewing the gantry, couch, and patient model.



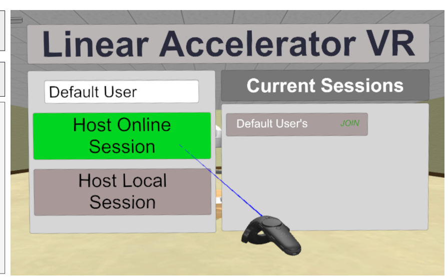
(b) The slider bar system for adjusting treatment couch position.



(c) A remote user (VR controllers and headset) standing next to the LINAC equipment and using a menu, as seen by a local user.



(d) Networking user interface. Host Local Session button is being selected (green).



(e) Networking user interface. Host Online Session button is being selected (green).

Fig. 3 LINACVR for simulation of radiation therapy.

a local user. Users joining this session will follow the same process as in the collaborative simulation. Each user is visible to others through a set of models representing the head, hands, body, and name of the user. The position of the head and the hands are based upon the position of the headset and controllers for that user, while the position of the body and name are calculated based upon the position and angle of the head. The reason that the body position is extrapolated rather than tracked is that the VR sensors can only detect specific tracking devices present in the headset and controllers. The VR controllers are used to represent where the hands are located. The body is a transparent capsule shape which represents the spatial area filled by a user than an accurate location. The head is represented as a VR headset which is influenced by a recommendation from Fraser et al. [11], who suggest explicitly showing the limits of field of view of other users in order to avoid miscommunication. The head representation also reminds users that the other person is wearing the same headset as they are, serving as a further reminder of the angle of vision. For example, by looking at this headset we can tell that the other user is looking at their menu, and that the view of the other user is slightly outside of their field of view.

Figure 3(d) shows the network selection menu. From this menu users can choose to host an online session, host a local network session, or join an existing session. A session name can also be entered, which is important for differentiating between sessions if there are multiple running. The session name is also displayed over the head of a user, identifying them to others in a session. The buttons are gray by default and turn green when currently selected.

Figure 3(e) shows the network user interface for the collaborative simulation. In this example there is one session currently being hosted, this is shown in the panel on the right. The patient perspective user interface shares the same layout and design, but uses slightly different text. The menu takes the form of a wall sized set of panels extending from slightly above the floor to slightly below the ceiling. It is interacted with by the user via a laser pointer that extends from the end of one of the controllers. When a button is pointed at, as Host Online Session is in Figure 3(e), it is highlighted green. By pulling the trigger on the controller, the highlighted option is selected. The reason for the large size of the menu comparative to the user is that it aids the ease with which they can correctly point the laser at a button and pull the trigger on the controller. After selecting the text box in the left panel containing the placeholder text 'Default User', a user can then type on their keyboard the name they want for their label and session. This requires the user to temporarily remove the headset, but could be implemented using a virtual keyboard in the future.

The patient perspective simulation functions in the same way as the multi-user except that the user hosting the session will find themselves placed on the treatment couch in the perspective of a patient while the other user is the therapist. Figure 4 shows the views of the patient (left) and therapist (right) who is adjusting the treatment couch using the movement controls and has turned on the laser grid for patient alignment. This means that the user can get used to the room and environment before being joined in the simulation by a therapist. This order is important, as the therapist will generally need to be observing the patient in the real world as they acclimatise to the simulation before they can join. This also means that the patient perspective

Fig. 4 Left: Patient perspective view. Right: Patient perspective therapist view.

simulation can be used by just one user. To ensure that the patient user sees the simulation from the perspective of someone who is lying on the couch, the translational movement of the headset is locked. This means that if the patient moves within the physical space they will not move within the virtual space. Rotational movement is allowed, and so the user can look around within the simulation as they would be able to during the actual procedure. The controller models for the patient user are hidden in the view but they can use them to control the movement of the gantry. As the treatment procedure shown to the patient is performed by an actual radiation therapist, they can tailor the experience to the exact treatment plan that the patient will undergo. This gives the patient a much more accurate preparatory experience, as the patient experience for different treatments can vary significantly. The therapist user has been deployed to an HTC Vive while the patient user has been deployed to an Occulus Go (wireless headset). This wireless VR headset allows us to demonstrate the patient perspective to patients in isolation or in a distributed environment where they can communicate with a radiation therapist at a different site. To further enhance the scenario patients can lay on a physical table while the therapist can physically walk around the environment.

