LINACVR: VR Simulation for Radiation Therapy Education

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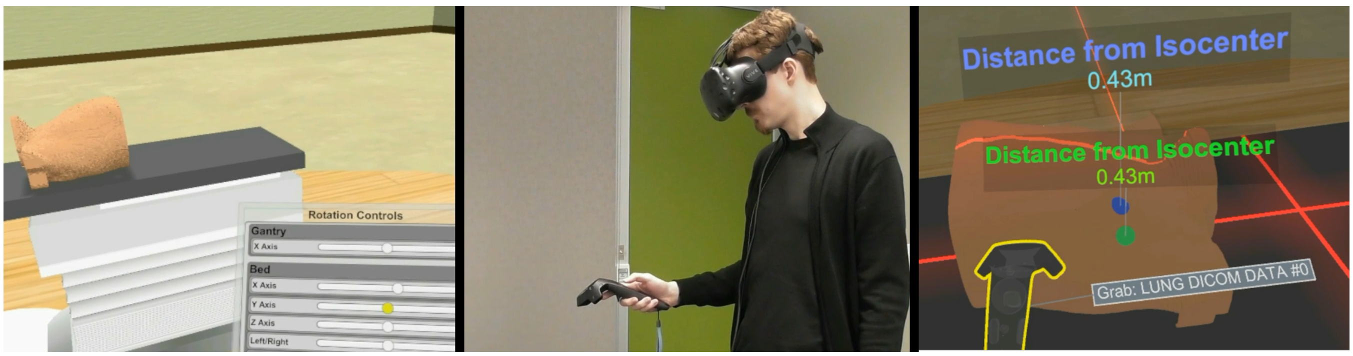

Figure 1: Educator in LINACVR (using HTC Vive). Controllers being used to view the gantry, and interacting to move the couch and position the patient model.

ABSTRACT

Cancer is the cause of over 15% 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 high demand upon Medical Linear Particle Accelerator (LINAC) equipment. Simulation of radiation therapy can provide an effective training solution, which has proven to be effective through the use of state-of-the-art simulation systems. Such simulation systems are still expensive, do not provide collaborative features, and interactivity with the patient which is necessary for effective training is limited. To overcome these issues, we have developed LINACVR, a collaborative 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 an effective and cost-effective alternative solution for radiation therapy compared to state-of-the-art simulators.

CCS CONCEPTS

• **Human-centered computing → Virtual reality**; *Collaborative interaction.*

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KEYWORDS

Cancer, Co-located Collaboration, Health-Care Education, Radiation Therapy, Simulation, Virtual Reality

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1 INTRODUCTION

Cancer was responsible for an estimated 9.6 million deaths in 2018, accounting for about 15% of all deaths globally [27], and it is estimated that 40% of people will have cancer at some stage of their life [20]. 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 [4]. Radiation therapy 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 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 [19]. These two pieces of radiation equipment are important for therapists to learn to position correctly.

Patients undergoing radiation therapy treatment often experience severe psycho-social stress [17] and psychological distress

[18]. Rainey [15] 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.

Carlson [2] discussed 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 [8] 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. Kaczur found that the cause of these accidents was usually poor radiation education and training.

Radiation therapy students must be able to train sufficiently before they interact with real equipment or assist with the treatment of real patients. 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 [24]. This makes it financially infeasible for an educational facility to have a dedicated LINAC machine for students to train with. 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.

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 collaborative simulation scenarios. The first allows radiation therapists to learn and practice the operation of a LINAC machine. The second shows the experience of the radiation treatment procedure from the perspective of a patient.

2 RELATED WORK

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. 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 [14]. 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. 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 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." 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.

Simulation training in healthcare has been widely adopted and some in VR. Cook et al. [1] 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. Mantovani et al. [12] 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 [7] 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. [3] 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. Sapkaroski et al. [16] uses a fully-immersive VR scenario in clinic simulation and found the use of realistic simulation and rich interaction with the system improved users' clinical and technical skills.

