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Threshold Concepts in Radiation Physics Underpinning Professional Practice in Radiation Therapy

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Abstract

This article identifies potential threshold concepts in radiation physics, and explains their relationship to professional practice in radiation therapy (that is,. the practice of radiation treatment and care of cancer patients). Concepts such as how the radiation beam spreads out (beam divergence), and how the distance from the ionising source affects the beam (inverse-square law), can be challenging for students entering higher education and experiencing their first clinical placements. Through observations of radiation therapy students in practice, mastery of these (and other concepts) appears essential for them to progress in their professional practice learning. The study used 'transactional curriculum inquiry' (Cousin 2009) in order to understand why particular concepts might be troublesome to students, and how mastery of these concepts could potentially lead to safe and accurate practice. While the study was conducted in a particular Bachelor of Science in Radiation Therapy programme, it has implications for how academic and clinical educators in other contexts might facilitate students' acquisition of the threshold concepts that underpin professional practice. The findings suggest that the typical progression in professional education that assumes the application of theoretical concepts to practice, might not be the best way to acquire the threshold concepts that lead to transformed practice.

Keywords: curriculum inquiry; radiation physics; radiation therapy; threshold concepts; transactional

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Introduction: The conceptual underpinnings of professional practice in radiation therapy

To the layperson, professional identity seems closely bound to what a professional can do, but professional competence is underpinned by what professionals know (Muller and Young 2014), and it is the engagement with specialised knowledge that creates a professional identity (Young and Muller 2014). Central to radiation therapy practice is the knowledge that enables accurate targeting and treatment of tumours, while ensuring maximum protection of the surrounding normal tissue. Advances in medical imaging such as computerised tomography (CT) and magnetic resonance imaging (MRI) have had a significant impact on radiation therapy practice (Baumann *et al*. 2016). For example, the ability to display anatomical information in an infinite selection of views has led to the emergence of three dimensional (3-D) conformal radiotherapy – a modality in which the volume treated conforms closely to the shape of the tumour volume (Kong and Wang 2013). Intensity modulated radiotherapy (IMRT), which shapes the radiation therapy beams while altering the intensity of the dose throughout the tumour (Webb 2015), and image-guided radiotherapy (IGRT), which uses imaging techniques that allow the location of the tumour to be tracked to ensure that it is accurately targeted during each treatment (Verellen *et al*. 2007), result in improved accuracy that in some cases allows higher doses to the target due to preferential sparing of the nearby sensitive organs and tissue. These (and other) developments have fundamentally changed radiation therapy practice, and thus have important implications for the training of radiation therapists.

‘Care’ has been identified as an important professional threshold concept in the medical and health sciences (Neve, Lloyd, and Collett 2017), but caring practice in the high technology and rapidly changing environment of radiation therapy requires the practitioner to be both caring and clinically competent in the foundational radiation physics concepts that underpin the complexities of clinical radiation therapy practice. In particular, the expanded scientific base of radiation therapy practice has meant that radiation therapy students need to master and internalise complex key concepts in radiation physics before they are able to achieve competent and safe clinical practice.

This article argues that without a deep understanding and internalisation of threshold concepts in radiation physics, radiation therapists are unlikely to achieve the necessary level of accuracy and consistency in treatment. There are many concepts to be learned in radiation physics, such as sources of ionising and non-ionising radiation, types of ionising radiation, ionisation and excitation, the inverse-square law, electromagnetic radiation, the electromagnetic spectrum, wave theory, properties of electromagnetic radiation, quantum theory, lasers and radiological quantities and SI units (Podgorsak 2005). These key concepts, while important, are not necessarily synonymous with threshold concepts (Meyer 2016). Key concepts are important building blocks for the acquisition of disciplinary knowledge, but what sets threshold concepts apart is their importance to professional knowledge, identity and competence, as well as opening the way for future learning possibilities. This study thus aimed to address the following research questions: 1) how can actual or potential threshold concepts in radiation physics be identified? and 2) how are these concepts related to radiation therapy clinical practice?

Key and threshold concepts in radiation physics: An overview of the literature

Much of the literature on threshold concepts in the health sciences relates to concepts underpinning care (for example, Clouder 2005, Neve, Lloyd, and Collett 2017), general professionalism (for example, Kinchin, Cabot, and Hay 2010), or concepts in the disciplines that are common across health professions, such as anatomy, and physiology (for example, Weurlander *et al.* 2016). Interprofessionality has emerged as a threshold concept for interprofessional education and practice (Royeen *et al*. 2010).

