

Review

Virtual and Augmented Reality as a Novel Opportunity to Unleash the Power of Radiotherapy in the Digital Era: A Scoping Review

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Abstract: Although radiation therapy (RT) provides several therapeutic advantages in terms of cancer control and quality of life, it continues to be a poorly understood field by most students and health workers. Theoretical lessons are not sufficient, while practical exercises are time-consuming, both in terms of man- and machine-hours. Furthermore, RT candidates often have several prejudices that may affect their treatment choices, favoring the more well-known surgical or chemotherapy approaches or resulting in a high level of anxiety during treatment. Moreover, the misperception of low treatment control and its related side effects could worsen the patients' psychological distress, already brought by a cancer diagnosis. Augmented reality (AR) and virtual reality (VR) could be a valid instrument for promoting the awareness of radiation oncology as a discipline with its own identity and respect in the scientific community. The aim of the present work is to provide a glance at the recent developments in AR/VR to support students' education, personnel training and patients' empowerment in this clinical setting. The main findings of our work show that such technologies have already become a reality in many institutions worldwide and it has been shown to be an effective strategy for raising educational standards, improving health workers' skills and promoting patients' well-being and compliance. These results seem to promote the further implementation of AR/VR technologies and their development as a driving force of a much-hoped-for revolution in the way patients are treated and radiation oncology is taught.

Keywords: radiation oncology; virtual reality; augmented reality; training; education

1. Introduction

1.1. Radiotherapy: A Niche in Healthcare

Radiation therapy (RT) represents a noninvasive and painless treatment modality for cancer patients. Thanks to modern and sophisticated techniques, the treatment delivery is precise and safe, leading to good clinical results while minimizing side effects [1]. Nowadays, about 45–55% of new cancer patients are treated with RT and about 20–25% are irradiated more than once during their oncological history. It has been estimated that, by 2035, optimal access to RT worldwide would save one million lives annually [2].

Even though evolving technologies and novel therapeutic panorama make RT a dynamic medical specialty, its potential is often underestimated due to cultural and economic issues, commonly configuring it as a Cinderella in the world health policy agenda. RT is

still considered a low-priority subject among the oncological specialties in comparison to surgical and medical oncology, even in the medical community at different levels, starting from undergraduates, who could lack a proper exposure and minimal teaching during their medical school course, to other-specialty physicians, who often look to RT as a fast-growing enigmatic world which is harder to understand than the majority of other medical disciplines. This could be explained by insufficient theoretical lessons and time-consuming practical exercitations. A comprehensive overview of a standard RT workflow is reported in Figure 1.

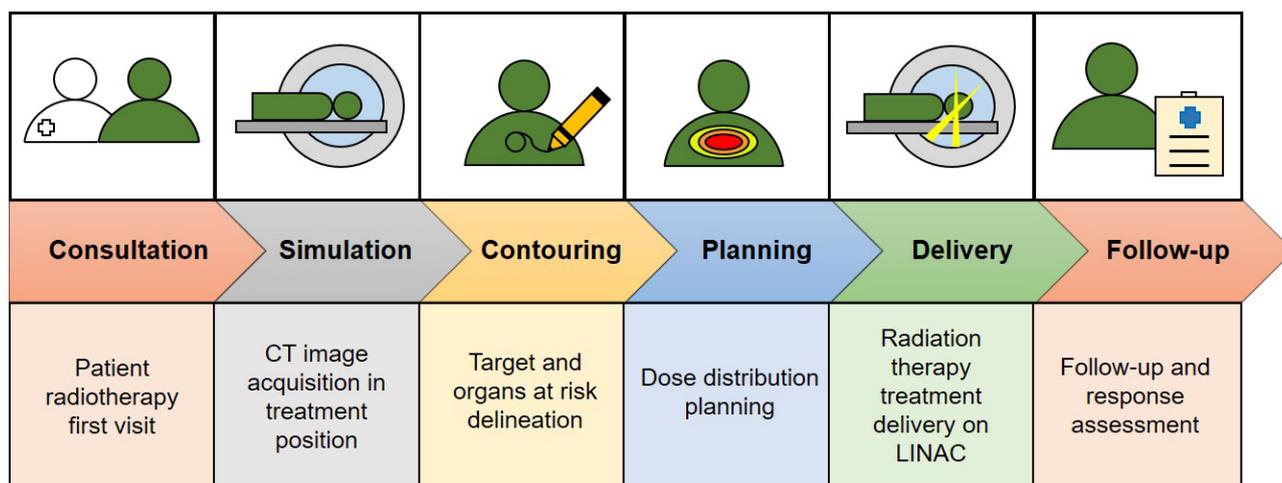


Figure 1. A schematic representation of radiotherapy workflow. Abbreviations: CT (Computed Tomography); LINAC (LINear ACcelerator).