Although proven to be successful for training in other areas of Healthcare, the application of VR systems for Radiation Therapy training is still limited. VERT is the only available training simulation for radiation therapy [25, 26]. 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. Kane [10] 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. Kane [9] further explores the impact that VERT has had upon a radiation therapy teaching program 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. [11] 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.

A limitation found in previous studies, was the inability to manually position a patient on the couch and is an important skill to learn. Instead they are limited to performing alignment by moving the treatment couch. This is due to the semi-immersive nature of the system, which limits their interactivity with the 3D objects.

Another limitation is that VERT only supports one user at a time, while 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 more realistic way. VERT can cost up to $700,000 (USD) which makes it very expensive for teaching institutions. A fully immersive low cost VR simulation, which allows collaboration, would give students a more affordable and easier way to familiarize themselves with LINAC operation in a way that resembles the real environment, which is what we propose with LINACVR.

3 LINACVR FOR RADIATION THERAPY

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 2). 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 1 shows a user with a VR headset 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 2(a)). The patient model and individual organs can be made transparent using 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 be activated.

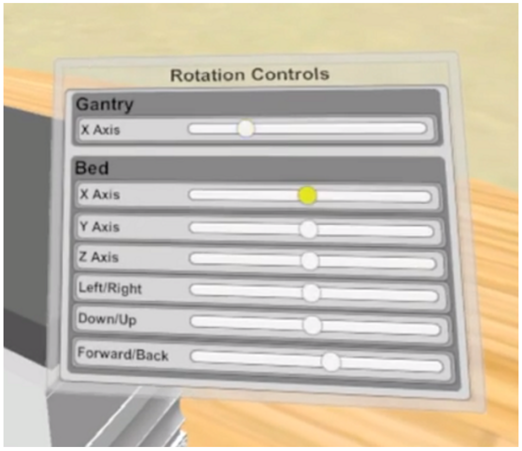
When a user first loads the collaborative simulation and equips the headset, they find themselves in the LINAC treatment room facing a user interface, giving them the option to either host a session or join an existing one. Once an option is chosen, the user is placed closer to the equipment and patient model and can now interact with them. From here they can see other users who are 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 2(b) shows a remote user ("Default User") standing next to the LINAC equipment and using a menu as they appear to 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. [6], 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.

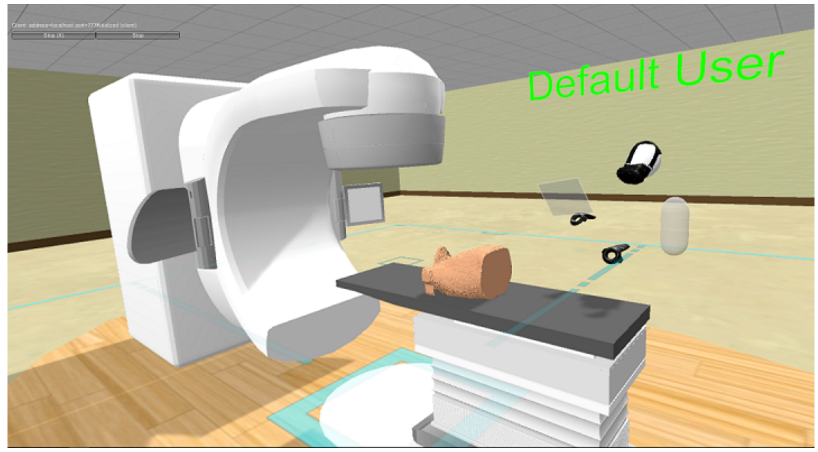
Figure 2(c) shows the network selection menu. From this menu users can choose to host an online session, host a local network session, or join an existing session. A session name can also be entered, which is important for differentiating between sessions if there are multiple running. The session name is also displayed over the head of a user, identifying them to others in a session.

Figure 2(d) 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 2(d), 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.

