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EDUCATIONAL NOTE

Successful implementation of Virtual Environment for Radiotherapy Training (VERT) in Medical Physics education: The University of Sydney's initial experience and recommendations

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Abstract This report outlines the University of Sydney's initial experience with the Virtual Environment for Radiotherapy Training (VERT) system in the Master of Medical Physics program. VERT is a commercially available system, simulating linear accelerators, patient computed tomography (CT) sets, plans and treatment delivery. It was purpose built for radiation therapy (RT) education and offers learners the opportunity to gain knowledge and skills within an interactive, risk-free environment. The integration of VERT into the RT physics module of the Master of Medical Physics program was intended to enhance student knowledge and skills relevant to the curriculum's learning objectives, and to alleviate some of the burden associated with student access to clinical equipment. Three VERT practical sessions were implemented: "RT treatment planning systems", "(CT) Anatomy for physicists" and "Linear accelerator measurements". Our experience and student evaluations were positive and demonstrated the viability of VERT for medical physics (MP) student education. We anticipate that integration of VERT into MP teaching is a valuable addition to traditional methods and can aid MP students' understanding and readiness for practice. Additional evaluations should be conducted to ascertain VERT's role in delivering efficient quantity and quality of MP education, and its potential in alleviating burdens placed on clinical departments.

Keywords VERT · Medical Physics · Education

Introduction

The use of virtual reality to support teaching and learning is rapidly growing in all areas of health and medical education. Purpose built systems have the advantage of supporting specific educational needs, such as technically challenging procedures which require considerable training for optimum performance [1, 2]. In health care education, these systems are driven by a number of factors, including pressures relating to delivering educational content efficiently given reduced budgets, while maintaining quality teaching and learning support for students [3].

A relatively recently available system is the Virtual Environment for Radiotherapy Training (VERT) (VERTUAL, Hull, UK) [4]. VERT was purpose built for radiation therapy (RT) education and offers learners the opportunity to gain knowledge and skills within an interactive, risk-free RT environment. The 3-dimensional (3D) immersive VERT consists of a back projection system displayed on a large wall sized screen, which requires users to wear 3D viewing goggles. VERT displays an interactive linear accelerator model, which can be operated with an authentic hand pendant to replicate realistic movements and sound, with a graphical representation of the radiation beam. In terms of patient and RT planning data, the system loads computed tomography (CT) data and RT treatment plans in Digital Imaging and Communication in Medicine standard (DICOM) format,

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with variable visualisation options for both anatomy and dose. An integrated physics module has several options for display and operation of RT medical physics (MP) equipment, enabling users to simulate dose and calibration measurements, with additional options for introducing patient and equipment errors. The system is also available as a 2-dimensional (2D) display, with similar visualisation tools and features [4].

VERT was initially implemented for RT students in the United Kingdom (UK) under a Government funded initiative. Initial reports from the UK concluded that after using VERT, RT students had increased psychomotor skills, a better handle on fundamental RT concepts, better knowledge of anatomy, simple RT delivery techniques and improved confidence [5]. These benefits were attributed to students' additional experience with virtual clinical equipment, in a safe learning environment, where users had the ability to perform repetitive activities without adversely affecting patients or equipment. Whilst other studies have since continued to validate VERT in RT student groups [6, 7], VERT's use in MP student groups is less well reported. One MP example is a case scenario which describes how controlled errors in the VERT equipment can demonstrate the impact of linear accelerator calibration errors [8]. The authors described the benefits of allowing students to experience a wide range of equipment error conditions, some which are uncommon in practice, hence may take years for MP students and even Radiation Oncology Medical Physicists (ROMPs) to experience. In another study [9], VERT was used by inter-professional groups from various RT departments in Australia in a "knowledge sharing day". In this educational setting, ROMPs and radiation therapists collaborated on improved application and planning practices of a newly introduced RT technique. Combined, the current evidence highlights the experiential and educational opportunities offered by a virtual system such as VERT.

The VERT system was integrated into the University of Sydney's Master of Medical Physics (MMedPhys) program in 2013. The purpose of this article is to report on the University of Sydney's initial experience with VERT in the MMedPhys program. We herein provide a description of the first three developed practical sessions, with a discussion of our institution's initial evaluation and experience with VERT.

