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Systematic Review

Graduate competencies, employability and the transnational Radiography workforce shortage: A systematic literature review of current pre-registration Radiography education and training models

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ABSTRACT

Introduction: Transnational mobility of the Radiography workforce is challenged due to issues with standardisation of current education and training models which has added to the workforce shortage. To address the growing volume, scope and complexity of clinical Radiography service delivery, educational models need to be given a critical look for transnational relevance in modern times. This study aims to synthesise the characteristics of current pre-registration radiography educational programmes linked with effective knowledge, skill acquisition, and graduate employability to address the current workforce challenges through the development of newer training models.

Methods: Using a mixed methods systematic review approach, secondary data was obtained from an EBSCOhost search involving key databases including MEDLINE, CINAHL, Academic Search Ultimate, ScienceDirect, and SCOPUS. Themes were developed following a result-based convergent data synthesis.

Results: Forty articles met the predefined inclusion criteria following the study identification and screening phases. The included studies were conducted from across diverse settings including both low- and middle-income countries (LMIC) and high-income countries (HIC). Two broad themes were developed from the findings including: *1. Factors influencing graduate employability* and *2) Radiography education and training programme characteristics.*

Conclusion: The findings highlight and advocate for an innovative model for Radiography education and underscores the significance of graduates possessing multi-modality skills, varied competencies, and effective accreditation processes for training. Prioritising alignment with industry needs and holistic skill development is vital to closing the employability gap, ultimately improving graduate skills and competencies to address workforce shortage while improving patient care outcomes.

Implications for practice: Radiography training institutions should explore the development of new innovative models for multi-modality pre-registration education. This should offer adaptable routes that align seamlessly with the evolving regulatory, technological, and clinical trends.

Introduction

The World Health Organisation projects a global shortage of ten million health and care workers by 2030, shouldered predominantly in low-middle-income countries.[1] Moreover, within this notion, there is a well-documented workforce crisis worldwide in the imaging[2–4] and radiotherapy workforce.[1,5,6] The result of these shortages is that optimal patient care experiences and outcomes are hampered[7] due to prolonged waiting times, radiographer burnouts,[8,9] and inadequate student clinical supervision opportunities.[10]

Globally, there is a growing number, scope and complexity of diagnostic imaging procedures performed as part of patient care and management, which are predicted to increase steadily.[11–13] Similarly, radiotherapeutic care remains key in managing cancer[14] as its prevalence rises.[15] Against this background, the entry-to-

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practice curricula for diagnostic and therapy radiographers have remained largely static[16] and divergent in provision over the years.[17,18] Consequently, it is argued that education regulation frameworks and workforce planning have somewhat remained inefficient and have contributed to the international shortage of diagnostic and therapy radiographers.[1,4,19–21]

Radiographers are integral to patients' quality of care and management. Therefore, addressing the shortage is critical and requires innovative human capital development approaches for an appropriately trained and adequately sized workforce.

Higher education's overarching goal is to address society's current and future challenges[22] by educating graduates with optimal knowledge, skills and attributes relevant to the demands of respective professions and labour markets.[2] However, the inability of some graduates to meet these demands raises questions about the quality of training, for which critics have assailed higher education providers for failing to design educational programmes congruent with the changing industry, service, and technological landscape.[23,24] For example, within medical imaging, many authors argue that current clinical education and training models have exacerbated the workforce challenge by failing to meet the existing demand for imaging services.[9,23] The linkage between workforce shortages and radiography education and training models has received much scholarly attention recently.[16,19] Cowling identified a mismatch between the increasing imaging demands across all modalities and the training of radiographers.[25] Furthermore, in his seminal text on the subject, Sloane[16] argues that:

> "… *evidence from the increase in the volume and mix of medical imaging procedures undertaken by the breadth of healthcare provider organisations supports the need to reform undergraduate curricula. If this does not occur, there will be insufficient training capacity to meet the workforce requirements, and graduates will not possess the range of skills needed to support the diversity of services offered by providers, both now and in the future as technology continues to evolve*",

A broadly similar point is also made by other researchers who have shown that training models for radiography technologists in the USA and university graduate radiographers in the UK, Australia, mainland Europe, and Africa exhibit distinct characteristics.[25–29] For instance, in the United States, there is an emphasis on technical training provided through associate degree programs,[30,31] which align with levels 4 or 5 on the Framework for Higher Education Qualifications (FHEQ) in England.[32,33] Contrastingly, the comprehensive entry-to-practice bachelor's degree and MSc pre-registration programs (FHEQ 6 and 7) [32,34] place significant emphasis on a diverse spectrum of theoretical coursework and clinical training, as opposed to the educational models found within the United States.[30,31] In certain nations, however, pursuing specialisation and advanced practice[35,36] roles occur through post-graduate avenues, accentuating the divergence in certification and registration procedures. Consequently, resource-limited settings, including Africa, further diversify the Radiography education landscape due to varying educational resources and infrastructures across nations.[25]Thus, there may be detrimental consequences to Radiography graduate competency outcomes and effectiveness if their education and training remain disparate within the changing clinical and technological landscape. Notwithstanding, educational institutions,[37] regulatory bodies[38] and healthcare systems are continually expected to develop future-facing curricula while retaining fundamental concepts upon which the radiography profession is built.