3.2 Implementation and Architecture

The simulations were developed in Unity3D [31]. A Unity application is constructed from objects placed in a 3D space, with scripts containing code attached to them. These scripts were written in C#. The multi-user applications are exported as executable build files. The application uses SteamVR library [32] which acts as a bridge between the application and the HTC Vive. The portable patient perspective simulation for the Oculus Go was also developed with Unity3D, but uses a combination of Android Studio [1] code libraries and the Oculus Core Utilities Unity library.

As the users of LINACVR may not necessarily be proficient with technology, it is important that the multi-user simulation runs without any manual network configuration. The network design goal has been to make launching a multi-user simulation no more difficult than launching a single-user version. For this reason the client-server architecture has been designed to not require a dedicated server. In many multi-user programs, there is a dedicated server program, which is then connected to by all of the users (the clients), using a separate client program. This server is then responsible for all communication between the clients. The server, running as a separate application, would receive input from the clients, process it, and then distribute the current program state back to each client. The issue with this design is that setting up a server creates another layer of tasks that a user must complete in order to start the simulation. Addressing this, and reducing the amount of expertise required to run a multi-user simulation, the server functionality is contained within the LINACVR program rather than being a separate program. This network design is known variously as both "peer to peer hosted" and "listen server" architecture. It is worth noting that in some strict peer to peer designs there is no server at all, and all clients share the responsibilities of a server. This however can cause large issues and delayed feedback when users are performing simultaneous actions, as each user must wait for an update on the actions of all other users every network refresh [10]. To avoid this, the chosen design uses some of the distributed processing of the peer to peer design, with the authoritative server of most listen server designs. As seen in Figure 5, in this peer hosted system design the program of the host user simultaneously and automatically acts as a server and a client. This means that there is only one program version needed for any user, and this version is able to act as both a host server and a local client, or just as a remote client. This design is easier to run than a dedicated server, and unlike a full peer to peer system the number of network connections per user is not exponential.

The network architecture has been developed using the Unity Multiplayer High Level API (HLAPI) [29]. The core of this implementation is a script called LinacNetworkManager, a class that extends the UnityEngine NetworkManager class. Through this, LinacNetworkManager is able to interface with, extend, and control the HLAPI functionalities. LinacNetworkManager manages the stopping and starting of server hosting, the creation and connections of clients, and the creation and joining of sessions. The setting up and maintenance of connections between

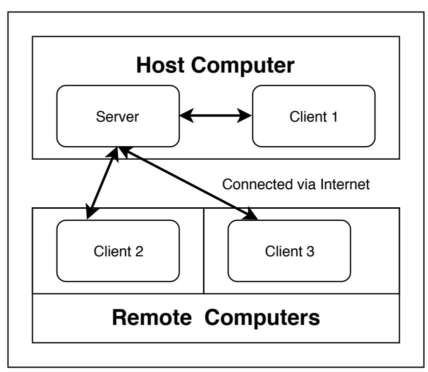


Fig. 5 LINACVR peer-hosted client/server architecture, showing a host computer running a local client and a server, which is connected to by two remote client computers.

remote clients and the server has been implemented using the Unity Internet Services platform [30]. An important advantage of this service, and a primary reason that it was chosen, is that users do not need to know or enter the IP address of the other users that they are connecting to. This gives greater convenience and accessibility to less technically experienced users, and drastically reduces the time taken to set up the simulation. Unity Internet Services allows the connection of up to 20 concurrent users across all sessions at any one time without any hosting costs. Sessions hosted on a local network using the 'Host Local Session' option are not effected by this limit, and have the added advantage of considerably lower latency due to not using an external match hosting service. The limit refers not to the number of actual users but to the number of potential users at any time. This means that if one online session containing only two users is running that has a user capacity of 20 users, then no other sessions can be hosted. For this reason the network is currently configured to allow online sessions a maximum capacity of four users. This limit was decided due to normal collaborative usage of LINAC equipment involving low numbers of operators. If the use of this needs to change to require larger sessions, for example if an institution acquired many HTC Vive units and wishes to use this simulation in a lecture type format with many simultaneous users, this limit can be easily raised using a 'Max Connections' field in the Unity Editor which interfaces with the LinacNetworkManager script. This LinacNetworkManager script is the main interface between the system and the matchmaking functionality given by the UnityEngine NetworkMatch class.