VERT funding

In 2012, the national (Australian) Medical Physics Course Co-ordinators Group (MPCCG)[1] received an Australian Government Better Access to Radiation Oncology (BARO) scheme grant to develop a Medical Physics University Network (MPUN). One objective of this initiative was to introduce networked teaching and training opportunities into university MP programs. One strand in the package of proposed workstreams was to develop use of the VERT systems (already installed in Australian RT schools) for MP education. The funding covered the purchase of 2D VERT licences at four of the institutions (with access agreements at the other two universities). The grant also supported a 0.5 full time equivalent MP academic position at each of the six universities to support the range of MPUN workstreams, including VERT development. Additionally, it specified access to the 3D immersive VERT systems which existed at five academic institutions (in RT schools) across Australia.

Master of Medical Physics at the University of Sydney

The MMedPhys is offered as a 2 year postgraduate program, which prepares students for subsequent entry into clinical training (Training Education and Assessment Programs [10]) and accreditation in MP with the main areas being in radiation oncology, diagnostic radiology or nuclear medicine. Traditionally, the radiation oncology modules within the MMedPhys have been undertaken using a combination of didactic lectures and tutorials conducted at university, as well as tutorials, practicals and demonstrations conducted in RT departments under the supervision of clinical ROMPs.

VERT MP practical sessions

The integration of VERT was aimed at supplementing classroom teaching and introducing students to virtual clinical environments, equipment and processes before real-world experience in RT departments. It was intended to serve two main purposes. Firstly, to enhance student knowledge and skills specific to MP equipment and linear accelerator operation, calibration and delivery of RT. Secondly to alleviate some of the burden associated with student access to clinical equipment, which traditionally resulted in after-hours access to equipment for students and the need for ROMP staff to be present at those times.

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[1] MPCCG: an academic group consisting of representatives from the six Australian universities which offer postgraduate Medical Physics programs in Australia; The University of Sydney, Queensland University of Technology, Royal Melbourne Institute of Technology (RMIT University), the University of South Australia, the University of Western Australia and the University of Wollongong; and with an observer from the University of Canterbury, Christchurch, NZ.

Table 1 Learning objectives for “RT treatment planning systems”, “(CT) Anatomy for physicists” and “Linear accelerator measurements” practical sessions

At the completion of the practical session, students should be able to:
RT treatment planning systems
1. Describe the RT treatment planning process
2. Using a treatment planning system
(a) Locate a simulation centre on a CT dataset
(b) Identify and contour organs at risk for a thorax plan
(c) Contour a planning target volume (PTV)
(d) Produce a clinically acceptable parallel opposed thorax plan
(e) Evaluate a RT plan (with respect to ICRU guidelines)
3. Describe role of clinical equipment in RT, the function of collimators and multi-leaf collimators, operation of linear accelerators and the role of quality assurance
(CT) Anatomy for physicists
1. Identify the major organs in the head and neck, thorax, abdomen, pelvis and extremities
2. Describe the major organs in the head and neck, thorax, abdomen, pelvis and extremities, with relation to
(a) Their characteristics
(b) Relationship to other organs
(c) Organ specific cancers
(d) Treatment planning
(e) Treatment delivery
(f) MP theoretical concepts
3. Discuss the image guided RT (IGRT) procedures for various regions in the body
Linear accelerator measurements
1. Identify and describe the function of an ion chamber, plotting tank, chamber calibration, QA plate and alignment phantom
2. Using the VERT system (Medical Physics module)
(a) Simulate Percentage Depth Dose (PDD) measurements in solid water for different energies
(b) Simulate PDD and beam profile in a water tank
(c) Simulate Cross calibration of ion chambers
(d) Simulate light and X-ray field alignment validation
(e) Demonstrate absolute dose calibration
3. Discuss the relationship between theory and practice relevant to linear accelerator measurements

ICRU International Commission of Radiation Units [11]

Three VERT practical sessions were developed: (1) RT treatment planning systems, (2) (CT) Anatomy for physicists and (3) Linear accelerator measurements. The duration of each session was 3 h. The learning objectives for each of the sessions are listed in Table 1.

RT treatment planning systems

The “RT treatment planning systems” practical session aimed to provide an introduction to treatment planning in RT and highlight the relationship between theoretical knowledge on dosimetry, anatomy and linear accelerators. The close proximity of the VERT room to the planning room at Sydney University created an ideal environment to deliver this session. The first part of the practical session employed a purposely developed student handout, which integrated procedural steps for a parallel opposed thorax plan, using the XiO treatment planning system (Elekta, Stockholm, Sweden). The student handout was designed to allow students to work independently and incorporated guidance through the XiO system and relevant planning activities, such as instructions to identify and contour organs at risk, how to expand a planning target volume from a tumour volume and guiding students through beam parameter decisions. Challenges of this section included students’ unfamiliarity with practical treatment planning generally, the XiO treatment planning system in particular and ensuring that treatment plans were clinically acceptable against ICRU criteria [11].