Even with the inherent pre-covid heterogeneity and less aligned curricula, the advent of COVID-19 further accentuated the need to rethink existing radiography education models, concepts, and practices into more innovative approaches that transcend regional differences. For example, Lawal and colleagues[26] posit the need for innovative approaches to teaching and learning by integrating hybrid modes of educational delivery within radiography. Although studies have recognised these challenges, research has yet to synthesise what characteristics of undergraduate radiography education programmes are associated with adequate knowledge, skill acquisition and graduate employability to address the workforce concerns. This study seeks to systematically review the literature to provide an understanding of the current pre-registration Radiography education models to inform steps toward harmonising future educational curricula. Additionally, this study aims to highlight essential and desirable components of existing pre-registration curricula through a transnational lens by addressing the question:

What characteristics of pre-registration radiography education programmes are associated with adequate knowledge, skill acquisition and graduate employability?

Methods

A mixed methods systematic review (MMSR) methodology[39] was used to identify and synthesise available evidence on the essential and desirable components of pre-registration radiography education and training models. While most reviews do not use a mixed-methods approach, there is a growing interest in strengthening review questions that address the effectiveness of interventions with a qualitative aspect of what contextual factors exist and why and how they lead to variable impact.[40,41] Thus, evidence addressing effective educational models, subjective experiences of key educational stakeholders on the phenomenon of interest or knowing the "*how*" type of evidence was searched and systematically screened and included for this review. It is further argued that including an assortment of evidence, regardless of type, allows for the triangulation of findings while providing requisite breadth and depth of understanding on the focus of inquiry to inform practice and policy.[39]

Data sources and search strategy

An adapted PICOS framework (i.e., PICS)[42] (Population, Phenomenon of Interest, Context, and Study Design) was employed to mould our inquiry, formulate a precise search strategy, and guide our article selection criteria (Table 1).[44]

An EBSCOhost search which included (MEDLINE, CINAHL (Cumulative Index of Nursing and Allied Health Literature, Academic Search Ultimate, ScienceDirect and SCOPUS) databases, was then conducted using the search terms "radiography OR radiologic technology OR diagnostic imaging OR Radiotherapy) AND/OR (training OR education OR school OR instruction, undergraduate student OR college student) and (curriculum, curricula, instruction, teaching, learning, program, model, course, or syllabus). Additional focused searches were conducted in key radiography-speciality journals for relevant publications, including the *Radiography Journal, Journal of Medical Radiation Sciences, Radiologic Technology, and Journal of Medical Imaging and Radiation Sciences*. The search was also complemented with a hand search of reference lists of included studies and guideline documents for other potentially relevant papers. No filters were applied to limit study designs; however, a filter was applied to only include peer-reviewed studies.

Table 1
Article selection criteria using the PICOS format.

Topic	Inclusion	Exclusion
Population (P)	Undergraduate radiography programmes, students, recent graduates, educators, or radiology service managers	Non-undergraduate radiography – (programmes, students, recent graduates, educators, or radiology service managers)
Phenomena of interest (I)	Studies addressing the structure and content of undergraduate radiography programmes (what is taught) and graduate competencies	Studies about pedagogy in undergraduate radiography programmes (how they are taught) and the accreditation of programmes
Context (C)	Undergraduate radiography programmes, clinical placement sites	Non-undergraduate radiography programmes or placement sites
Study design	Published scholarly research, expert opinion, reviews of literature	Studies where insufficient information was reported on methods used, editorials, study protocols

Eligibility criteria

Articles were included if they are: original research focussing on existing Radiography educational programmes where an objective assessment of radiography-related knowledge has occurred, published within the years 1990–2023, educational programmes that offered single or combined specialisations and used either face-to-face, e-learning or blended instructional methods. Studies were excluded if they involved non-radiography educational programmes and non-radiography medical professionals participating in radiography-related education or were not in English. Radiography educational programmes addressed projection radiography, medical ultrasound, computed tomography, magnetic resonance imaging, radionuclide imaging and radiotherapy.

Quality assessment

The included articles were evaluated using the QATSDD criteria,[43] and the assessment categorised the articles as having quality ranging from moderate to high. Studies were classified as high-quality (n = 33) if they achieved an overall score of over 70 %. Studies falling between 50 % and 70 % (n = 5) were considered moderate quality, while those with scores below 50 % (n = 2) were categorised as low quality. These quality scores were not a part of the exclusion criteria however, they influenced the weighting of findings in our discussion for a current and an unbiased perspective of transnational relevance. Not including studies with low aggregate scores might limit the transnational nature of the review, as certain findings are pertinent to specific geographic areas.

Data extraction

Two independent reviewers (ES and TNA) conducted title, abstract, and full-text screening to determine eligibility before extracting data; consensus between the two reviewers resolved disagreements. A third reviewer (JT) double-checked the process to ensure the strategy adhered to guidelines.[32] Bibliographic information was abstracted from each included article to address the purpose of the literature review, including author and year, title, country or continent of study, study participant or data source, sample characteristics, study aims, design and findings.[44]

All included articles were exported from EndNote™ reference manager and loaded into NVivo qualitative data analysis software (v.12.5). To uncover underlying patterns and emerging trends, a word search of frequently employed terms in the included studies was conducted using NVivo™ (Fig. 1). The word cloud generated was employed to visually emphasise[45] the prevailing themes[46] encapsulated within the reviewed studies, effectively portraying