More complexity arises when the patient, as an RT-treatment candidate, needs to understand what RT is: commonly, people have many irrational concerns about RT and associate radiation with atomic bombs and nuclear incidents. Furthermore, the vocabulary used in RT could have some negative, fearful and war-related connotations (e.g., ‘cobalt bomb’ for the cobalt treatment unit, bunker for treatment room), and patients are often worried that they would become radioactive themselves and that it would become dangerous for them to be near their relatives, especially children. These misconceptions and fears about RT could potentially influence the treatment choice and lead cancer patients to avoid RT treatment [3] in favor of surgery or chemotherapy, which are frequently more accepted by patients, even in cases of the same curative intent and same oncological outcome in many cancer types (prostate, head and neck, anal canal, etc.) [4–6].

In addition, most patients have a poor or no understanding of RT and only a minority identify RT as a “modern” cancer treatment, suggesting that the perception of RT has not kept up with significant advances in the field [7].

Paradoxically, the perception of the risk/benefit ratio is more unfavorable for RT when compared to surgery or chemotherapy, even if the risk of peri-operative mortality (0.5–3% for surgery) or death due to chemotherapy-related toxicity (0.5–2%) is higher than that for RT (the risk of RT-related death is extremely low) [8,9]. The popular understanding of a double-edged sword effect of any treatment (toxicity vs. efficacy) seems much more indulgent in the case of surgery or chemotherapy than of RT.

For example, in a study on breast cancer patients, women interviewed on their initial feelings regarding RT commonly reported fear and anxiety [10], due to the misbelief that radiation is painful and not easily controllable since it is invisible. Overall, the physical, psychological and social distress caused by a cancer diagnosis can be further exacerbated by the perception of having little control over treatment indications and their related side effects [11]. If, on the one hand, general awareness of RT is scarce, on the other, it is often difficult for healthcare professionals to convey clear and concise explanations through

conventional and static approaches (e.g., pictures, computer screens), especially in the rather limited timeframe dedicated to medical consultations.

This misconception has to be changed in the collective mindset to make patients consciously choose the most appropriate and effective treatment. In the Fourth Industrial Revolution era—which conceptualizes a rapid change in technology, industries, societal patterns and processes by increasing interconnectivity and smart automation—augmented reality (AR) and virtual reality (VR) technologies could constitute a powerful tool to further promote radiation oncology as a science with its own identity and recognition in the public and scientific communities.

With the aim to provide an up-to-date overview of the applications of AR and VR in radiation oncology and to help readers have a clear idea of the actual scenario for addressing the further developments of these valuable technologies, the present review offers an insight into the most recent advances in AR/VR technologies to support student education, personnel training and patient empowerment in the radiation oncology field.

1.2. Virtual and Augmented Reality: Two Mainstays in the ICT Era

Extended Reality (XR) is the umbrella category that encompasses all the various forms of computer-altered reality, including Augmented Reality (AR), Mixed Reality (MR) and Virtual Reality (VR), which are Information and Communication Technologies (ICT) part of the emerging technological evolution and already widely used in the entertainment and military industries.

VR involves the use of immersive computer simulation methods, e.g., 360° videos, 3D modelled videos, by the usage of a headset with headphones, a screen and a gyroscope. More affordable technologies (such as cardboards: foldable paper viewers) have been introduced in the market in past few years, promoting an increased diffusion of VR technology in everyday life. While the facilitated access to VR technology has led many costumers to develop experiences with no need for coding, the development of complex VR experiences, which include interactions with the virtual environment by joypads or other human interface devices, still requires dedicated ICT teams.

AR can be defined as an enrichment of the perception of the real world by adding new layers of information that otherwise would not be possible to be perceived by the user. This ICT requires the usage of headsets that could be transparent or include cameras to stream the real-time video on an inside screen where the new layers are added. AR is quite expensive in comparison to VR and requires dedicated teams to create even simple AR experiences, in which the roles of the ICT developers and computer graphics are crucial. Even if AR could be considered an enhanced tool, the limits linked to the resources needed make them difficult to be developed in a broad spectrum of applications. Recently, the increasing physical elaboration capacity of the consumer-technology has piloted the development of applications that use the screen, the camera and the gyroscope of mobile devices to propose AR experiences.

Further developmental progress has made VR integrated with AR, creating a new blended experience known as Mixed Reality (MR). The MR term usually refers to artificial products that could interact with the users in the real world. It has been introduced in different health educational scenarios, such as physiology or anatomy, in which the 3D representations of a model can help students better understand morphology and the relations of rendered objects.

Thanks to the increase in consumer-level devices with XR capabilities, the current literature has focused on the role of the XR technologies to boost the educational patterns in different health scenarios, such as surgery [12], dentistry [13], health professions students' education [14], and patients' education [15]. Furthermore, a recent systematic review on the use of XR experiences in education reported how most of the studies available in the current literature have shown at least non-inferior results in terms of learning when compared to conventional teaching and training, while enhancing the enthusiasm and enjoyment [16]. The engagement to which XR technology leads could make this

technology a useful companion to conventional education, while its growing availability could represent an opportunity for lower- and middle-income countries to gain access to more specialised training.