4 Evaluation

To evaluate the effectiveness of LINACVR for simulation of radiation therapy education we conducted a user study. The simulation is designed to be used by radiation therapy students and radiation therapy educators, and so these people were the target participants for this study. The aim of the study was to evaluate the multi-user and patient perspective features and the simulation in general by addressing the following questions:

- How easily do users learn how to operate the simulation, controls, and interface?
- How effective is manually positioning the patient?
- How effective are the couch controls for positioning the patient?
- How effective is the multi-user feature?
- How effective is the patient perspective simulation?
- How effective would this simulation be in training to use LINAC machines?
- How does this simulation compare to existing LINAC simulation programs?
- In what ways could this simulation be improved in the future?

Participants were recruited from the Department of Radiation Therapy at the University of Otago, Wellington. Any student was considered eligible for the study if they had used, or experienced any computer simulations of LINAC machines. Similarly, any educator was considered eligible if they have taught the use of LINAC machines in any sort of educational capacity. The participants were recruited through email mailing lists, and the researchers advertising the study in person during student lectures at the university. Upon completion of the study, participants were awarded an honorarium in the form of a $10 supermarket voucher. We recruited 15 participants, 11 of these being students and 4 being educators.

This study was conducted in a clinical examination room at the Victoria University of Wellington hospital campus which is right next to the Department of Radiation Therapy. The edges of the room was set up within the headset as a border for the SteamVR Chaperone system. This created a grid in the virtual space to prevent participants from walking outside of the cleared space and colliding with real world objects. This was essential for when the experimenter was also in the virtual space, as they cannot be watching the participant at all times.

The user study was conducted over three days. Each user study was a one on one session between the participant and the experimenter, and lasted approximately 60 minutes. The study was a within subjects study, where all participants were exposed to all study conditions [20]. Participants were given an information sheet, consent form to sign, and a pre-study questionnaire. Each participant was screened for nausea via verbal questioning. Participants were then given some training time with LINACVR where the features and control options were demonstrated. Participants then completed the study tasks for each of the scenarios: individual and then collaboratively with the experimenter acting as another educator. Participants then experienced the collaborative and the portable version of the patient perspective. The study was then concluded with a post-study questionnaire and follow up interview. During the study participants were regularly asked whether they are experiencing any motion sickness.

The study tasks are as follow and repeated for both times the participant performed the two scenarios.

1. Navigate to the equipment, either by teleporting or by walking.
2. Manually adjust the patient on the bed.
3. Turn on the laser grid to aid positioning.
4. Move the bed using the menu controls.
5. Line up, through preferred combination of manual adjustment and bed positioning, the isocenter with the indicators.
6. Use transparency controls.
7. Initiate radiation delivery.

Data collection took the form of two questionnaires and observation notes taken by the experimenter during the session. The first questionnaire was a pre-study questionnaire in order to determine background factors such as experience with the various technologies involved. The second was a post-study questionnaire about the participant's experiences with the simulations. The first 11 questions in this survey were Likert Scale questions, recording the participant's perceived effectiveness through ratings from 1 (Very Ineffective) to 5 (Very Effective). The remaining 4 questions sought qualitative responses via free text answers.

5 Results

We now present the results from the user study from a quantitative and qualitative perspective based on responses from the the post-study questionnaire.