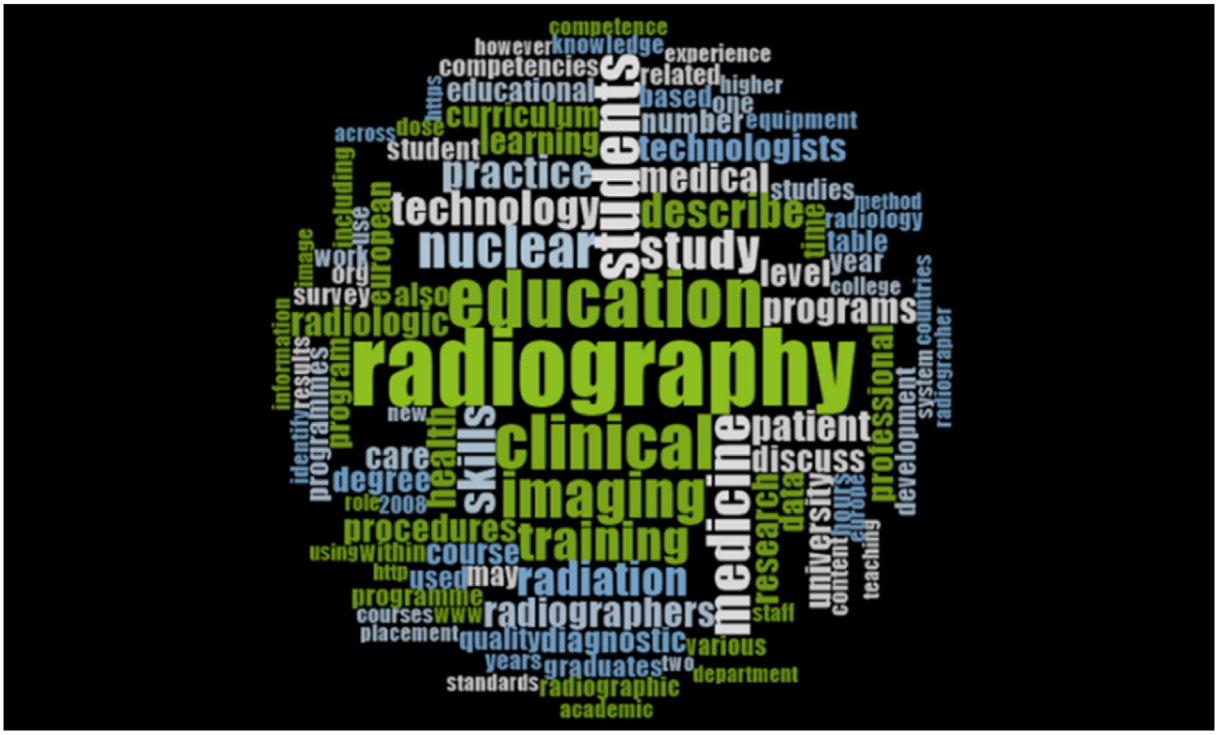

Figure 1. Wordcloud showing the most frequently occurring words in the included studies.

the frequency of certain key terms. Notably, terms like “radiography," “education," “competence," and “programme" emerged as the most frequently occurring terms in the reviewed studies. Additionally, utilising NVivo's code function, relevant study findings from the results and discussion sections were extracted and coded for textual analysis, systematically enhancing transparency, plausibility, and rigour in integrating the results.

Data analysis and synthesis approach

Braun and Clarke's six steps to thematic analysis were employed, as highlighted in Table 2. To substantiate this course of action, we draw on Maykut and Morehouse's viewpoint,[47] which underscores the pivotal role of language in comprehending one's circumstances. This approach enables the identification and presentation of patterns within participant expressions, facilitating meticulous examination by others. Additionally, the synthesis in this study adhered to the convergent integrated approach, following the methodology outlined by the Joanna Briggs Institute (JBI) for MMSR.[48,49] This approach involved transforming all extracted quantitative findings into qualitative ones before simultaneously synthesising data from various types of evidence,[49] resulting in meaningful codes.[50]

Results

The initial search yielded 2185 articles (Fig. 2),[51] with forty articles fully meeting the inclusion criteria following the study's identification and final screening phases.

Study characteristics

The review encompasses older and newer articles from diverse participant types; , including radiography students, graduates, lecturers, radiology managers, and documents from radiography programmes. These participants come from different parts of the world, representing low and middle-income countries (LMIC) and high-income countries (HIC). The use of older references allowed us to provide a historical context and a baseline for cross-comparisons of educational systems across different regions. It further helped us identify long-term trends and patterns and highlight the much-needed data representation from underrepresented communities whose challenges have not substantially changed over time. Using a mix of old and new references provided a broad perspective and a more holistic transnational view of the pre-registration radiography education landscape, which this review aimed to highlight. Briefly, the included studies were conducted in Europe (n = 8), Africa (n = 4), Asia (n = 1), North America (n = 12), the Caribbean (n = 2), United Kingdom (n = 6), Australia (n = 3), and three were multinational studies. The studies comprised qualitative (n = 12), quantitative (n = 17), and mixed methods (n = 11) designs. The volume of studies over the years has been fairly constant (mostly, n = 1) until 2016 (Fig. 3). Notably, compared to high-income countries, there is a paucity of publications available from resource-limited settings. Quality scores using the critical appraisal QATSDD tool ranged from low to high (38–95 %).

Key emergent themes

Two overarching themes were developed from the data analysis.

1) *Factors influencing graduate employability:* This theme underscores the multidimensional essence of employer-related factors and attributes constituting the preferred graduate attributes within the diagnostic and therapeutic imaging industry domain. Fig. 4 presents two main factors (subthemes) influencing graduate employability: employer-related factors and graduate profile.
2) *Radiography education and training programme characteristics:* This theme pertained to the radiography programme's structural aspects, curricula content, and the consequential impact of the accreditation process on the perceived calibre of educational programmes and the subsequent employability prospects of graduates (Fig. 5).

Discussion

The evidence from the findings of this systematic review indicates that the employability constructs combine a complex interlinkage between individual graduate attributes and contextual dimensions. The review's findings affirm the strong employer preference for graduates possessing diverse non-imaging related competencies alongside their multi-modality diagnostic imaging skills.[29,52] Similarly, oncology professionals, including radiotherapists, require a comprehensive skillset beyond specific clinical competencies to encompass teamwork, interprofessional collaboration, decision-

Table 2
Analytical Steps to data analysis adapted from Braun and Clarke's six stages of thematic analysis.