2. Materials and Methods

2.1. Eligibility Criteria

We included in our scoping review all the fully retrievable original articles, reviews and editorials written in English on the use of AR/VR technologies on the designed target population, represented by radiation oncology health professionals, students and patients. The exclusion criteria were the absence of a clear and quantifiable understating of how XR technology impacted on the target population and the presence of the same article in different forms (e.g., poster, oral communication): in this case, only the full article was included in the review.

2.2. Search Strategy

A review protocol compliant with the PRISMA extension for this scoping review was adopted [17]; its checklist is available as in the Supplementary Materials Section. An initial search in the literature for articles written in English, dating from 1995 to 2022, and on the use of AR/VR for educational use at the medical student level, for radiation oncology professionals and for patients' education in RT field was performed. Specifically, articles that dealt strictly with radiation oncology education and patients' empowerment were sought. A combination of the terms "virtual reality", "augmented reality", "VR", "AR", "medical student", "patients", "education" and "empowerment" was queried on PubMed, Embase, WOS and Dimensions.

2.3. Selection of Sources of Evidence

A total of 1012 records were considered for study inclusion: 215 records in the Dimensions database, 583 in Embase, 20 in Pubmed and 194 in WOS. A total of 297 duplicate records were removed. A screening of the available articles was performed by two senior radiation oncologists and a bioengineer with experience in XR technologies. Of all the records, after further purging of the not retrievable full texts, a total of 97 articles were initially considered for the review; notably, given the novelty of the concept, the more dated papers (before 2010) were excluded, along with the ones reporting overlapping information. In conclusion, 41 papers were deemed eligible for inclusion in this scoping review. Details on the workflow of the study and the search strings and explored databases are reported in Figure 2 and Supplementary Materials File S1, respectively. Synthesis of the information was performed based on different approaches of AR/VR for radiation oncology health professionals, students and patients, and comparing AR/VR with conventional approaches.

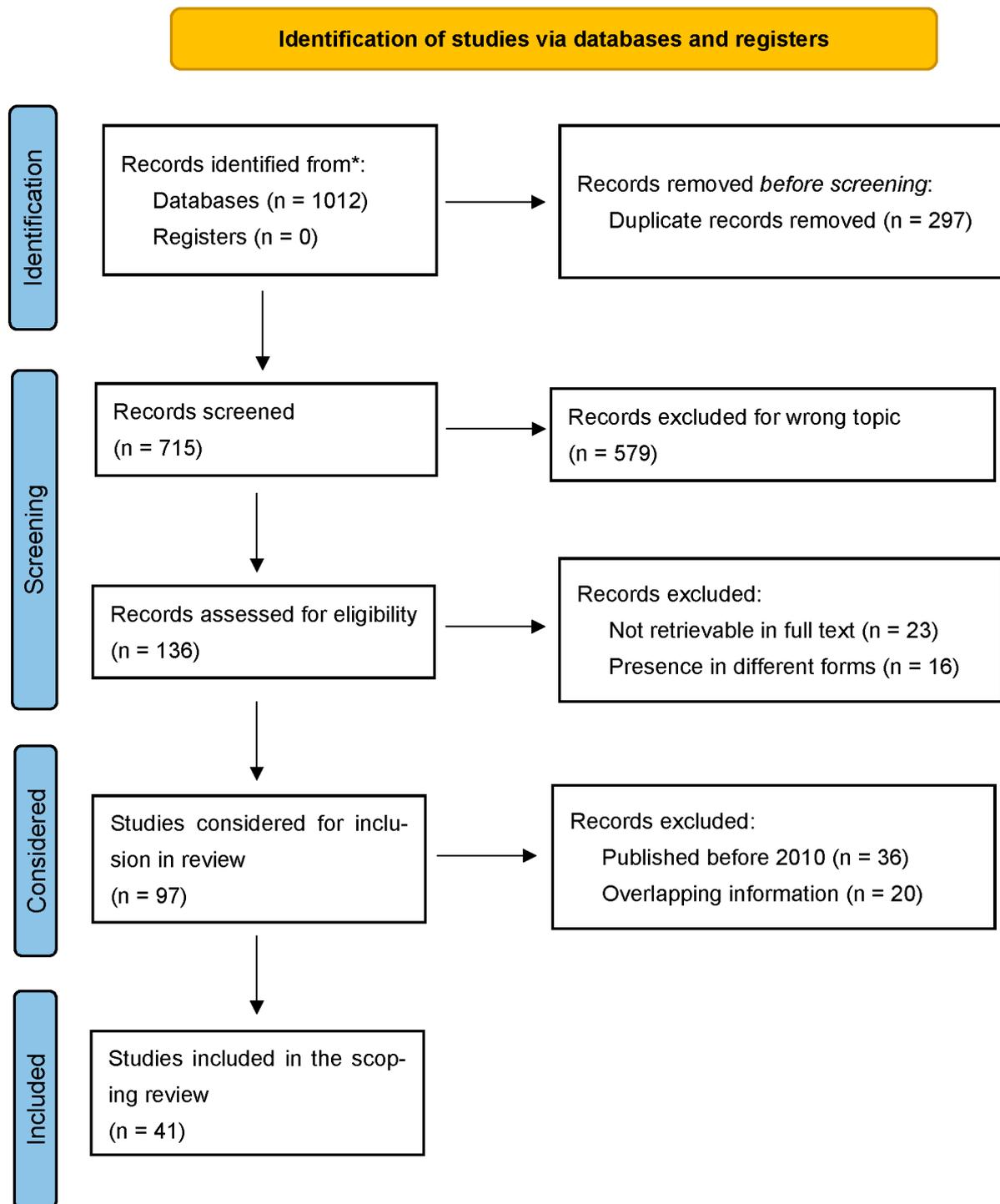


Figure 2. Workflow of the study.