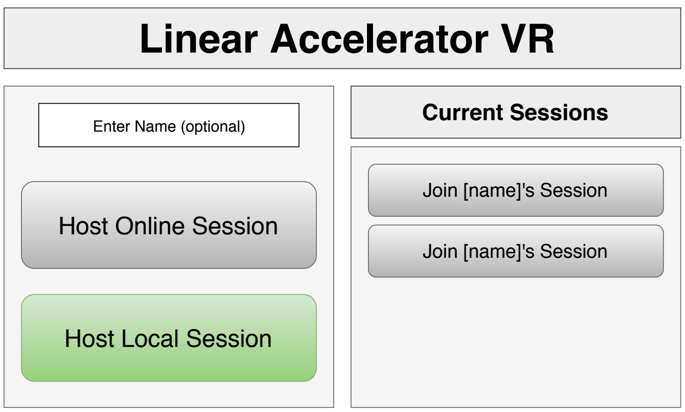
The patient perspective simulation functions in the same way as the multi-user except that the user hosting the session will find themselves placed on the treatment couch in the perspective of a patient while the other user is the therapist. Figure 3 shows the views of the patient (left) and therapist (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 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



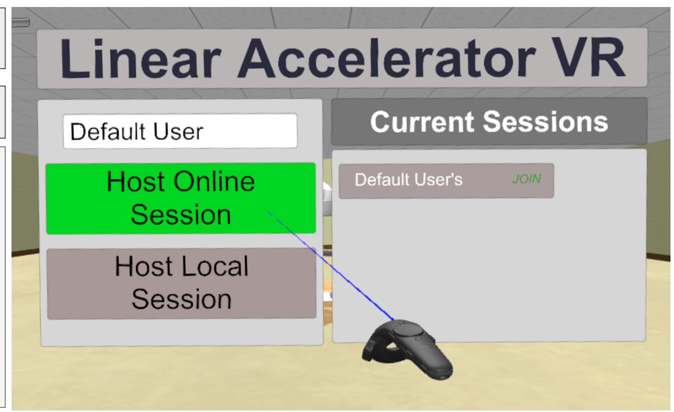
(a) The slider bar system for adjusting treatment couch position.



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



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



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

Figure 2: LINACVR for simulation of radiation therapy.

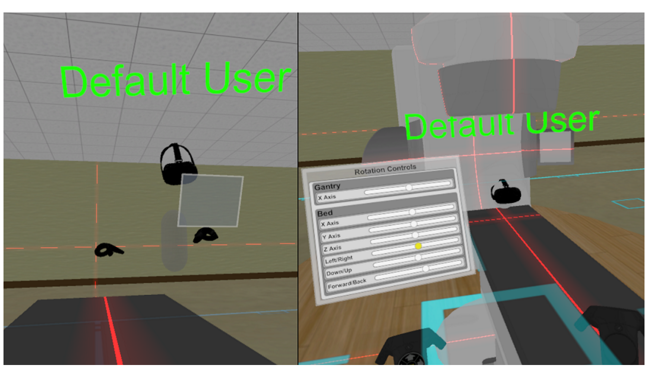


Figure 3: Left: Patient perspective view. Right: Patient perspective therapist view.

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 using C#. The SteamVR library was used to develop for the HTC Vive. The portable patient perspective simulation for the Oculus Go was also developed with Unity3D C#, but uses a combination of Android Studiocode 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. This is accomplished by bundling the server functionality within the LINACVR program, and using the architecture style referred to as "peer to peer hosted" or "listen server", where a single client acts as a server for a single group session.

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 [5]. 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 4, 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.