5.1 Quantitative Data

Figure 6 shows the ratings for each Likert scale question in the post-session questionnaire for all participants. The colour representation is green (Very Effective) to red (Very Ineffective). From this data we can see some interesting features. From this we can see that the median rating for every question was Effective, and that no question received less than two thirds of its ratings being positive. Some participants gave generally higher or lower ratings than others. Comparing participants number two and three we can see this trend, with two giving consistently higher ratings. Reasons for these differences can often be explained in some form by the information given in the pre-study questionnaire. In this specific case, participant two was a first year student with six months practical experience and little exposure to virtual reality or to VERT. Participant three however was an experienced radiation therapy educator and specialist practitioner. This could indicate that those with higher experience with LINAC machines have higher expectations of functionality or realism due to their increased experience with the real environment. This is corroborated by the fact that participants six, seven, and ten were the other educators involved in this study, with both six and ten giving relatively lower scores than most participants. However, participant seven gave relatively high scores however, so this relationship likely bares further investigation. We now discuss the results from the four open ended questions.

5.2 Question 1: What differences did you notice between this simulation and the real world LINAC environment?

The most frequent reported difference given was sound. Participants pointed out that in real life the LINAC machines make a considerable amount of noise, mainly when they are activated and emitting radiation. Many verbally noted that this was particularly important for the patient perspective simulations, as the noise made by

Fig. 6 Likert Scale Results from post-study questionnaire, 11 questions.

a LINAC machine was likely to be one of the most frightening aspects of treatment. As both headsets support binaural audio, this could make a valuable and effective addition to the project in the future.

"No radiation sound." - PID 1
"Lack of sound." - PID 3
"Lack of sound made a difference as often LINACs can be relatively loud." - PID 4
"Sound the machine makes as it delivers RT." - PID 6
"First thing to notice is sound - LINACs are noisy!" - PID 10

An aspect commonly mentioned differences was the LINAC control pendant. While the menu system and Vive controller have the same functionality as a pendant controller, it seems that it is still very different to use.

"Hand controls different to LINAC pendants." - PID 1
"Controls of the LINAC are important, touch controls take some getting used to." - PID 3
"LINAC controls are more easier to get mm movements for accuracy." - PID 8
"Controllers feels very different." - PID 11

The positioning of the patient using bed controls received overall quite positive ratings, indicating that this is not an issue based on difficulty of use in the simulation, but rather of the quality and transferability of training with the actual controls.

"Manual couch movements." - PID 7
"We move the couch manually more often than using the pendants of the couch controls to make the required adjustments." - PID 8
"Scale of couch is similar, the machine feels smaller." - PID 10
"Different way of using couch controls." - PID 13

A common comment was that in the real world it is much more difficult to manually position a patient. Seemingly due to how hands on it is to physically move a patient in real life, operators are less likely to choose to do so instead of moving the treatment couch compared to how likely they are in this simulation.

"Much more hands on in the real world in terms of handling the patient." - PID 5
"Equipment to position immobilise a patient." - PID 7
"Unable to roll patient's skin when positioning. Aside from the using the remote to adjust couch position., RT's commonly use controls underneath the couch and on the floor next to the couch. This component is missing from the VR simulation." - PID 9
"It was easier to setup the patient with the VR simulation." - PID 12

A further difference that was mentioned by multiple people was the terminology used to refer to planes of direction. Where in this simulation the directions are refereed to as forward/backwards and up/down, the equivalent terms used by therapists would be superior/inferior and anterior/posterior. The directions of left and right use the same words, but in the medical context the directions should be from the perspective of the patient, not the operator as in this simulation. The directions are also used in reference to the laser positioning lines. For example, a therapist might say to their colleague: "Please move the patient superior from the horizontal laser", rather than "Please move the couch forwards."

"Different terminology forwards/backwards vs superior/inferior." - PID 13

Many participants reported that the motorized movement of the couch and gantry is a lot slower in the real world, making it considerably easier to accurately position a patient with higher precision. Apparently some treatment couches have a manual, non-motorized, mode for large movements and then slow motorized controls for precise positioning. One participant suggested having more gradual movements, but a feature to speed movement up if required.

"Slower gantry." - PID 1
"In the real world the bed moves slower, more momentum, e.g. with heavy patient." - PID 15

There were also many other small differences related to visual feedback such as: Tattoo marks being crosses so that they can line up with the laser grid, tattoo marks being on both sides of the patient, lasers being thinner in real life, viewing patient organs, real room being darker, and a light field being emitted from the gantry head for some treatments.