3. Education and Training for Students and Radiation Oncology Professionals

3.1. AR/VR in RT Education and Training

In recent years, there has been a decline in residency applications to radiation oncology due to multiple factors, including the limited exposure to radiation oncology in medical school training worldwide [18], while the need for radiation oncology education has become more urgent as the COVID-19 pandemic left many medical students without in-person clinical rotations. In fact, since many medical schools do not offer formal radiation oncology

curricula [19], the elective rotation represents one of the few opportunities that students have to experience the radiation oncology field [20,21].

Whereas simulation in health science represents a rapidly evolving field, VR-based tools in RT are still limited (Kane, 2018). However, there are several advantages of adopting such approaches in RT education and training, such as allowing users to become familiar with a linear accelerator without employing clinical resources [22], reproducing real-life scenarios while avoiding the possible risks associated with procedural failure and creating a safer environment without the need for expensive simulators [23,24]. On the flip side, simulation might generate a false feeling of security, regardless of how close simulation might be to reality [23].

In educational contexts, VR or AR could broaden the chances for radiation oncology to better engage students with hands-on experience and improve both their learning experience and clinical skills. This approach could be valuable for both medical students and other RT specialists in training, such as medical physicists.

While this training could be at different levels of depth according to the different professional figures, since the AR/VR contribution has the same purpose, different classes of health workers were not considered separately in order to provide a comprehensive overview of the potentiality of these novel training techniques.

Some of the possible applications of AR/VR technologies in this setting are reported in Figure 3.