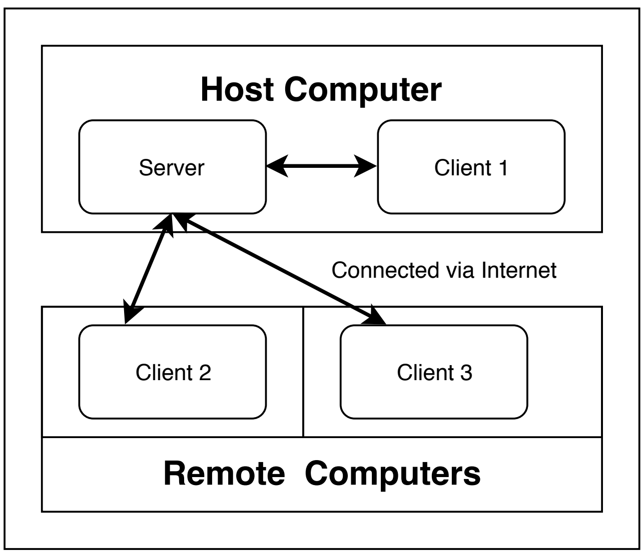


Figure 4: LINACVR peer-hosted client/server architecture, showing a host computer running a local client and a server, which is connected to by two remote client computers.

The network architecture has been developed using the Unity Multiplayer High Level API (HLAPI) [22]. The setting up and maintenance of connections between remote clients and the server has been implemented using the Unity Internet Services platform [23]. 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. We chose to impose a soft limit of four users, due to normal collaborative usage of LINAC equipment involving a low numbers of operators. If an institution acquired many HTC Vive units and wished to use this simulation in a lecture type format with many simultaneous users, this soft limit can be easily removed. We next present an evaluation of how LINACVR has been used with educators and students.

4 EVALUATION

To evaluate the effectiveness of LINACVR for training using simulation of radiation therapy 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?

(1) In what ways does this simulation differ from the real LINAC environment?
(2) What advantages do existing LINAC simulation programs have over this project?
(3) What further improvements could be made to this simulation?

Participants were recruited from a Department of Radiation Therapy at another university. Any student or educator was eligible for the study if they had used, or experienced any computer simulations of, LINAC machines. Participants were awarded an honorarium for participating. 15 participants were recruited (11 students and 4 educators).

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 [13]. 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 were 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, by teleporting or 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 present the results from the study from a quantitative and qualitative perspective based on post-study questionnaire responses.

5.1 Quantitative Data

Figure 5 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). 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 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 VR or 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.

5.2 Qualitative Data

Q1. 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 a LINAC machine was likely to be one of the most frightening aspects of treatment.

> *"Lack of sound made a difference as often LINACs can be relatively loud."* – PID 4

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.

> *"Controls of the LINAC are important, VR controls take some getting used to."* – PID 3
> *"LINAC controls are more easier to get mm movements for accuracy."* – PID 8

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.

> *"We move the couch manually more often than using the pendants of the couch controls to make the required adjustments."* – PID 8

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.

> *"It was easier to setup the patient with the VR simulation."* - PID 12

There were also many 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.

> *"We can view certain organs on the machine rather than imaging it."* – PID 5
> *"Skin marks are important to visualize during patient positioning."* – PID 13

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

> *"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

Q2. How did this application compare to any other LINAC simulation programs you have used (e.g.: VERT)?

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.

> *"LINACVR was a lot more user friendly than my experience with VERT."* - PID 4
> *"Would be way more useful than VERT in preparing students for the clinical environment."* - PID 13

A common comparison was that LINACVR gave a simulation that was more interactive, tactile, and realistic. The interaction capabilities in LINACVR made for a more effective teaching and collaborative experience.