Analytical Process	Application of Process in NVivo	Objective	Iterative process
1. Data Familiarisation	Import included studies into NVivo from EndNote, create each publication as a case and link to its metadata. Cases act as the unit of analysis, storing all text from the publication. Read data actively, analytically and critically	**Manage data** through open and hierarchal coding in NVivo	Assigning data to refined concepts to portray meaning.
2. Coding the Data	Open coding-code what is analytically relevant across the entire dataset and collect data relevant to each coding label.		
3. Generating initial Themes from coded data	Organising and gathering the codes into initial potential themes	**Descriptive Phase -** marked by the reordering of the coding process.	
4. Reviewing and Developing and Naming Initial Themes	Identify the nature or characteristics of each theme and the overall storylines that the analysis tells.		Assigning data to themes/concepts to portray meaning. Assigning meaning
5. Producing the Report	Generating analytic commentaries or memos, synthesising the memos and drawing out analytical conclusions relating the analysis to the research question	**Drawing out analytical Conclusions,** drafting memos through NVivo	

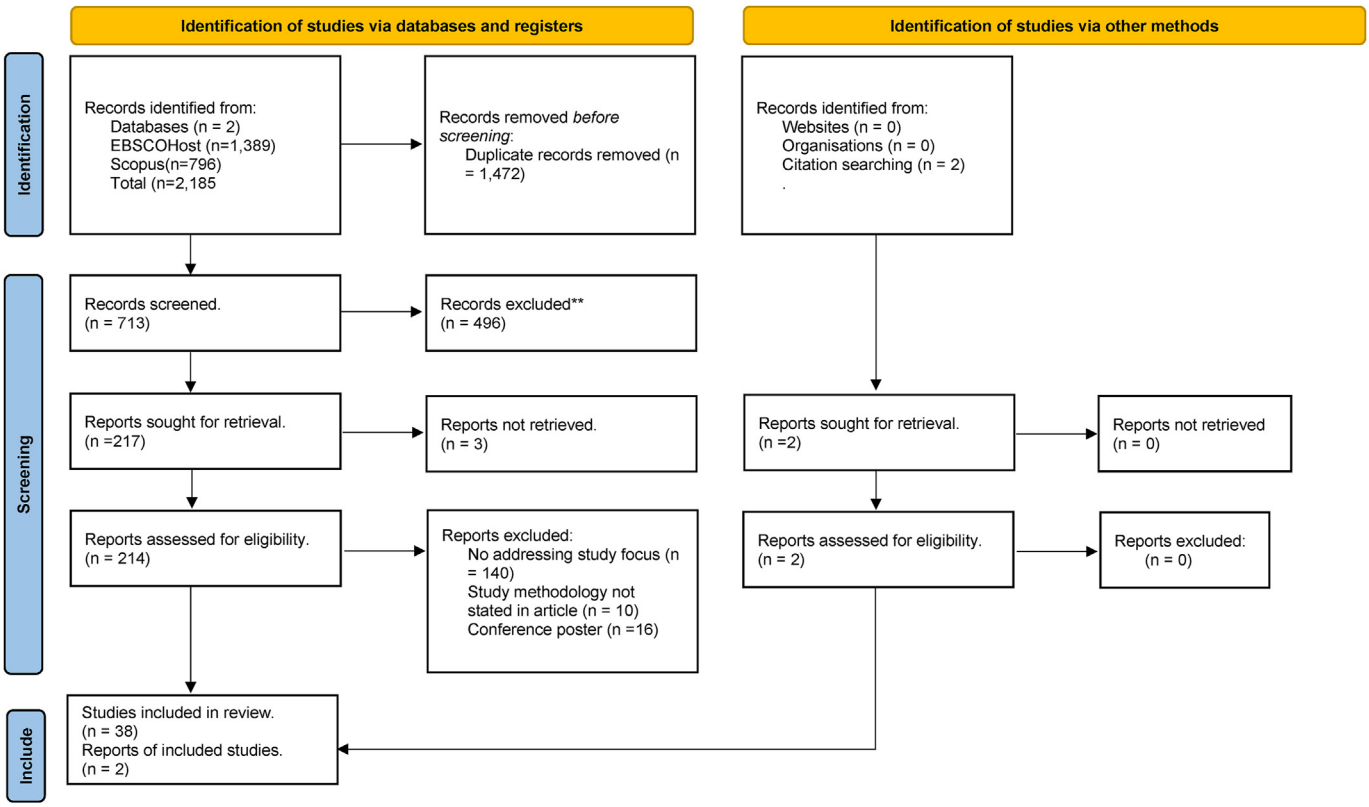

Figure 2. PRISMA Flow chart.