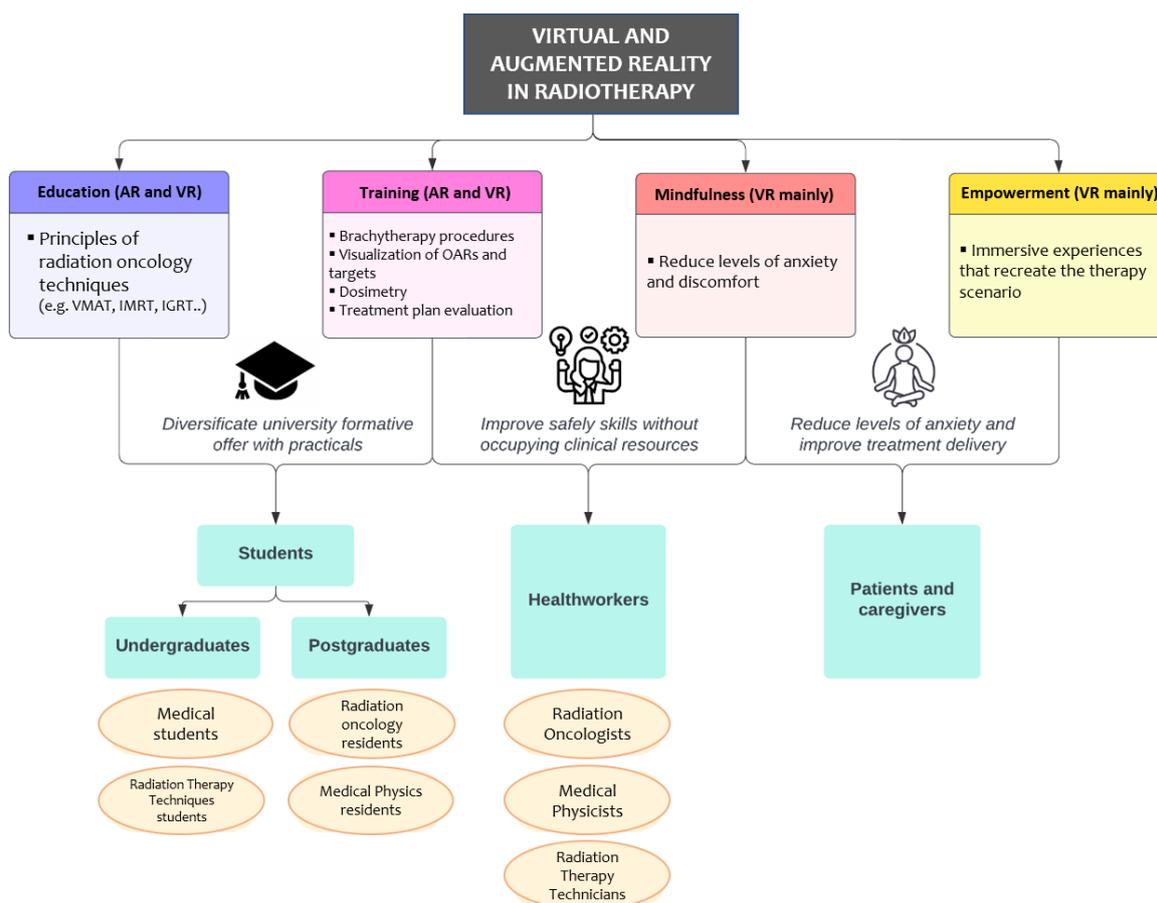


Figure 3. Overview of AR/VR applications in radiation oncology. For each field of interest, the main technologies involved are indicated in brackets. Abbreviations: AR (Augmented Reality); IGRT (Image Guided RT); IMRT (Intensity Modulated RT); OAR (Organ at Risk); RT (Radiotherapy); VMAT (Volumetric Modulated Arc Therapy); VR (Virtual Reality).

3.2. VR in External Beam RT and the Central Role of VERT

One of the most common systems for education and training in external beam RT is Virtual Environment Radiotherapy Training (VERT), developed in 2008 and based on a VR environment emulating the RT delivery treatment procedure [23]. Specifically, it includes the RT treatment room, the linear accelerator (LINAC), the patient and the impinging beams, with the user having full control of the equipment, as is the case in real life [25].

Several universities and hospitals worldwide have made preliminary attempts to integrate VERT for the education of students in the field of RT (Table 1).

Table 1. Examples from literature of use of Virtual Environment Radiotherapy Training (VERT) for students’ education.

	Students Category (N)	Topics	Experimental Design	Effectiveness Assessment Modality	Reported Benefits	Reported Drawbacks
Chamunyonga et al., 2018 [26]	Undergraduate RT students (NA)	IMRT, VMAT, and DCAT plans; QA concepts	Plan evaluation for dose to target and OARs for the different techniques	NA	<ul style="list-style-type: none"> Improvement in students’ engagement and communication Improvement in the ability to evaluate treatment plans 	-
Chamunyonga et al., 2020 [27]	Undergraduate RT students—year 3 (NA)	IGRT and image matching	VERT-based matching of CBCT images	NA	<ul style="list-style-type: none"> Improve students’ hands-on skills Better prepare students for clinical environments More engaging and interactive teaching 	-
Cheung et al., 2021 [28]	Year 3 RT bachelor students—year 3 (26)	Medical dosimetry	Two groups (Grs): <ul style="list-style-type: none"> Gr1: TPS only (10); Gr2: TPS +VERT (16) 	Survey to students	<ul style="list-style-type: none"> VERT helped Students in learning RT planning Higher confidence Reduced time 	-
Czaplinski et al., 2020 [29]	Postgraduate medical physics students (14)	Basics of RT	Theoretical + VERT + practical modules administered sequentially	Survey to students	Improvement in students’ engagement	<ul style="list-style-type: none"> Modern teaching strategies might develop an illusion of competence
Leong et al., 2018 [22]	RT bachelor students (29)	3DCRT, IMRT, VMAT	Cross-over design, two groups (Grs): <ul style="list-style-type: none"> Gr1: theory before, VERT after; Gr2: VERT before, theory after 	<ul style="list-style-type: none"> Survey to students Survey to lecturers 	<ul style="list-style-type: none"> Increase in confidence and understanding both in Gr1 and Gr2 All students but one interested in further VERT lectures 	-
Green et al., 2011 [30]	Year 1 (23) and 2 (21) pre-registration RT students	Skin apposition electron technique	Group demonstration sessions followed by individual practical assessment	<ul style="list-style-type: none"> Objective score Survey to students 	Moderate correlation was shown between spatial ability and improved performance outcome	<ul style="list-style-type: none"> A minority of students (9%) reported dizziness and nausea after VERT
Flinton et al., 2013 [25]	Year 1 and 2 RT students (52)	Managing an electron patient’s set	Two groups (Grs): <ul style="list-style-type: none"> Gr1: real treatment unit Gr2: VERT 	<ul style="list-style-type: none"> Scores assigned by assessors Survey to students 	Students were positive about VERT	<p>SCORE:</p> <ul style="list-style-type: none"> Performance of Gr1 higher than that of Gr2 SURVEY: <ul style="list-style-type: none"> Lack of immersion No tactile feedback Limited viewing angle Poor comfort of visors

Abbreviations: 3DCRT: 3D Conformal Radiotherapy; CBCT: Cone Beam Computed Tomography; DCAT: Dynamic Conformal Arc Therapy; Gr: Group; IGRT: Image-Guided Radiotherapy; IMRT: Intensity Modulated Radiotherapy; N: number of students; NA: Not Available; RT: Radiation Therapy; TPS: Treatment Planning System; VMAT: Volumetric-Modulated Arc Therapy.