"The lasers are only 1-2mm thick." - PID 2
"We can view certain organs on the machine rather than imaging it." - PID 5
"Darker room, X tattoo marks to align to." - PID 6
"Markings on skin." - PID 7
"Skin marks are important to visualize during patient positioning." - PID 13
"Light field can be helpful for breast setups." - PID 14

As a tool for training purposes some participants thought LINACVR could be quite useful, helpful, and complementary to exisiting tools and techniques.

"The detail of the machine were minimal, however it was beneficial for giving an overall impression of a LINAC bunker and could be quite useful for training." - PID 4
"LINACVR could be complementary to several current training programs." - PID 10
"Some aspects of LINACVR could be helpful for training." - PID 14

5.3 Question 2: How did this application compare to any other LINAC simulation programs you have used (e.g.: VERT)?

It is worth noting that in the pre-study survey no participants reported having used a LINAC simulation other than VERT in the past. Similarly, all answers to this question compared LINACVR to VERT as the participants had no other simulation experiences.

Comparisons to VERT were almost exclusively positive towards LINACVR.

"Really great but I have not used VERT much before." - PID 2
"LINACVR was a lot more user friendly than my experience with VERT." - PID 4
"Fills many of the gaps in experience offered by VERT." - PiD 7
"Would be way more useful than VERT in preparing students for the clinical environment." - PID 13
"So much better than VERT." - PID 14
"Much more immersive + similar to real world application." - PID 15

A common comparison was that LINACVR gave a simulation that was more interactive, tactile, and realistic.

"Really liked the tactile component. I think more practice with it you could become more proficient and able to make fine adjustments." - PID 6
"Ability to interact with patients in LINACVR is fabulous." - PID 7
"I like that LINACVR is more interactive and that you can do a lot more with it. I like that it provided an experience in the role of a radiation therapist whereas VERT is more observational." - PID 8
"LINACVR was more interactive and hands on which is an advantage." - PID 12

The interaction capabilities in LINACVR made for a more effective teaching and collaborative experience. One participant also stated that the controllers were similar in feel to LINAC pendants, contrary to the feedback of several other participants.

"LINACVR is much more hands on application, allowing a more realistic and more useful teaching experience." - PID 9
"Nice to be able to have collaborative work that makes it a bit closer to an authentic experience. The controllers were similar in feel to the LINAC pendants'.' - PID 10
"LINACVR way more interactive and cool that you can do two users to work together at the same time." - PID 13

Some aspects of LINACVR which are not present in VERT include the patient perspective which were an advantage for educational aspects.

“Wireless headset is a convenient option for introducing patients to the clinical environment.” - PID 3
“LINACVR would be beneficial for patient education to give an idea of what a LINAC machine actually looks like ” - PID 4

The freedom to move around and to interact with patients were both also reported as positive comparisons.

“The ability to moved through 3D space is a valuable feature compared to VERT.” - PID 3
“Similar to VERT but LINACVR gives us the freedom to move around and we feel like we are in the clinic when we are not.” - PID 5

Some participants mentioned there were disadvantages with LINACVR due to the lack of a LINAC pendant remote for moving the bed.

“VERT includes real LINAC pendants which is an important component for training.” - PID 3
“VERT has a pendant with a lot more buttons on the trigger (controller) than in the virtual world.” - PID 5
“VERT uses real life LINAC equipment such as the pendant which makes the patient movement more like the LINAC machine.” - PID 11

Another disadvantage of LINACVR compared to VERT is that it does not support different radiation treatment modes such as electron therapy, a type of radiation therapy (but not very common) that targets cells near the skin rather than inside the patient.

“Would be good to add electron option like VERT has as electrons can be hard for students to learn and not as common so heaps of practice would be great.” - PID 14

5.4 *Question 3: Are there any improvements you think could be made to this VR simulation?*

There were some additional improvements participants suggested. Sounds of the real LINAC machine was a key important aspect that needed to be included.