A number of studies have identified threshold concepts in general physics that have some relevance for radiation physics. ‘Probability’ and ‘energy quantisation’ were identified as threshold concepts for understanding atomic structure as scientific models (Park and Light, 2009), while ‘electronic transition’ and ‘photon energy’ were identified as threshold concepts for students’ scientific understanding of atomic spectra (Körhasan and Wang 2016). These general physics concepts were identified as threshold concepts because of their importance for enabling progression towards more advanced concepts. However, Wolfson *et al*. (2014) argue that transferring general physics concepts to more specialised fields of study (for example, biophysics) is not helpful for identifying threshold concepts in more specialised fields. This is the case in radiation physics which has its own set of key concepts. While most health professionals need to understand the importance of radiation protection, for example in dentistry (Crane and Abbott 2016), general clinical practice (for example, Miller *et al*. 2010), or in emergency medical care (for example, Ditkofsky *et al*. 2016), few of the clinical health sciences focus as much attention on radiation physics as radiation therapy.

While no literature was specifically found on threshold concepts in radiation physics – and much of the general literature on radiation physics focuses on quality assurance (see for example, Rosca *et al*. 2006) – a number of potential threshold concepts emerged. A central concept is that of the ‘isocenter’, the point in space through which the central rays of the radiation beams pass. Fundamental to understanding the isocenter is the axis of rotation of a rigid body which is determined “using the trajectory of any point on a plane that intersects the rigid body” (Zhang, Zhou, and Qu 2015: 233). An essential mathematical tool to achieve this is three-dimensional coordinate transformation. The complexity of understanding the rotation isocenters of treatment machines suggest that they are threshold concepts. ‘Beam divergence’, the concept that “the width of the radiation beam increases linearly with distance” from the isocenter (Tyler and Hanna 2015: 57) is another potential threshold concept, as is the ‘inverse-square law’, which states that if you double your distance from a source of ionising radiation you will reduce your exposure by 4 – thus if you triple your distance from the source, the exposure will reduce to 1/9 of the original value. These concepts are cornerstones of radiation protection and strongly linked to radiation therapy practice, thus potential threshold concepts.

A conceptual framework for the study

The study takes key concepts in radiation physics as its starting point, understanding that there is a difference between threshold and key concepts. To help distinguish threshold concepts from key or core concepts Meyer and Land (2005: 373) suggest five descriptors:

Bounded (threshold concepts are relevant, significant, and limited to particular disciplinary contexts);

Irreversibility (they cannot be unlearnt without considerable effort);

Troublesome (they contrast with the dominant paradigms that a student may carry);

Integration (they show the interrelatedness of knowledge and allow new conceptual associations to be built);

Transformation (they change a student’s perception of a subject).

From the literature on radiation physics, potential professional threshold concepts were identified, as in Table 1:

Table 1: Potential threshold concepts for radiation therapy

Characteristics of threshold concepts	Examples
Bounded	Concepts such as 'dose limits', 'radiation protection' and 'radiation conversion' are rarely taught outside of radiation physics (for example, in general physics), and are thus key to the specialised practice of radiation therapy.
Irreversible	Concepts in atomic structure, ionisation and excitation are difficult to unlearn once grasped – and are thus potentially threshold concepts for radiation physics.
Troublesome	The 'inverse square law' is a potential threshold concept as it is difficult to master (it is a geometrical progression, in contrast to 'beam divergence' which is a linear progression).
Integrative	Basic radiation protection principles integrate radiation physics knowledge into protocols for practice; these are potentially threshold concepts as they imply an internalisation of several threshold concepts towards competent and ethical practice.
Transformative	Understanding and using concepts such as the International System of Units (SI) and Common Unit Terminology (for example, for radioactivity, absorbed dose, dose equivalent, exposure) is potentially transformative for the safe administration of radiation therapy-related prescription, radiation dose measurement, and radiation energy uniformity (Noh *et al*. 2014)

The concepts listed above were observed to be challenging for radiation therapy students, often because they are counter-intuitive from the perspective of common sense. It is to be expected that students would experience difficulty in mastering these concepts, but that once understood, further and more advanced learning and development becomes possible. The opportunity for advanced learning is what contributes to the irreversibility of a threshold concept: "the learning becomes part of the very fabric of the learner" (Barradell and Peseta 2016). Students are likely to experience frustration or disruption as the threshold is navigated, but conquering the threshold concepts of radiation physics is likely to underpin professional expertise in radiation therapy.