Chamunyonga et al. [26] reported their experience at the Queensland University of Technology with VERT for the support of the teaching of intensity-modulated radiotherapy (IMRT), volumetric-modulated arc therapy (VMAT) and dynamic conformal arc therapy (DCAT) techniques for undergraduate radiation technology technician (RTT) students. They found that the use of VERT for collaborative plan evaluation sessions is likely to engage the students and improve their knowledge in the field. To corroborate the aforementioned results, in 2020, the same group [27] published a study evaluating VERT in supporting the teaching of image-guided radiation therapy (IGRT) and image matching concepts. The study seems to encourage the implementation of this technology to provide students with hands-on skills in preparation for real clinical environments. Similarly, Cheung

and Coll. [28] conducted a study to evaluate whether using VERT in the delivery of the RT planning and dosimetry course can help students improve their learning experience. A direct comparison was conducted between the 2015 (control group, TPS only) and 2016 groups (measured group, TPS + VERT) through pre- and post-course questionnaires for both groups. The improvement in understanding and confidence of students was assessed, and the TPS + VERT group commented that VERT helped them in learning RT planning for aspects such as anatomy, control of the planning system, understanding DVH and treatment technique. The overall experience in the TPS + VERT group was better compared to the TPS group, suggesting that VERT should be incorporated into RT training. The evidence acquired showed how the students receiving the TPS mode reported a lower level of confidence in completing the planning and required a longer time for self-study and practice compared to the students who received the TPS + VERT mode.

Czaplinski and coll. [29] reported the experience of medical physics students for whom teaching was re-designed to increase active learning by including scaffolded in-class and online tasks supported by VR simulations. The results of a survey administered to these students indicate that there was an overall improvement in their engagement with the learning activities when they were supported by the VERT system. Similarly, Leong et al. [22] investigated the potential of this virtual clinical environment to enhance the learning experiences of RT students in teaching two modules on 3DCRT, IMRT and VMAT techniques. The students were divided into two sub-cohorts, and cohort A only used VERT for module 1, while cohort B only used VERT for module 2. Likert-scale questionnaires were administered both to lecturers and students to explore their perceptions on the usefulness of the VERT tool in the education process. The two lecturers involved in the training process were enthusiastic about the VERT teaching modules, as it enabled a more direct visualization of concepts and favored students' interaction. Regarding the sequence of modules delivery, they had the opinion that the standard one should precede the VERT one. Results from questionnaires administered to students showed that the combination of the two modules, regardless of the sequence of delivery, increased their perceived confidence and understanding of the topics object of training [22]. While the above-mentioned study investigated the potential of VERT in combination with standard theoretical teaching, Flinton et al. [25] evaluated its usefulness when compared to exercitations for electron patients' set-ups on a real treatment unit. Outcomes were evaluated with both scores assigned by assessors and with questionnaires administered to students. The quantitative scores showed that the performance of students was higher with the actual treatment unit than with its holographic counterpart. The questionnaire highlighted some perceived weaknesses of VERT, including its lack of immersion, no tactile feedback, limited viewing angle and poor visor comfort, but also highlighted its strengths, namely, the possibility to make mistakes and training in a safe environment for patients. Green et al. [30] also tried to assess the added value of VERT in the training of RT students on the skin apposition electron technique. For this purpose, group demonstration sessions were followed by individual practical assessments during which a score on the accuracy and efficacy of set-up was assigned to each student. A moderate correlation was shown between spatial ability and improved performance outcomes. A questionnaire administered to the students to assess their overall experience highlighted that most respondents (89%) felt more confident in their practical skills after the training sessions. Of note, a minority of students (4/44, 9%) also reported adverse reactions to the training, specifically, dizziness and nausea [30].

Even if VERT dominates the applications of VR in RT education, other initiatives are being explored. Specifically, Khan et al. described the implementation of a virtual educational program for medical students called Radiation Oncology Virtual Education Rotation (ROVER) and its effect on student interest and knowledge in RT. In detail, the ROVER approach consists of a series of virtual educational panels with case-based discussions across disease sites tailored to medical students. The effectiveness of this educational approach was evaluated by pre- and post-session surveys collected from the students involved. The results of the study demonstrated that the tested approach improved the

overall perceived knowledge of radiation oncology from the medical students across all disease sites covered along with their ability to evaluate treatment plans.

The reported experiences show that the employment of VR in radiation oncology could improve both theoretical knowledge and practical skills. The establishment of a connection between visual effects, memory process and recall of new knowledge can help RT personnel become prepared in a safe offline environment and without the employment of clinical resources. The most important take-home message from these preliminary experiences is that VERT and similar technologies should not substitute traditional teaching methods, but rather be integrated with them to foster the overall level of teaching.

3.3. VR/AR in Brachytherapy

Brachytherapy (BT) is an even smaller and lesser-known niche of RT in which seeds, ribbons or capsules that contain a radiation source are placed directly in or near the tumor. The great advantage given by the proximity between the source and target is what makes BT attractive for boosting limited-size target volumes to high doses; however, the success of this therapy is determined by the accuracy of radioactive source placement, which then becomes crucial. Nowadays, three-dimensional (3D) image-guided techniques by computed tomography (CT), magnetic resonance imaging (MRI) and ultrasound (US) are used to guide the surgical placement, which is still largely dependent on the confidence and expertise of the operator. Moreover, it is well known that factors such as unfamiliarity with the target region can result in tension of the operator with the risk of medical negligence. In this context, the use of VR or AR in BT has recently gained momentum, both for training and clinical purposes. For instance, a realistic training VR scenario, able to provide an immersive experience, could help doctors become familiar with the surgery scene and with the location of the source, increasing placement accuracy and the confidence of the operator, and thus the rate of success. A lot of effort has been put into works focused on the development of a virtual training system for BT, often involving head-mounted displays (HMDs) to provide an immersive and entertaining learning experience.