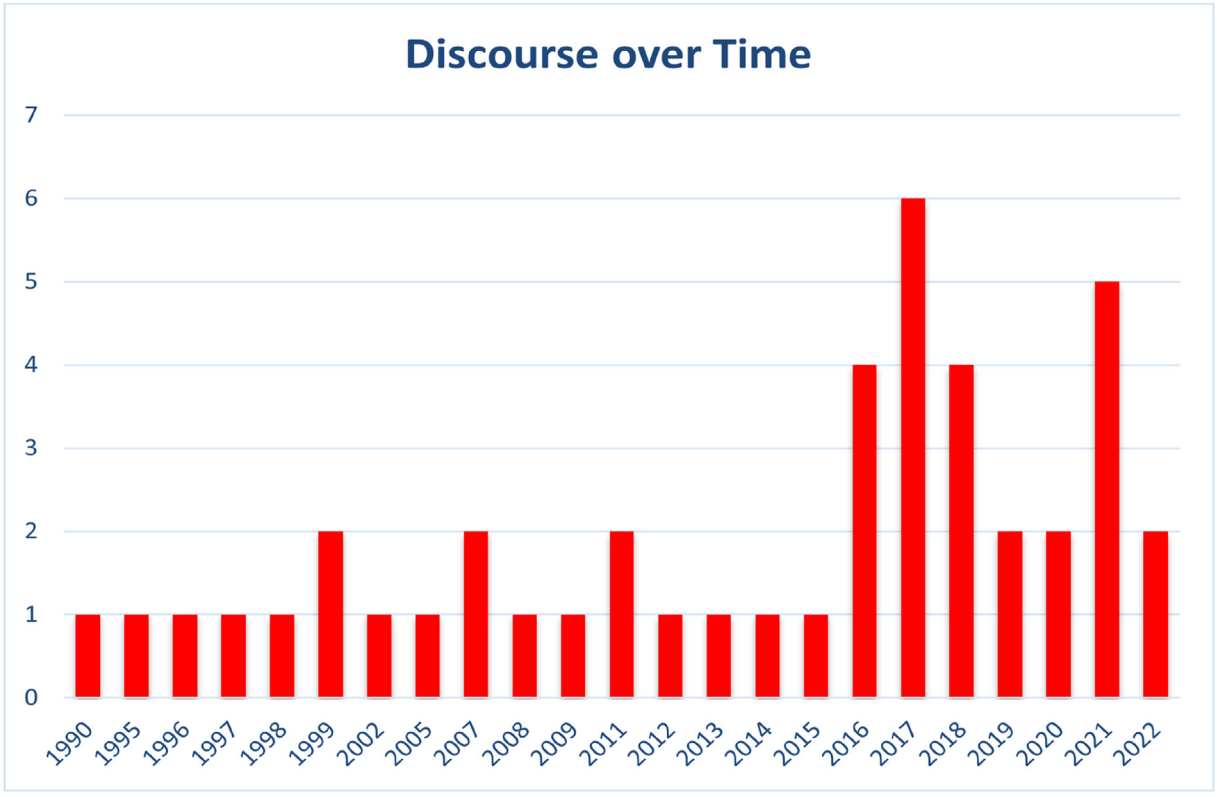

Figure 3. Discourse Over time of publications included in the review.

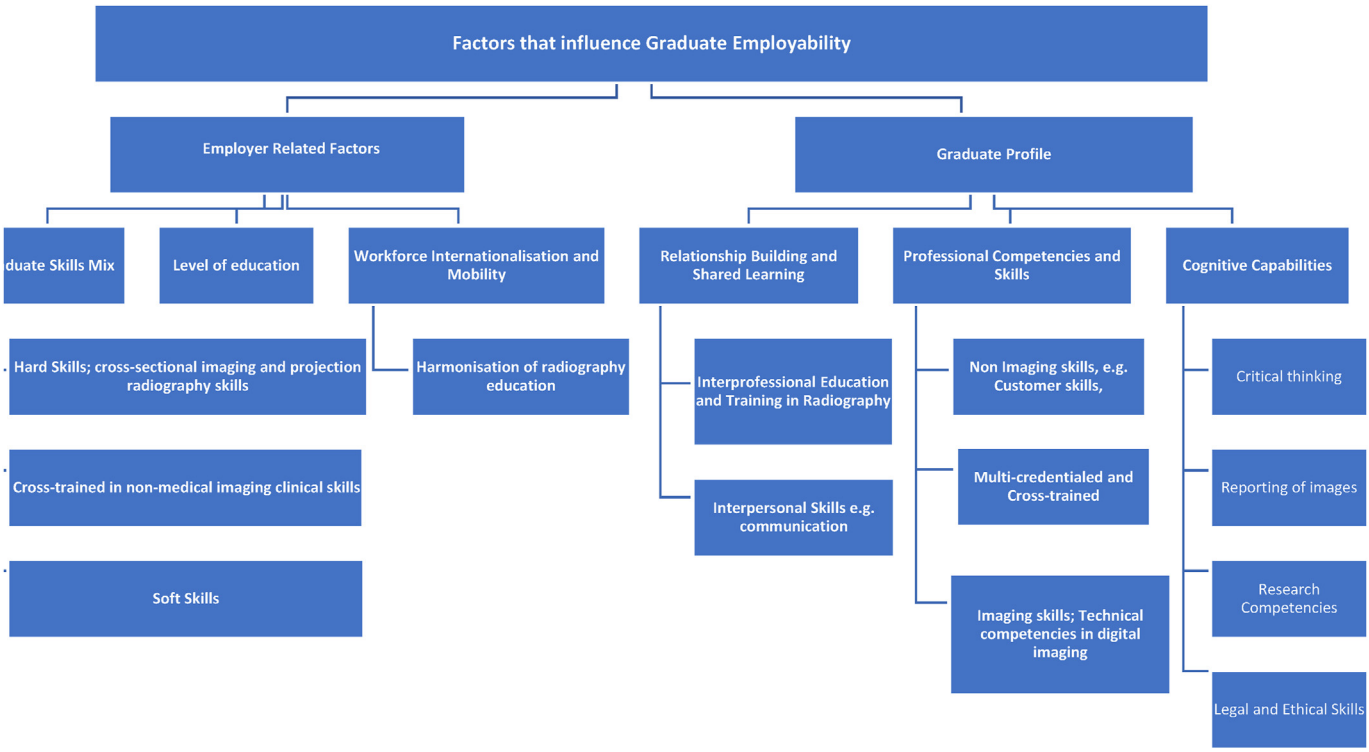

Figure 4. Factors that influence graduate employability.

making, pharmacology, management, and leadership to improve patient care coordination.[53] This underscores the necessity for pre-registration radiography curricula that are forward-looking and innovative, capable of adapting to the evolving technological and service landscape.