The study context: Training radiation therapists in South Africa

Radiation therapy is a scarce-skilled profession globally, and more radiation therapists need to be trained in order to address this shortage particularly as healthcare changes from the curative paradigm of the 20th century to a more pre-emptive model in the 21st century. Imaging and treatment modalities are central to this model, and are driving that change to the benefit of the patient. Medical imaging and oncology play a key role in understanding complex biological systems, and are dependent on interdisciplinary knowledge (for example, physics, human biology, computer sciences) to extract that information. The particular context of this study is a Bachelor of Science in Radiation Therapy qualification that leads to professional registration and opportunities for employment in both the public and the private sector as part of a multi-disciplinary team providing a holistic health care service in general and radiation therapy in particular. The qualification requires a minimum of four years' full-time study that combines clinical placements from the first year. All students accepted for this qualification are required to be registered by the professional council for the duration of the period of study at accredited clinical training centres and higher education institutions.

A research methodology for identifying threshold concepts

Cousin's (2009) 'transactional curriculum inquiry' was used as a methodological approach that provided opportunities for students and subject experts to engage in extended dialogues to uncover why particular concepts might be troublesome, as well as how mastery of these concepts might be achieved. Transactional curriculum inquiry is an approach that involves a range of stakeholders in the identification of threshold concepts. The interdisciplinary (or transdisciplinary) discussions and reflections between students, academic and clinical staff offer 'a more holistic representation of the complexity of knowledge, skills and practice within a curriculum' (Barradell and Peseta 2016). The research design used in this study is summarised in Table 2:

Table 2: Summary of research design for identifying threshold concepts in radiation therapy

Research sub-questions	Source(s) of data	Data collection method	Unit of analysis	Analytical method
What are the key concepts in undergraduate radiation physics?	Curriculum documents	Formal curriculum	Key concepts in radiation physics	Documentary analysis (Cousin 2009)
	Study Guide	2016/17 Guides		
	Assessment tasks	Tests and assignments		
What concepts do students find challenging/less challenging?	Nine first-year BSc: RT students	Semi-structured focus group interview	Level of challenges in acquiring radiation physics concepts	*In vivo* and theoretical analysis (Saldana 2013)
	Four academic/ clinical educators	Semi-structured individual interviews		
How do difficult concepts relate to clinical practice?	Nine first-year BSc: RT students	Semi-structured focus group interview	Concepts that underpin clinical practice	
	Four academic/ clinical educators	Semi-structured individual interviews		

The main stakeholders in the study were the students themselves, in this case first-year radiation therapy students. It was important that students' work, their feedback and suggestions were drawn on in the identification of why particular concepts were challenging, as well as why some concepts might not be as challenging. It was equally important to elicit information from academic and clinical staff both to triangulate the student data and to hear all voices on the threshold concepts in radiation physics and the clinical practice of radiation therapy. The multi-voice perspective was an important ethical consideration towards the benefit of all participants.

The study was conducted in line with the research ethics protocol of the faculty of Health and Wellness Sciences at a University of Technology in South Africa, and received ethics clearance from the faculty. Permission to conduct the study, access supporting documents, and interview participants was granted by the Head of the Department of Medical Imaging and Therapeutic Sciences. Voluntary participation, informed consent, confidentiality, maximizing benefits while causing no harm to participants were key ethical issues that guided the study.

Findings

By studying the radiation physics curriculum documents, the students' study guides and assessment tasks and tests, a number of concepts were initially identified. Concepts were defined in terms of 1) those relatively easy to define and apply, 2) those that were difficult to define, but not to apply, and 3) those that were both very difficult to define and to apply. Category 3, as in Table 3, identified potential threshold concepts.

Table 3: Potential threshold concepts in radiation physics

Characteristics of threshold concepts	Easy (to define and apply)	Difficult (to define, not to apply)	Very Difficult (to define and apply)
Bounded	Dose limits Electromagnetic spectrum As Low As Reasonably Achievable (ALARA) Time, distance shielding rule	Basic radiation protection principles	Radiation conversion Radiobiology concepts Atomic structure Ionisation and Excitation Inverse square law
Irreversible (building blocks for additional conceptual development)	Dose limits Electromagnetic spectrum ALARA Time, distance shielding rule Last menstrual period (LMP) Regulatory control	10-day rule Completing patient records Basic radiation protection principles	Unit conversions Radiation conversion Calculations Radiobiology concepts Atomic structure Ionisation and Excitation Inverse square law
Troublesome	-	-	Unit conversions Radiation conversion Calculations Radiobiology concepts Atomic structure Ionisation and Excitation Inverse-square law
Integrative (essential building blocks for practice, underpin clinical practice)	Dose limits Electromagnetic spectrum ALARA Time, distance shielding rule LMP Regulatory control	-	Unit conversions Radiation conversion Calculations Radiobiology concepts Atomic structure Ionisation and Excitation Inverse square law
Transformative (radiographer identity)	Dose limits Electromagnetic spectrum ALARA Time, distance shielding rule LMP Regulatory control	-	Unit conversions Radiation conversion Calculations Radiobiology concepts Atomic structure Ionisation and Excitation Inverse square law