In this setting, the use of VR in BT has been reported in a few studies. In a 2021 work by Taunk et al. [31], a VR training video of an intracavitary BT was created, involving fourteen resident physicians, with or without previous experience, who were invited to perform an intracavitary BT procedure before and after viewing the simulation on an immersive headset. Both procedures were timed, objective measures of implant quality were recorded, and pre- and post- simulation questionnaires were used to assess, among many other areas, users' self-confidence and the perceived usefulness of the session. After viewing the simulation, the subjects found the VR experience extremely useful, enjoyable and easy to use; moreover, confidence improved, as well as technical skills in the assembly and insertion and the average time of implant, confirming the potentiality of VR.

In another work by Zhou et al. [32], an interactive training system for BT based on VR dedicated to young and unskilled doctors was developed. The virtual environment is linked directly to the TPS, which provides all the information about patient images, needles and seeds; through this system, users can pre-simulate, both in an immersive environment and with mouse and keyboard, the whole surgery procedure: grabbing and positioning the 3D template on the virtual patients, puncturing the tissue seeing what structures the needles pass through, and implanting seeds into the target. A total of 32 physicians took part in the test, performing a training bot test with the VR system and the traditional training one (a software on a computer); after the training was completed, each participant was required to perform the simulated surgery on a dummy with non-radioactive seeds and verification of the implantation was conducted by re-scanning. This system confirms that VR can improve learnability, and the conformity index improved in all the groups except for the expert one, whose CIs were not expected to increase.

Later, the same group developed a system which allows the visualization of planning images, volume rendering of organs and preoperative planning on the patient and the tracking of surgical tools in real-time [33,34]. This mixed reality system was then validated

both on phantom and animals as a surgical navigation system to be used as an aid during real surgical procedures. Compared with the traditional image-guided system, the procedure had successful results and reduces the number of CT scans required, allowing doctors to perform surgery based on a visualized plan.

In light of the above, AR/VR could play a central role in taking BT to a new level in controlling dose and achieving greater precision in needle placement, thus resulting in even better clinical outcomes.

4. Patient Empowerment and Mindfulness

4.1. The Pivotal Role of Empowerment in Modern Healthcare

The term “empowerment” is defined by the World Health Organization as “a process through which people gain greater control over decisions and actions affecting their health”, which includes both an individual and a community perspective [35]. More specifically, patients’ empowerment—sometimes referred to with the broader term “participation”—encompasses the concepts of knowledge (of the disease condition), awareness (of their active role in the care path) and the acquisition of specific skills in a facilitating environment. While oftentimes neglected, the environment plays an essential role, as it may promote active participation and recognize individual and cultural differences at a community level.

Preliminary efforts to increase patients’ awareness have mainly encompassed the use of leaflets or short educational videos, to provide general information on sample tumors and treatment plans. However, these approaches have several limitations, including the difficulty in visualizing the actual treating rooms, individual positioning and the targeted anatomical regions.

Currently, several systems have been investigated, and developed, in the context of AR and VR applications, to foster patients’ empowerment in RT, with the intent of alleviating psychological distress, promoting awareness and, ultimately, enhancing compliance and oncological outcomes. This derives from the concept that a well-informed and actively involved individual will be more likely to adhere to the treatment plan, comply with medical prescription and follow physicians’ recommendations, thus incorporating health-promoting behaviors in their everyday life [11,36].

As suggested by several studies, the use of AR/VR methods, such as the VERT and Patient Education and Radiotherapy Learning (PEARL) tools, could improve the delivery of complex information while decreasing patients’ anxiety toward RT.

As an example, Jimenez et al. [37] reported their successful experience with the use of VERT in breast cancer patient candidates regarding RT to the mammary gland and/or to nodal areas. The efficacy of VERT as an educational tool was investigated through a control group, who had received conventional pre-RT information, and the efficacy of both methods (VERT vs. traditional) was assessed by the administration of questionnaires at four pre-defined time points. In both cases, the educational sessions aimed to provide information on CT simulation, treatment planning and RT delivery. While all patients showed the highest levels of anxiety following the first medical consultation with the referring Radiation Oncologist, the VERT group compared favorably with the control in terms of decreased apprehension towards the treatment, despite that the authors estimated a higher predisposition to anxiety in this group. Interestingly, the longitudinal assessment of knowledge on RT highlighted that the effect of the VERT approach was maintained throughout the treatment course, thus suggesting its educational efficacy [37].