“Put in sounds the LINACs make.” - PID 1
“For the patient perspective you could add sound as the sound of the LINAC and the room alarms aren’t that pleasant.” - PID 2
“Include sound.” - PID 3
“The addition of sound a LINAC makes could be beneficial for patient education” - PID 4
“Addition of sound if possible.” - PID 6

One of these that was suggested by several participants is to have props in the background of the treatment room and more detail on the LINAC model and features in order to make the environment more realistic, particularly for the patient perspective simulations.

“Add in more details specific to LINACS e.g. light fields, collinators, laws. A simulation of a CBCT scan.” - PID 3
“More in the surrounding environment to the treatment room so it more lifelike.” - PID 6
“Permanent representation of the isocentre.” - PID 7

The pendant and controls could be improved so they resembled closer to what the pendant is like in a real environment similar to what is available in the VERT simulator that the participants are more familiar with.

"The pendant could mimic the real controller in the department when doing couch movements for a more representative idea of what it is like in the clinic." - PID 8
"The controls on the remote were a bit too sensitive at times especially the up, down, left, and right arrow buttons. I opened the wrong menu multiple times by accidentally tapping the down arrow and the the centre button. A more gradual/slower sliding tool when adjusting the couch could be useful. Maybe double tap to speed things up. Add another controller at the couch." - PID 9
"The controls for scrolling through the menus seemed tricky." - PID 15

Some participants would have liked to have seen more data about the simulated patient such as the complete model and avatars of other users.

"Whole body for realism." - PID 3
"Datasets that showed the whole patient anatomy rather than a torso to be more lifelike." - PID 6
"Maybe a body of the person using the VR simulation." - PID 12

A suggested further improvement to the realism of the patient perspective is to include the panels that fold out from the gantry on either side of the patient's head. This would help the patient prepare themselves for the experience, as the panels can come quite close to the patients head for some treatments and can cause feelings of claustrophobia.

"Panels coming out for the patient mode as can come quite close to the patient." - PID 14

The multi-user and collaboration with patient features were particularly useful but there was some feedback on how to improve these aspects and not all participants were comfortable with that simulation scenario.

"Maybe when the partner is working we could see what they are doing instead of their hands/trigger/controller dissolving into the couch." - PID 5
"It's good to have the multi-user function. The next step in really effective VR for radiation therapy is mannequins to provide feedback to the users. Currently it helps in teaching the steps through which a team sets up a patient but the most variable part of the setup is the patient." - PID 10
"The use of another user was hard - being unfamiliar with the controls of this technology. Felt with the other user a bit lost as I worked a lot slower not understanding the controls." - PID 11

Some participants would like to use LINACVR with treatment plans they have designed in other tools and import them into LINACVR.

"Making use of treatment plan data from DICOM files." - PID 7

Some participants would have liked more time with the tool, but if we were to deploy LINACVR in an educational setting this would be possible. This could help to alleviate some of the interaction usability issues with participants having more time to learn the controller options.

"More time to familiarise with the environment and controls." - PID 3

5.5 Question 4: Do you have any other feedback about the simulation that you would like to give?

Most participants feedback in general was positive and encouraging about supporting a VR radiation therapy simulator experience.

> *"Was cool to use."* - PID 1
> *"Really advanced and hope to see it in clinical when I start working."* - PID 5
> *"Really impressive."* - PID 6
> *"Very impressed."* - PID 7
> *"Really enjoyed the the experience."* - PID 8
> *"It was very effective, a good representation of a real life LINAC."* - PID 12
> *"Really cool!"* - PID 13
> *"This is awesome. Well done!"* - PID 14

Several participants specifically mentioned that the patient perspective seemed like it would be very beneficial for patient education and preparation. Another mentioned that while actual clinical experience is still more important for training, that LINACVR would be a good way to educate beginners and to introduce staff to new concepts.