The second part of the practical session involved evaluation of student plans using the VERT system. Each student plan was transferred to VERT and an interactive group discussion was facilitated by the VERT academic. Topics of discussion involved accuracy of contoured regions, advantages and disadvantages of different plans and techniques,

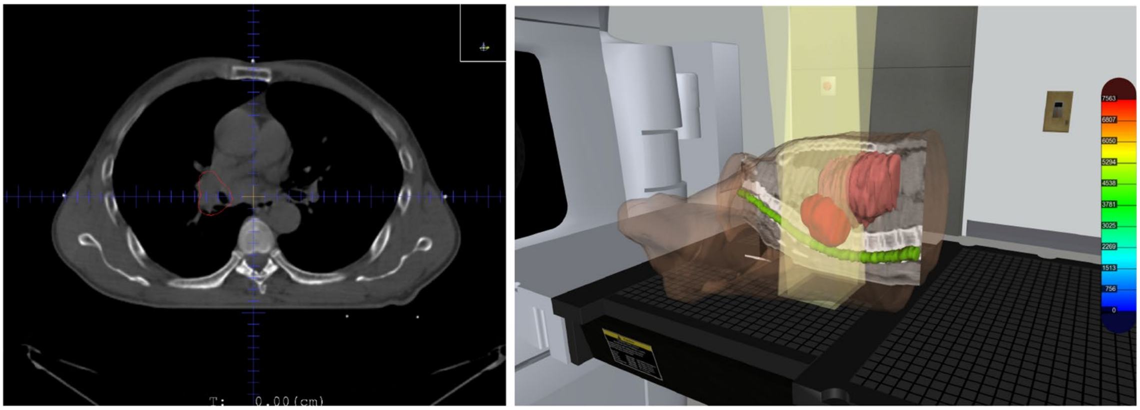

Fig. 1 Screenshots from the "*RT treatment planning system*" VERT practical session, showing cross-sectional image at level of simulation centre on the XiO system (left) and a RT thorax plan showing radiation beams, heart, PTV and spinal cord as rendered volumes, in the VERT system (right)

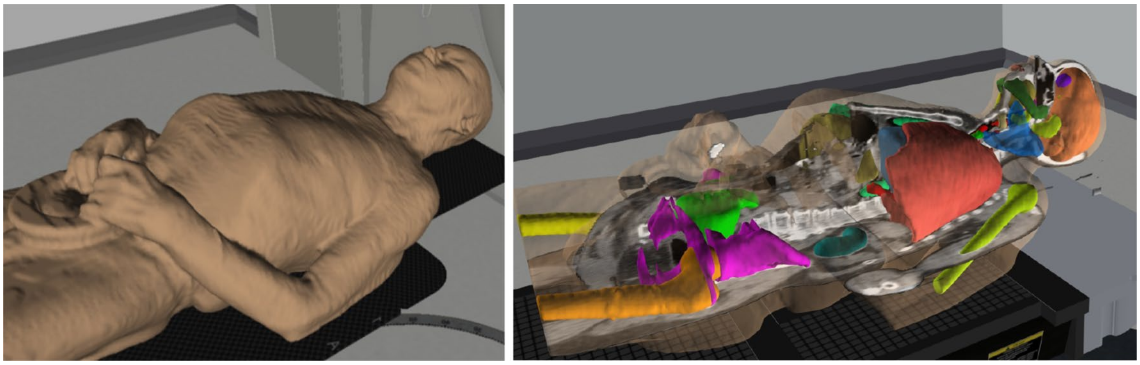

Fig. 2 Screenshots from the "*(CT) Anatomy for physicists*" VERT tutorial, showing the patient's external view (left) and the internal anatomy shown as 3D volumes and CT images (right)

aspects of treatment delivery, role of clinical equipment in RT, function of collimators and multi-leaf collimators, operation of linear accelerators and quality assurance (QA) performed on the linear accelerator. A range of treatment scenarios was used to illustrate the challenges of RT treatment. Students also participated in the manual operation of the VERT linear accelerator, with the handheld controller. Figure 1 shows screen shots from the VERT system used for this tutorial.