A further step forward in the implementation of VR-based education for patients’ empowerment was accomplished by Wang et al. [11], who developed a software capable of rendering the 3D delivery of individual treatment plans on a life-size virtual human positioned on a treating machine, in a commercially available VR headset. The innovation behind this approach is that each patient is able to visualize their own treatment plan, rather than a standardized one, with the possibility of exploring the scene from multiple angles and getting close to the treatment table while the virtual treatment was being delivered. Additionally, the patient’s radiation oncologist and caregiver(s) could follow the simula-

tion on a separate 2D monitor, which offered the possibility of sharing the educational experience, on the one hand, and providing further information, on the other [11].

Albeit less common, the potential of AR to enhance patients' empowerment has also been investigated. A possible AR application has been recently proposed by Martin-Gomez et al. [38], who developed an AR headset to guide patients' breathing during deep inspiratory breath-hold irradiation (i.e., a technique especially used for breast cancer, consisting of the delivery of the RT beam only when the patient is holding a deep breath, to minimize the unwanted dose to the healthy lungs). The author not only created a 2D graph to help patients visualize their respiratory pattern through a valve-based system, but also developed a game-based interactive user interface to better engage patients in the breath-hold procedure. In detail, breath volume and rate are used to automatically control the height at which a bird is flying on the screen, and the patient is asked to hold their breath to avoid obstacles appearing in the form of trees and clouds for an overall duration of 25 s; rewards were also presented, to further enhance the patients during the whole procedure. Notably, the game-based interface was effective in reducing standard deviations in the airflow rates, while no significant differences were noted between the lack of AR-guidance and the use of the 2D-graph [38]. This suggests that the choice of intuitive and possibly engaging interfaces is relevant in increasing patients' compliance, and that a playful, relaxing experience can also be realized in the setting of oncologic care.

4.2. Mindfulness and Stress Relief

According to the definition provided by the Merriam-Webster dictionary, the concept of mindfulness includes both the "state of being mindful" and "the practice of maintaining a nonjudgmental state of heightened or complete awareness of one's thoughts, emotions, or experiences on a moment-to-moment basis" [39]. Considering the physical and psychological distress associated with cancer diagnosis, symptoms and treatment, it is straightforward to understand how the practice of mindfulness may serve as an alternative to or complement the use of drugs against pain and/or anxiety. Several works, including randomized trials, have shown the positive effects of mindfulness in alleviating somatic symptoms, reducing distress and promoting patients' spiritual wellbeing, both in the setting of general oncology and radiation oncology [40–42]. Notably, mindfulness can also be considered as a strategy to manage emotional distress in health workers, and to improve communication between physicians and patients, as investigated in a systematic review by Amutio-Kareaga et al. [43].

VR is playing an effective role in stress relief and relaxation promotion in various settings and it has been already established as a consolidate method in some RT facilities [44], which offer to patients, caregivers and physicians the possibility to experience a relaxing atmosphere, such as the sight of a natural scenario on a lake with a narrated guided meditation throughout the evening and sunrise [45]. Furthermore, VR could be used in hypnosis guidance to control the respiratory motion [46] with beneficial effects on patient's positioning stability during treatment.

VR could be even used as an educational method for patients undergoing RT using immersive experiences that recreate the therapy scenario: this technique could lead the patient to a better comprehension of the treatment which in turn could provoke a decrease in anxiety [47]. AR has not been implemented in the mindfulness and stress relief setting yet, probably due to the need for dedicated developmental teams and the need for more immersive technology to blind the patient from external stimuli.

5. Discussion and Conclusions

Despite its therapeutic benefits in terms of efficacy and quality of life, RT still struggles to receive the regard it deserves; the developments in RT technological equipment, as well as the training and education of the involved professionals, still lag behind, while the knowledge of this technical discipline amongst the general public is still somehow fogged, resulting in an increased level of anxiety in patients undergoing RT treatment.

This scoping review has some limitations. First of all, we only included evidence published in English language, which may have resulted in missing relevant studies published in other languages, and not all titles/abstracts were screened by two reviewers due to resource constraints and the wide breadth of evidence identified on the topic of interest. Additionally, in this work, we included both studies on VR and AR, but studies describing a combination of both of these approaches, namely MR, were excluded. Finally, we included only primary studies published in the 12 years prior to the research. These limitations may have resulted in the researchers missing relevant articles published on the topics of interest.

Despite the limits linked to the scoping review process, the current literature clearly shows how, from an academic point of view, the implementation of VR/AR has already become a reality in many universities and hospitals worldwide, and its integration with traditional educational methods was proven to be successful approach to improve health workers' expertise. Unfortunately, still only a limited number of research works have been published, and the absence of common quantitative methods makes the comparison between different studies difficult. Further studies are needed and a broader consensus on the methodology should be reached in order to provide better insights into the benefits that AR/VR, among other XR technologies, could produce.

From a practical point of view, in light of these reported preliminary experiences, our work promotes the further implementation and development of AR/VR tools to promote patients' empowerment and bring the potential to guide the much-hoped-for revolution in the way patients are treated and radiation oncology is taught.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/app122211308/s1>, Supplementary Materials File S1: Summary of the search strings.

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