The ‘inverse-square law’ was identified as both difficult to define and difficult to apply under each ‘threshold’ category, and thus was selected for further investigation by students, academic and clinical staff.

For the first-year students, the inverse-square law was particularly troublesome – '…*the square law.. it is difficult, because it is a new term, so we don't know how to apply it'* (Student 1). The concept was new to them and confusing when they first saw it on paper (as part of a formative quiz). A variety of educational resources (for example, drawings, videos, and peer group discussions and a face-to-face discussion in class) were used to help the students to build an understanding of the concept. Many of the students struggled with the concept as they commented that they '… *were confused, and didn't know how to calculate it, how to understand it'* (Student 4). The typical progression in professional education is from theory to practice, and this might not be the best way to acquire the threshold concepts that underpin practice. The findings question the assumption that theory is first understood and then applied to practice, as in this study it seemed that practice (or observing practice) helped to explain the concept. For example, when the lecturer demonstrated the inverse-square law by using a simulated treatment bed and virtual computer software, the students' conceptual understanding was considerably enhanced as confirmed by one of the student participants '…*the demonstration on the laptop enhanced my understanding…'* (Student 1).

Expert academic and clinical staff identified a number of core concepts (which were referred to as 'bread-and-butter' concepts during some interviews). Because these concepts were so familiar, lecturers found them difficult to teach. As Lecturer 2 remarked: '*I find it difficult to teach basic concepts*'. One of the challenges associated with threshold concepts is that they are difficult to teach, because it is difficult for experts to put themselves back in the novice position and "remember the troublesome nature of certain ideas and concepts" (Barradell and Peseta 2016: 273).

Both academic and clinical educators could quite easily relate key concepts to clinical practice and referred to this as seeing the 'bigger picture'. One of the lecturers explained the potential consequences of students not fully grasping a potential professional threshold concept: '…*students need to understand the building blocks, in order to identify errors and incidents*…' (Lecturer 1). Academic and clinical staff often assume that students are aware of the dangers of radiation and therefore do not teach the key concepts in a way that links them to avoidable errors and incidents in practice.

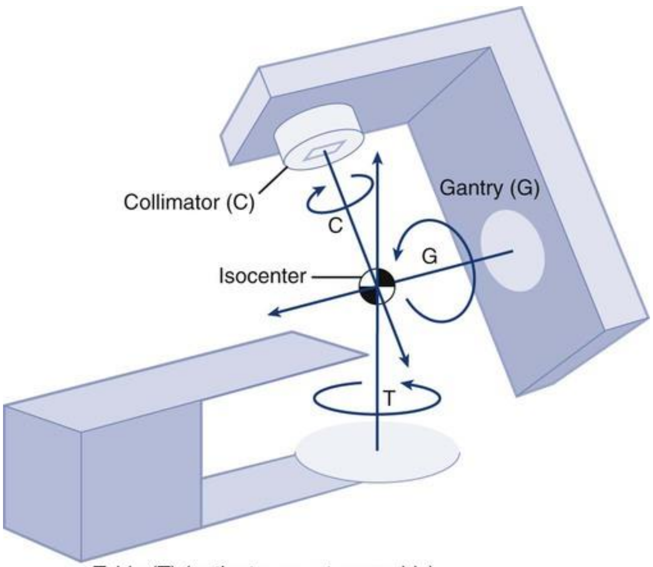
Conclusion and key message: 'Seeing the unseen'

What do we conclude about identifying threshold concepts in radiation physics? Identifying and separating non-threshold concepts (that is, core concepts and building blocks) from threshold concepts is challenging. It requires 'mapping' the key concepts in the field to form a coherent whole, and then identifying those concepts that are particularly 'troublesome'. It was clear from this study that threshold concepts are indeed 'troublesome', often (as in the case of the inverse-square law) involving both complex mathematics and physics calculations. The concept integrates more foundational concepts, such as the 'isocentre' and 'beam divergence', and a part of what makes it both integrated and troublesome are the different sets of calculations involved: the isocentre is plotted using three-dimensional geometry (x, y, and z axes); beam diversion is calculated using arithmetical progression; radiation effect uses the inverse-square law, a geometric progression. The investigation into threshold concepts for radiation physics thus highlights the importance of the sequencing of topics from a student learning perspective: from types of radiation to properties of radiation, to interaction with matter, shielding, radiation protection and dosimetry.