(CT) Anatomy for physicists

The "(CT) Anatomy for physicists" practical session aimed to introduce students to major organs in the body and to emphasize the association between various anatomies to RT planning and MP theory. An anonymised male CT dataset was imported into the VERT system, which included data from the top of the cranium to mid femur (308 slices, 3 mm thickness). The CT data had a total of 43 anatomical structures outlined in the head and neck, thorax, abdomen, pelvis and extremities regions. These structures were a combination of clinically used contours and purposely defined contours for this tutorial. Figure 2 shows screen shots from the VERT system used for this tutorial.

During the practical session, a PowerPoint presentation and the visualisation tools in the VERT system were used to systematically describe and discuss regions of the head and neck, thorax, abdomen, pelvis and extremities, with relation to their characteristics, relationship to other organs, organ specific cancers, treatment planning, treatment delivery and MP theoretical concepts. The facilitator led interactive discussions, on associations between radiation oncology and anatomy, ensuring high student participation by using VERT's on-demand visualisation features.

Image Guided Radiation Therapy (IGRT) procedures for various regions were also discussed, using the IGRT features in the VERT system. This assisted in relating the anatomy

Beam Energy (MV): ◉ 6MV ● 15MV

Field Size (mm x mm):

Cross: 300 Inline: 300

◉ Depth profile (mm)

From: 0 To: 300

Step: 1

● Crossline profile (mm)

● Inline profile (mm)

Length: 500 Offset: 0

Step: 1 Depth: 0

Fig. 3 Screenshots from the "*Linear accelerator measurements*" VERT tutorial showing water tank (left) and dose measurement profile (right)

to RT concepts. Student questions were encouraged and the VERT system was used to exemplify answers.

Linear accelerator measurements

The "Linear accelerator measurements" practical session aimed to provide an introduction to various MP QA measurements. This tutorial session employed VERT's physics module. A student handout guided students through concepts and practicalities of QA measurements on VERT's virtual linear accelerator and physics equipment. All measurements included a small noise component, so that repeated measurements were not identical and therefore needed careful measurement methodology to reveal a robust result. During this practical session, students were encouraged to complete equipment calibration activities in teams, which involved taking turns with the hand pendant and selecting variables in the calibration chambers. The following virtual measurements were conducted:

(i) Percentage depth dose (PDD) measurements in solid water using different beam energies. Students simulated measuring PDD with ion-chambers in solid water and plotted results in Excel to allow them to appreciate where each data point in a PDD curve originates from (Fig. 3).
(ii) PDD and beam profile in a water tank. The virtual water tank in VERT was used to create PDD plots, measuring the influence of beam energy and field size on PDD. The beam profiles were measured for different sizes and at different depths to visualise the penumbra and the divergent beam.
(iii) Cross calibration of ion chambers. A chamber cross calibration was performed of a new ion chamber against one with a known calibration factor.
(iv) Light and X-ray field alignment validation. The facilitator set up the linear accelerator with a collimator angle error and students were required to test if the accelerator was ready for treatment. A virtual fluorescent QA plate was used to illustrate the difference between the light and radiation fields.
(v) Absolute dose calibration. The dose from the virtual accelerator was measured and validated with the expected dose.

Figure 3 shows examples of screen shots from this tutorial.

Student evaluation of MP VERT practical sessions

Generally, positive verbal and anecdotal evaluation was received from students in all three practical sessions. Additional student evaluations were conducted using pre- and post-session questionnaires ("RT treatment planning systems" and "(CT) Anatomy for physicists" sessions) and a post questionnaire ("Linear accelerator measurements" session).

RT treatment planning systems

A range of pre- and post-session questions were asked of the students. A sample of these questions are listed in Table 2. 13 students participated in this tutorial and 13 completed questionnaires were received. Table 2 shows the score statistics for each item in the questionnaires (on a scale of 1–5, with score of 1 indicating poor and a score of five indicating excellent). It was also encouraging to see that students' perception of the importance of practical sessions was increased following participation in this tutorial. Students reported that

Table 2 Student score statistics for “RT treatment planning systems” practical session

	Pre-questionnaire[a] (n = 13)				Post-questionnaire[a] (n = 13)			
	Mean	SD	Median	Range	Mean	SD	Median	Range
How would you rate your current knowledge regarding RT?	2.4	0.96	2	1–4	3.1	0.64	3	2–4
How would you rate the TPS/VERT practical?[b]	–	–	–	–	4.4	0.77	5	3–5
How well does the TPS/VERT practical fit in the RT physics course?[b]	–	–	–	–	4.4	0.65	4	3–5