Theme 1: Factors influencing graduate employability

A. Employer-related factors

Of the forty included studies, thirty-four (85 %) examined determinants impacting graduates' employability. Salient factors such as the composition of graduate skills, educational attainment levels, and the imperative for a versatile workforce adept at seamless adaptation across varied operational contexts are evident in this context. Noteworthy findings from the collective studies reveal a predilection among radiology service managers, as evidenced in select studies, to favour the recruitment of radiographers characterised by a multifaceted array of competencies[54] and proficiencies as a cost-containment strategy. These sought-after attributes encompass a mosaic of cross-credentialing[55] and cross-training, coupled with adeptness in hard competencies about cross-sectional and projection radiography. Additionally, acquiring soft skills further embellishes the profile of the preferred radiography candidates. For example, in one survey of 104 hospital radiology departments in Nebraska (response rate 51 %), 93 % of respondents said,

> *"It was very likely that they would hire a multi-credentialed technologist in the future".*[52]

A congruent perspective was echoed in another study, wherein it was elucidated that a predominant proportion of chief technologists exhibit a preference for recruiting staff technologists who hold associate degrees (30.4 %) or bachelor's degrees (38.2 %), alongside a pronounced emphasis on the possession of multifaceted non-imaging clinical competencies, e.g., venepunctures (75.2 %) and the attainment of imaging skills in more than one modality (82.4 %)[56]. Whilst a minority of studies in the USA mentioned that competence in projection radiography[57] only did not disadvantage graduates from being hired, most agreed that multi-modality and cross-trained graduates[52,56,58,59] were preferred by hiring managers. In a UK study,[60] divergent views emerged. Some advocated for the specialisation of projection radiography, contending that the complexity of general radiography hindered new graduates from maintaining competence across modalities, necessitating extensive preceptorship in certain cases. Conversely, others asserted that recent graduates lacked the skillset required for service needs, advocating for tailored training to attain post-graduation autonomy in cross-sectional imaging, underscoring the demand for multi-modality education and training[60,61]. Similarly, a study in radiotherapy[61] in selected European countries observed that a greater focus on advanced imaging like MRI or CT reduces X-ray training hours. Particularly revealing were how fifteen recent graduates in the USA reported that they could not find work in radiography because they lacked competencies in mammography, CT and sonography, as employers most frequently cited them as desirable additional skills beyond projection radiography for employment.[62] These findings imply that the multifaceted demands of the workforce may necessitate novel approaches in educational routes and regulatory mandates.

B. Graduate Profile

Graduate profile emerged as a factor (subtheme) influencing employability. This article adopts the term "*graduate profile*" to encompass essential graduate outcomes and attributes learned in their preparation or achieved during their education.[63] Notably, most studies implied that graduates who possessed the following skills were more likely to be hired.