We identified the inverse-square law as 'bounded' in the sense that it is discipline-specific. Students entering radiation therapy studies would be familiar with more basic mathematical and scientific concepts learned at school. At school-level, the physics that is taught is the physics of the natural world. Radiation physics is the physics of treatment machines and doses. Thus students have to unlearn high school concepts and re-learn the concepts of the new discipline. The inverse-square law is thus beyond what students would have encountered in mathematics or physics at school, it is a disciplinary concept that borrows from standard mathematics or physics but has evolved in the context of practice. The abstract nature of a concept that one cannot see physically, but has to understand in terms of its mathematical and physical properties is particularly difficult for students to grasp – students often ask: 'where does the dose go?'

Figure 1 summarises and visually represents how a threshold concept such as the isocenter and disciplinary concepts such as 'gantry', 'couch' and 'floor rotation' come together in clinical practice.

Figure 1: Threshold concepts in practice (from Bourland 2016: 96 Figure 6-3 © Elsevier 2016 All rights reserved. www.elsevier.com Figure reproduced with permission.)



With regard to its 'irreversibility' while this characterises experts' grasp of the concept (and explains why it is so difficult for them to explain), for the students the inverse-square law was something they 'got' and then 'lost' – being in a liminal space. Repetition and reinforcement is therefore implied in the attainment of a threshold concept: "there is no simple passage in learning from 'easy' to 'difficult'; mastery of a threshold concept often involves messy journeys back, forth and across conceptual terrain" (Cousin 2006: 5). The 'transformative' nature of the concept was not evident in the learning process but could potentially transform practice.

What do we conclude about how the threshold concept underpins radiation therapy clinical practice? In our study, we found a reciprocal relationship between concept and practice. The inverse-square law underpins radiation therapy clinical practice, but equally, it is the practice that 'makes visible' the abstract nature of the concept and which helps students to integrate and internalise the concept (thus rendering it 'irreversible'). In becoming familiar with treatment machines and understanding the scientific principles of their functions, students are making connections between theory and practice. They are 'seeing the unseen' – 'seeing' abstract concepts become real and impact actual patients.

Understanding how the core and threshold concepts relate to the bigger, clinical picture has always been a central concern of health science education. In this regard, practicing radiation therapists, who have direct contact with students and more fully understand how abstract radiation physics concepts taught in the classroom come to life in practice made an important contribution to the study. As the scientific base of practice in radiation therapy education extends and requires more time in the classroom, it is important that entry into the clinical environment is not delayed. The growing theory/practice divide was explained by a research participant as '*the* *rapidly changing clinical platform [that] is making it even more difficult to see the unseen*' (Lecturer 3). In this regard, the visualisation of concepts through a virtual learning platform (such as the Virtual Environment for Radiotherapy Training [VERT™] platform used by one of the academic lecturers) offers an innovative way of bridging the increasing theory/practice divide in radiation therapy, and in other health sciences.

This study has made a contribution to the identification of threshold concepts in professional fields. The findings pose questions about whether a threshold concept should satisfy all five of Meyer and Land's (2005) descriptors, or whether its troublesome nature is its essential characteristic. Our study proposes a number of factors that contributes to the 'troublesome-ness' of threshold concepts as well as ways to facilitate the acquisition of threshold concepts.

The degree of abstraction of the concept is strongly related to its degree of difficulty. With regard to 'integration', it is not the accumulation of prior concepts that makes the threshold concept troublesome, but the complexity of the particular string of related concepts that it integrates. Making the abstract concepts visible through observing and engaging in supervised or virtual practice supports their acquisition and internalisation towards an 'irreversible' state.

Without an understanding of the inverse-square law, radiation therapists could never practice safely. We thus conclude that in professional education, threshold concepts are considerably entangled in practice, and that it is the movement between concept and practice that is key to their acquisition. These conclusions were confirmed by one of the student participant's comment… '*when you don't understand what you've been taught in class but the fact that you will be working in a hospital under supervision, it will make a lot more sense. It will give you an opportunity to go back and understand things more'* (Student 4).

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