SD standard deviation

[a] Scale range of 1–5 (score of 1 = poor and score of 5 = excellent)

[b] Item only included in the post-questionnaire

Table 3 Student score statistics for the “(CT) Anatomy for physicists” practical session

	Pre-questionnaire[a] (n = 8)				Post-questionnaire[a] (n = 8)			
	Mean	SD	Median	Range	Mean	SD	Median	Range
Rate your current knowledge on how anatomy connects to MP theory	3	0.76	3	2–4	4	0.53	4	3–5
How would you rate your expectations of the VERT anatomy practical?[bc]	3.5	0.53	3.5	3–4	–	–	–	–
How would you rate the VERT anatomy practical?[d]	–	–	–	–	4.1	0.35	4	4–5
How useful were the CT images to your understanding of anatomy?[d]	–	–	–	–	4.6	0.52	5	4–5
How well did the VERT system allow for interactive discussion?[d]	–	–	–	–	4.4	0.74	4.5	3–5
How well did the VERT system help you connect anatomy to MP theory?[d]	–	–	–	–	4.3	0.71	4	3–5

SD standard deviation

[a] Scale range of 1–5 (score of 1 = poor and score of 5 = excellent)

[b] “Expectations” in questionnaire defined as how the VERT practical would assist with the theoretical component of the course

[c] Item only included in pre-questionnaire

[d] Item only included in the post-questionnaire

the “RT treatment planning systems” session helped them link the knowledge from the theoretical lectures and several argued that the “RT treatment planning systems” session might be even more useful at the start of the MP course.

Questionnaires also asked each student to rank how important the following five items were for their education: “lectures”, “course materials”, “assignments”, “practical sessions” and “homework”. Practical sessions moved from fourth most important out of 5, at semester start, to equal first most important way of promoting understanding the course contents (along with course material) after the VERT session.

(CT) Anatomy VERT session

Eight students participated in this tutorial and eight completed questionnaires were received. Students were asked to rate their current knowledge on how anatomy relates to MP on a scale of 1–5, with score of 1 indicating poor and a score of five indicating excellent. The mean self-score by students regarding their current knowledge on how anatomy connects to MP increased from 3.0 to 4.0 ($p = 0.02$, Wilcoxon sign rank test). Students reported high evaluation scores in the post-VERT questionnaire. Table 3 shows the score statistics for the pre and post questionnaires.

Open ended questions in the pre-session and post-session questionnaires found positive responses. Pre session responses indicated that students had positive expectations about the practical session: For example:

- “Excited and confident that it will help me understand what a medical physicist actually does”
- “Relate anatomy more directly to medical physics”

Post-session comments were also positive. For example:

- “My expectations have been met, it is as exciting as I had imagined”
- “It was interesting to observe the actual rays hitting the parts of the body and the percentage of dose it received. This made it interesting as I could connect the anatomy”

Linear accelerator measurements

Eight students participated in this tutorial and eight completed questionnaires were received. Students were asked to

Table 4 Student score statistics for "Linear accelerator measurements" practical session evaluation (post-questionnaire, n = 8)

	Mean	SD	Median	Range
How would you rate the VERT measurement practical?	4.1	0.64	4	3–5
How useful were the questions (raised in the practical session) in helping wider understanding of the RT physics course?	3.8	0.46	4	3–4
How well did the VERT system allow for interactive discussion?	4.6	0.52	5	4–5
How well did the VERT system help you connect the theoretical knowledge with MP practice?	4.4	0.52	4	4–5

Scale range from 1 to 5 (score of 1 = poor and score of 5 = excellent)

evaluate the practical session using a 5-point scale for seven statements about it (with score of one indicating poor and a score of five indicating excellent). Questions and score statistics for each of the seven statements are show in Table 4.

Summary and implications

This paper describes our initial experience with the VERT system over a 1.5 year period of development and introduction of VERT based practical sessions. The three VERT practical sessions described here have been shared with members of the MPCCG, where each university can adapt the resources to their institutional needs. At the University of Sydney, it is proposed that VERT continue to be used as a supplementary teaching component in the MMedPhys program.