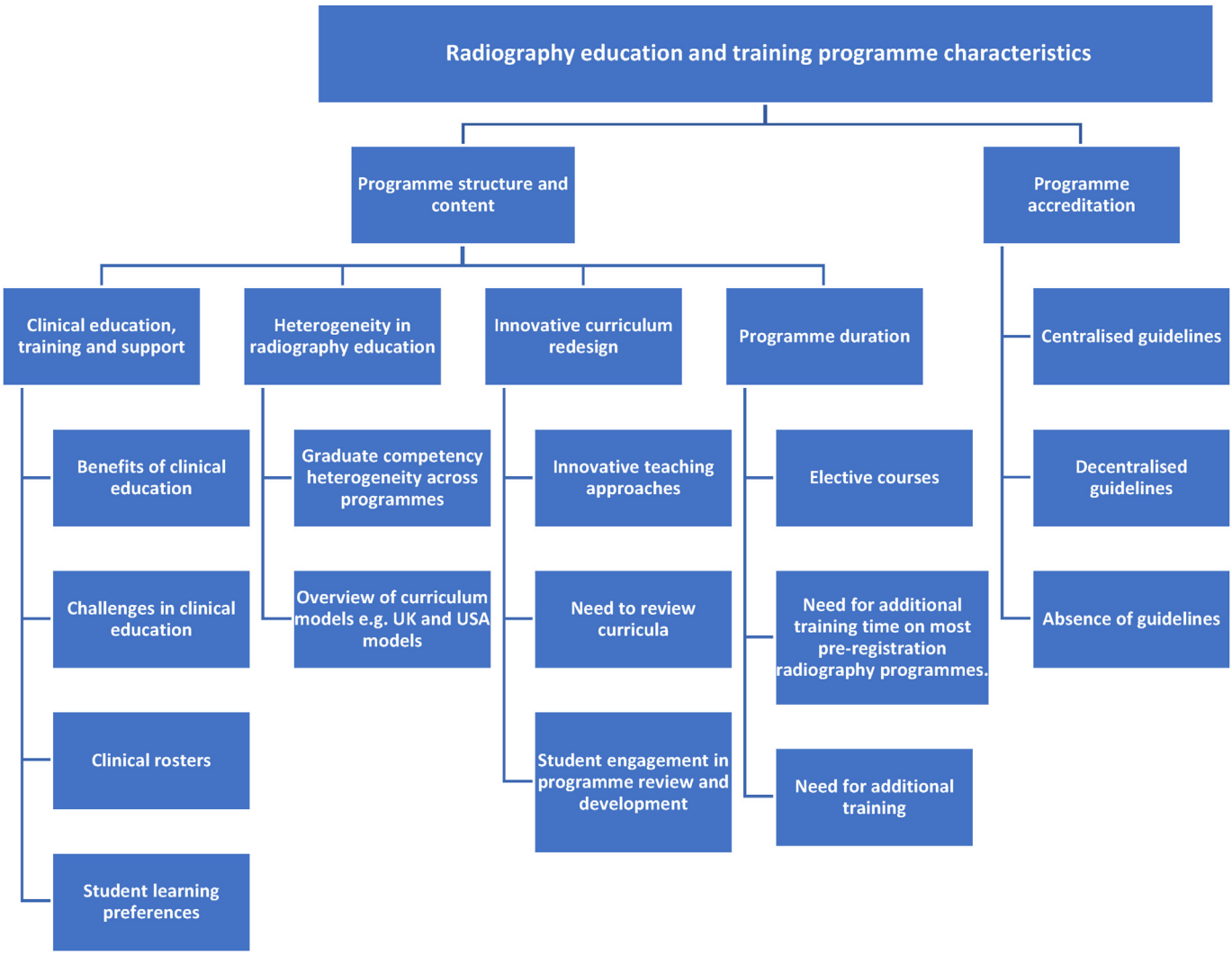

Figure 5. Radiography education and training programme characteristics.

i. Professional competencies and skills,[64] e.g., multi-credentialled or cross-trained in more than one diagnostic imaging technology and
ii. Relationship building and shared learning skills.[65]
iii. Cognitive capabilities,[66] e.g., research competencies, critical thinking, and preliminary evaluation of radiological images.

Primarily, a recurrent theme resonates across most studies, intimating that prospective graduates equipped with specific proficiencies tend to garner increased employability prospects. This discernment underscores three key dimensions:

Firstly, the imminence of professional competencies and skills substantiates the distinct desirability of graduates proficient in various diagnostic imaging technologies. The favour towards multiskilled radiographers is articulated by managers who anticipate qualities ranging from communication skills and quality assessment[64] participation to cost consciousness[67] and ethical cognisance.[59] These multifaceted attributes, envisaged against a backdrop of a customer-centric[68–70] healthcare milieu, are acknowledged as pivotal in ensuring the sustained competitiveness of radiographers in the employment arena.

Secondly, this review suggests that graduates with interpersonal acumen, denoted by relationship-building and shared learning skills, emerge as a pivotal graduate attribute potential employers seek. This skill is underscored by the recognition that radiography students in structured interprofessional education programs can cultivate the essential competencies for effective collaborative clinical practice.[65]

Lastly, cognitive capacities,[71] including research proficiencies,[72] critical thinking, and adeptness in radiological image appreciation and evaluation,[73] formed an integral facet of the desired graduate profile.[74] This cognitive dimension is epitomised by the capacity to envision beyond departmental confines and recognise the broader organisational implications of actions or inactions.[75] The corollary impact on patient care efficacy is emphasised, reinforcing the significance of graduates' capacity to transcend their immediate roles.[60,76]

Theme 2: Radiography Education and training programme characteristics

An interesting aspect of Radiography programmes lies in their nebulous and diverse structure and curriculum content[13,77,78]; jurisdictional regulations and legal requirements have subsequently led to varied graduate competencies. This complexity hinders graduates' mobility to different jurisdictions for practice and challenges employers in determining the expected skill set of

new employees. For example, studies focusing on the European radiography education landscape found significant differences in the structure and content of diagnostic and therapy programmes.[18,53,79,80] Furthermore, differences in radiography education models are noted between the United States of America[77,81] and mainland Europe,[18,61,73,79,82] the UK, Australia and Africa. While the USA focuses on single modality specialisation in training through associate degree programs,[81,83] the latter regions emphasise comprehensive bachelor's degree education[74,78] encompassing theoretical coursework, clinical practice, post-registration specialisation opportunities, and advanced practice roles in some cases,[84] underlining the variance in certification and registration processes. Radiography education in Africa and other relatively resource-limited settings are further diversified due to varying resources and infrastructure across nations.[10,28,85,86]

A second important finding pertained to the perception of various key stakeholders across different populations on the characteristics of radiography programmes. Most studies involving radiology service managers and recent graduates suggest that programmes offering multi-modality and multi-skilled capabilities over a single specialisation are preferred.[54] For example, in a Ghanaian study that evaluated graduate perspectives on diagnostic radiography programmes, participants suggested that

> "*Increased training hours in modern imaging modalities such as MRI, CT and U/S are also said to improve the training*[85]."

Similarly, another study found a need to develop a wider range of competencies in other modalities beyond conventional X-ray in Caribbean-English-speaking countries.[87] These views are further supported by several American studies that argue for the need for multi-modality[52,59,83] skilled radiographers, a deviation from America's traditional single-modality medical imaging training model.