> *"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*

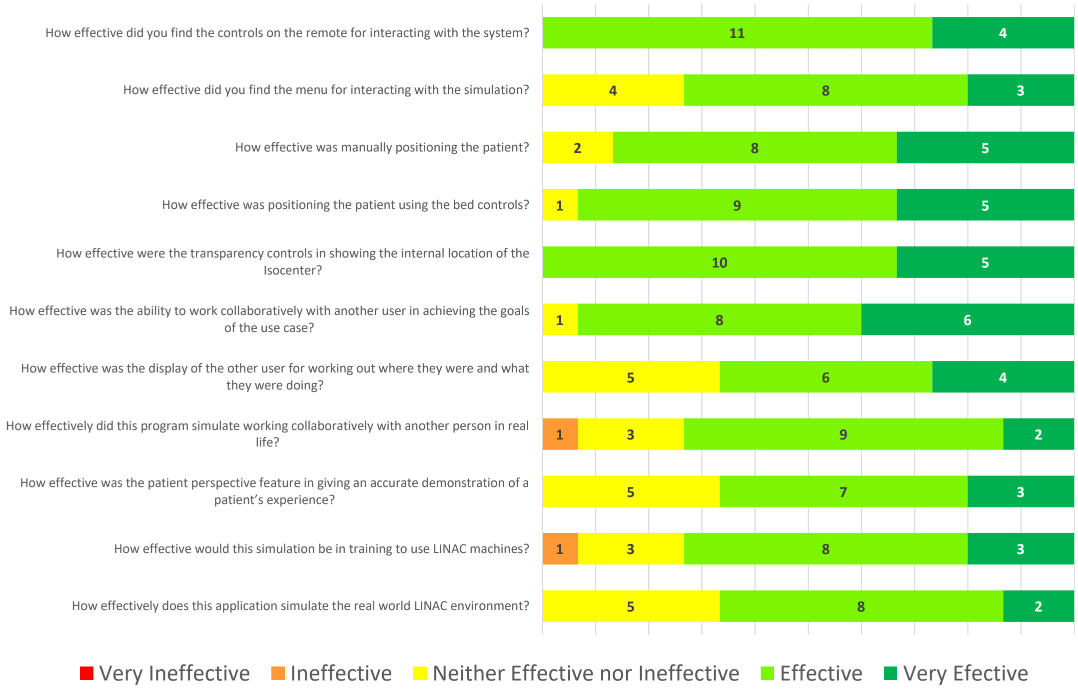


Figure 5: Likert Scale Results from post-study questionnaire, 11 questions.

> *VERT is more observational."* – PID 8
> *"LINACVR is much more hands on application, allowing a more realistic and more useful teaching experience."* - PID 9

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

> *"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.

> *"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. Another disadvantage of LINACVR compared to VERT is 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.

> *"VERT uses real life LINAC equipment such as the pendant which makes the patient movement more like the LINAC machine."* - PID 11

Q3. Are there any improvements for LINCAVR?

Sounds of the real LINAC machine was a key important aspect that needed to be included.

> *"Put in sounds the LINACs make."* - PID 1

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

> *"Add more details specific to LINACS e.g. light fields, collinators, laws. A simulation of a CBCT scan."* – PID 3

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.

> *"Pendant could mimic the real controller when doing couch movements for a more representative idea of what it is like in the clinic."* – PID 8

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

> *"Datasets that showed the whole patient anatomy rather than a torso to be more lifelike."* – PID 6

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.

> *"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

Q4. Do you have any other feedback about LINAVR?

Most feedback in general was positive about LINACVR. Several participants 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 introduce new concepts.

> *"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

> *"Really advanced and hope to see it in clinical when I start working."* – PID 5

6 DISCUSSION

For those who have never used VR before, it can be a novel experience. It is important to isolate the effects of VR novelty in studies [21]. For example, a user who has never used VR before may give positive feedback because the VR paradigm is very effective compared to 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 VR 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.

One limitation 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 real world applicability of the simulation training procedure. There was a significant difference between the virtual simulation and the real world in manually positioning the body of a patient. Future work could explore a physical mannequin and table which could allow for an even greater level of training accuracy and realism.

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.

7 CONCLUSIONS

Cancer is one of the leading global causes of death, and requires treatment by highly trained medical professionals often with LINAC machines, but these professionals have limited access to effective training tools. In this paper we presented LINACVR which is the first collaborative VR tool which represents a radiation therapy environment without needing to use actual LINAC equipment.

LINACVR provides an immersive simulation of radiation therapy treatment for both therapist training and patient education. LINACVR also supports multi-users which allows customized treatment experiences for patient education, increasing patient preparation effectiveness. We conducted a user study of LINACVR to evaluate the usability and effectiveness of both the training and patient perspective simulations. 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. We found that the patient perspective simulation gave an effective representation of the patient experience which would be beneficial for patient education. For future work we would like to explore how LINACVR could be used for training and education purposes throughout the life-cycle of a degree in radiation therapy.

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