Our reported observations (based on relatively informal student feedback by two small student cohorts), showed a combined student appreciation of the VERT system as a useful learning tool. The VERT system resulted in increased student interest, wishing to learn more about the topic, and enthusiasm for additional VERT based education. Anecdotal feedback and discussion also identified a number of suggestions which may improve the VERT tutorials in future academic years. To date, the VERT practical sessions have been offered to two different student cohorts (14 students in total) and the "RT treatment planning systems", "(CT) Anatomy for physicists" and "linear accelerator measurements" have been attended by 13, 8 and 8 students respectively.

Student knowledge and skill

From our experience, integration of the VERT system into the MMedPhys program was found to facilitate students' understanding of the complex and numerous associations between disease process, internal and external anatomy, immobilisation, planning systems, dose delivery, QA processes and RT and MP equipment. Students' ability to see, hear and interact with simulated patient and equipment displays facilitated spatial understanding and theoretical knowledge. From a teaching perspective, the VERT system also supported the explanation of difficult concepts with rich visual cues.

Prior to the BARO grant, access to MP clinical equipment, such as linear accelerators was only possible within clinical RT departments. Whilst this strategy continues to offer clinical experience for students, education is limited in terms of access (after hours use of equipment and ROMPs' availability), range of demonstration capabilities (difficult to simulate errors, not all equipment is available for education) and risks posed to clinical equipment. We believe that the VERT practical sessions supported students' experience by enabling clinical education to occur before entering RT departments and provided a more flexible way to teach.

Each of the three tutorials involved active participation by students. Consequently, it can be argued that VERT allowed better engagement compared to didactic sessions, which may create a deeper level of understanding of the material. For example, anatomy is a difficult topic for MP students to understand, since the majority of MP teaching content is heavily focused on physics and mathematics, where reasoning is used to memorise and understand concepts. In gaining anatomical knowledge however, recollecting names of organs is closely related to the organs' function and physiology. The benefits of simultaneously viewing the location of organs, their relationship to surface anatomy along with CT slices have previously been reported in VERT education sessions [12]. In the future, it would be helpful to assess if accrued experience increases performance and confidence, incorporating a formal survey specifically designed to assess the student learning experience.

Access to clinical experience in a classroom setting

In our experience the VERT tutorials could potentially remove two or three of the in-hospital sessions attended by MMedPhys students. This was particularly true for the "Linear accelerator measurements" practical session, where students participated in a number of simulated dose measurement activities. The VERT system allowed the range of clinical demonstrations to be greater in terms of what could have been clinically possible within the given timeframe, thereby saving time and freeing up clinical resources. In addition, as the VERT practical sessions were delivered in a classroom based setting, students were free to make mistakes and learn from them, not having the pressures of a clinical department (time allowed on equipment, cost and availability of equipment) also provided students with a more relaxed and friendly learning environment, under the guidance of an academic educator.

Limitations of VERT

As with other virtual reality systems, the VERT system cannot replace real life experience. For example, the water tank in the MP module “appears” in the treatment room with a single button click, whilst clinically, the transport and stabilisation of a water tank is a time consuming and laborious task for ROMPs. Similarly, the movement of the ion chamber in solid water would clinically take hours, instead of minutes as seen on the VERT system. It should also be considered that reasonable time should be allocated to hands-on session components using VERT, which can be easier to facilitate when small student numbers are involved.

Limitations of the study

The sample size for this study was small. Whilst this reduces the ability to generalise results to a greater population, the data collected supports our local evaluation objectives. The student evaluation questionnaires were based on self-evaluation, hence the results are subjective and no standardised assessment of student knowledge was performed. Contradictions may also exist in how students identify individual questionnaire items. Whilst this approach may be suitable for the exploratory nature of students’ perceptions of the newly developed VERT tutorials presented in this article, future work needs to assess student knowledge and engagement with current and future VERT tutorials. An assessment of VERT tutorials compared with other education methods may be warranted to provide evidence for VERT’s influence in MP education.

Conclusion

Our experience with the VERT system in the MMedPhys program at the University of Sydney was positive and demonstrates the viability of VERT for MP student education. We anticipate that integration of VERT into the MMedPhys curriculum, and the development of further VERT-based learning modules, can be a valuable addition to traditional methods and can aid MP students’ understanding and readiness for practice. Additional evaluations should be conducted to ascertain VERT’s role in delivering efficient quantity and quality of MP education, and its potential in alleviating burdens placed on clinical departments.

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Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest regarding the publication of this paper.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the Medical University of Warsaw and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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