Closely linked to programme structure and content was observed to influence the accreditation processes and perceived quality of graduate employability. Accreditation was closely linked to the achievement of expected graduates' competencies.[53,80] Additionally, a close correlation between the calibre of education and the proficiency of graduates, which were intricately linked to the duration and content[88] of their programme was reported. Although it was challenging to determine the precise number of programme hours required for optimal learning, it was unsurprising that the findings strongly indicated a noteworthy positive association between training hours and the educational standard.[78] This was particularly identified in a study that sought to determine how much time is spent in breast imaging and other specialist areas in undergraduate pre-registration curricula, both academically and in clinical placement.[88]

Interestingly, the findings in this review align implicitly and, in many cases, explicitly with the newly revised 2023 Health and Care Professions Council standards of proficiency for radiographers in the United Kingdom.[89] These updated standards demand registrants to perform diverse routine imaging techniques, encompassing contrast agent-involved procedures across relevant modalities and a comprehensive spectrum of computed tomographic (CT) scans. From standard head CT examinations to aiding in acute trauma-related CT scans of the spine, chest, and abdomen, registrants are expected to contribute substantially to various CT studies. Furthermore, proficiency in standard magnetic resonance imaging procedures, assisting ultrasound imaging, and engaging in imaging sessions utilising radionuclides, including PET tracers and particle emitters, are essential. Notably, this expertise entails the critical analysis of clinical images for diagnostic and technical excellence, with a proactive role in suggesting enhancements whenever necessary.

Like in many other countries, however, within the UK, most pre-registration radiography programmes remain stalwart against the ongoing changes in regulatory standards,[89] recent imaging workforce reform programmes,[90–93] digital skills landscape[25] and the current College of Radiographers Education and Career framework.[33] While holding positive affirmation of the changes in regulatory standards, we argue that there is an urgent need for consensus in reconciling the underpinning standards of proficiency[89] and radiographer education and career framework[33,94] with existing pre-registration radiography curricula in the UK.

The findings suggest that most pre-registration radiography graduates need more preparation and are more likely out-of-step with current service needs upon graduation as most need multi-modality skills. While it could be argued that this might be due to the slow rate at which radiography curricula and programme accreditation processes are reviewed to adapt to an ever-increasing technological and service landscape, the reason for this needs empirical clarification.

Notably, programmes with well-developed clinical education frameworks provided robust student support mechanisms[95–97] to enhance the learning experience[98] and prepare graduates for real-world challenges.

Notwithstanding, caution is due as these findings cannot be extrapolated to all settings, given that variations to these inferences are noticed in European studies where post-graduate education is required to gain competency in CT, MRI and mammography.[74]

Finally, this multinational literature review agrees with earlier research findings[78] that showed variations in the USA,[99,100] Europe, Africa, and the United Kingdom's radiography educational landscape, suggesting heterogeny and context-specific workforce imaging needs. The consequences stemming from disparities in pre-registration radiography programmes within individual countries[28] and between nations[101] are far-reaching and significant. When education exhibits inconsistencies, the resulting outcomes can be highly detrimental to graduate and patient outcomes. The heterogeneity in curricula within medical imaging must be seen as a key driver in designing new, innovative, standardised curricula and pathways that can promote a more cohesive and uniform educational experience for radiography students, improving graduate outcomes.[102] More specifically, educators should consider including topics that help graduates develop soft skills such as relationship building and shared learning, professional competencies, and core modality-specific imaging competencies.

Limitations

Potential limitations stem from the focus on primary research published solely in English. As a result, this study may have overlooked grey literature and studies in other languages. Nevertheless, the review incorporates diverse reports from various educational and healthcare systems spanning different resource levels. This diversity suggests that the addressed themes could have broad applicability.

The included studies display notable methodological heterogeneity, and most lack an explicit statement of their underlying theoretical framework. This heterogeneity and absence could compromise the review's coherence, interpretability, and comparability. Nonetheless, utilising the Braun and Clarke 'Framework' approach, empowered by a robust qualitative data analysis technique and a critical appraisal of included studies of diverse methods which added riqour to our research design. It unearthed key themes across the entire literature corpus through a meticulously documented audit trail of the analytic process, insights, interpretations, and eventual conclusions. These are all firmly rooted

in the synthesised data, evidenced in the data diagrams and direct quotations.

Conclusions

This systematic review brings to light the crucial factors that underscore the effectiveness of Radiography education and its impact on graduate employability. Aiming for consistency, modernity, and adaptability, the study emphasises the necessity for standardisation of training across multi-modalities for the development of multi-skilled capabilities among pre-registration radiography graduates. Notwithstanding the role of context-specific workforce needs, this review suggests that integrating cutting-edge modalities like MRI, CT, RNI, and ultrasound is imperative within traditional projection radiographic imaging curricula is crucial. Similarly, skills for radiotherapists including some requirements for use of diagnostic modalities (i.e., CT and MRI) for treatment planning and others such as post-treatment care counselling are essential for future primary graduates. Such curricula re-alignments have the potential of fostering a generation of graduates equipped to meet evolving industry demands towards developing hybrid practitioners. Notably, this demand goes beyond technical skills to encompass diverse non-clinical competencies. Graduates' success in the healthcare industry hinges on adherence to evidence-based accreditation processes, which is paramount to ensure competency, consistency and adaptability in the face of technological advancements.

A pivotal finding is the correlation between program effectiveness and features like a robust clinical education framework, innovative curriculum design, ample training time, and alignment of learning outcomes with national regulations. These facets collectively shape graduates into competent professionals ready to excel.

The review concludes that continuous curricular evaluation and adaptation, alongside evolving accreditation processes, are vital in equipping graduates with the comprehensive skill set needed for success in the dynamic healthcare landscape. By embracing these insights, educational institutions can significantly enhance radiography education, bridging the gap between academia and industry demands.

Future research should boldly confront the existing conceptual limitations in published findings in shaping the road ahead. It should aim to explore and investigate the experiences of crucial stakeholders of pre-registration radiography programmes. Furthermore, an evaluation of pre-registration radiography education, training and graduate competencies across limited settings is recommended. These insights will illuminate the landscape of graduate fitness for purpose within pre-registration programmes offering training and education across all modalities and inform curriculum review and workforce planning.

Conflict of interest statement

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.radi.2024.01.001.

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