> *"It would be very beneficial to nervous patients/children receiving treatment."* - PID 1
> *"I think the use of VR could be very helpful for patient education and easing anxiety of patients. Clinical experience will still be more valuable I think for education, however I can see the value in VR use for educating beginners, or introducing new techniques for staff."* - PID 4
> *"I like the idea of having it from the patient's perspective and it being portable."* - PID 6
> *"I think it could be real beneficial for both staff and patients."* - PID 8
> *"It was very cool, would be a great learning and teaching tool!"* - PID 15

6 Discussion

For those who have never used VR before, it can be an exciting and novel experience. In a user study involving VR, it is important to isolate the effects of this novelty upon the results. For example, a user who had never used VR before may give positive feedback because the VR paradigm is very effective compared to virtual systems they have used before, not necessarily because the simulation being studied is effective. Comparing mean rated effectiveness across all scale based questions between those who had experienced virtual reality before and those who had not gives us a mean rating of 3.964 for no prior experience, and of 4.005 for prior experience. This shows that for this study the bias most likely did not have a significant effect on rating.

While this tool would in theory be used in an educational setting and so students would initially be taught in the use of it by an expert, having the researcher present and assisting may still have influenced the results. Due to the unconventional nature of the VR control scheme and interface, users were not left to figure controls out by themselves but were rather initially guided through them by the experimenter. This may have had an impact on the participants impression of the usability and learnability of the user interface.

The comparison by users of the single and multi-user use cases may have been impacted by several factors. The first is that counterbalancing was not used. Counterbalancing should normally be used in a comparative VR user study to control the effects of user learning and fatigue [14]. This was not included in the design for this study as it was necessary for the experimenter to observe and assist the participant learning how to use the system, which would not have been possible with the experimenter also using the simulation for the multi-user scenario. Likewise, the fact that the other user that participants worked collaboratively with in the multi-user use case was the experimenter could also have impacted results. Ideally this would have been another radiation therapy student or educator.

Additionally, the small participant sample size may not have been representative of the radiation therapy education industry as a whole. In particular, while most students were in their first or second year of training, the third year students were all on practical placements during this study and so only one of them participated, meaning that results may not be representative of all experience levels within an educational institute. All participants were from the same institution which may also mean that results from this study may not be applicable to other institutions.

Overall, the results of the study indicate that LINACVR provides an effective training solution. 11 out of the 15 participants responded that this solution would be either effective or very effective for the training of radiation therapy. For the remaining four, only one considered it ineffective. A similar majority also considered the collaboration and patient perspective features effective or very effective. It was found that the simulations developed have distinct advantages over the existing alternative VERT system which includes interactivity, immersion, and collaboration features. The study also produced a set of useful potential future improvements to realism and effectiveness that could be implemented in the future.

7 Conclusions

Cancer is one of the leading global causes of death, and requires treatment by highly trained medical professionals, some of whom currently have limited access to effective training tools. To provide better access to this training, our goal was to provide the experience of radiation therapy using a Linear Accelerator (LINAC) Machine from the perspective of both the radiation therapist and the patient through the use of VR simulation. The therapist perspective would provide effective low cost training to radiation therapy students. The patient perspective would give patients thorough education and preparation, reducing the psychological stress of treatment.

LINACVR is the first collaborative VR tool which represents a radiation therapy environment without needing to use actual LINAC equipment. LINACVR provides an effective and immersive simulation of radiation therapy treatment for both therapist training and patient education. The inclusion of multi-user functionality increases realism, accuracy, and therefore training effectiveness for students. The multi-user functionality allows customized treatment experiences for patient education, increasing patient preparation effectiveness. LINACVR features a completely portable version of the patient perspective.

We conducted a user study of LINACVR to evaluate the usability and effectiveness of both the patient perspective and training simulations. We found that the patient perspective simulation gave an effective representation of the patient experience which would be beneficial for patient education. We found that the training simulation was easy to learn, very effective compared to the existing alternative (e.g. VERT), and effective in the training of radiation therapy. The main disadvantage of LINACVR was the lack of a real life physical treatment couch remote control. The development and integration of this pendant hardware would be a valuable addition, and would further increase the applicability of the simulation training to the real world procedure. There was a significant difference between the virtual simulation and the real world in manually positioning the body of a patient. Future work would be to explore a mixed reality solution using a combination of a physical mannequin and table but a virtual LINAC machine as this would allow for an even greater level of training accuracy and realism.

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