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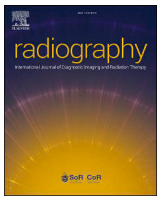

Advancing environmental sustainability concepts in medical radiation science education: A document analysis

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ABSTRACT

Introduction: Medical radiation science (MRS) practices contribute significantly to the carbon footprint of healthcare. As the need for environmental sustainability (ES) increases, it is crucial to integrate ES concepts into MRS education curricula to prepare students for environmentally sustainable professional practice. Consequently, this document analysis examined current ES practices in MRS education and identified barriers and improvement strategies.

Methods: A qualitative document analysis was conducted following the 'READ' (Readying, Extracting, Analysing, Distilling) approach. Data were retrieved from two databases (Scopus and PubMed) and MRS-specific journals and professional websites. Studies and documents published between 2015 to February 2025 that addressed ES practices, barriers, and improvement strategies in MRS education were included. Data were analysed using qualitative content analysis.

Results: A total of 2330 articles and documents were identified, 11 of which met the selection criteria. Three themes emerged: (i) current ES practices in MRS education, (ii) barriers to improving ES practices in MRS education, and (iii) strategies for enhancing ES training. ES practices in MRS education include patient safety education through risk-benefit analysis and fostering research and collaboration, while insufficient knowledge and awareness and limited capacity (funding, resources, and time) were barriers identified. Strategies for improvement included raising ES awareness and adopting environmentally sustainable teaching practices.

Conclusion: MRS education and training incorporate ES practices in line with the global call for sustainable health professions education. Nonetheless, awareness creation and adoption of ES-oriented pedagogies could enhance MRS students' confidence and attitudes towards planetary health.

Implication for practice: To advance ES practices in MRS curricula, educators should practically incorporate them into teaching, learning, and assessment activities. This could be achieved through problem-based learning, case studies, interdisciplinary learning, and including ES concepts in rubrics.

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Introduction

The call for sustainable practices among health professionals aligns with the United Nations Sustainable Development Goals (SDGs).[1] Within the healthcare landscape, medical radiation science (MRS) practices (including medical imaging, radiation therapy, and nuclear medicine) have been shown to contribute significantly to the carbon footprint due to the use of high energy-dependent imaging and therapeutic equipment, iodinated contrast media, and other consumables.[2] According to Chinene and colleagues,[3] environmental sustainability (ES) refers to a "*… recogni[tion] that nature and the environment are not an unlimited source of resources, but rather require protection and responsible use.*" (p.23) The absence of environmentally sustainable practices may lead to adverse climate conditions, a situation regarded as the most profound threat to global health in the 21st century.[4] As healthcare systems continue to rely on resource-intensive technologies, there is an urgent need to integrate ES into health and medical practices to mitigate their environmental impact. This highlights health professionals' essential role in promoting environmentally sustainable activities.[5]

The need for sustainable healthcare and the strategies for achieving this are well documented in the literature.[6–10] These strategies include the 'education for sustainable healthcare',[10] 'faculty-students partnership for sustainable health education,[6] and teaching and learning for sustainable healthcare.[7] They apply planetary health concepts to healthcare education, allowing learners to develop professional attitudes and skills to cope with complex problems in interprofessional collaborations.[10] Planetary healthcare education has become relevant due to potential consequences of poor ES practices,[11] which may result from non-adherent attitudes to, and/or lack of awareness of, sustainable healthcare needs among health professionals. Of note, education has been reported as a significant contributor to behavioural change and the major contributor of climate change awareness.[12] As a result, educational institutions are in a position to shape the cognitive and behavioural perspective of individuals to address current and potential future environmental challenges.[13] Moreover, education and training have been identified as attributes of a sustainable workforce,[14] while other studies have emphasised the need for ES training to be lifelong — starting from basic education and continuing thereafter.[5]

It has become necessary to include concepts of ES in the MRS education and training curricula[15] due to the gap in the knowledge of the workforce regarding strategies for achieving sustainable working environments.[5] For example, Soares et al.'s[5] study reported that most radiation therapy professionals have inadequate knowledge of sustainability concepts and are unaware of local and national ES policies. Similarly, Irlam and colleagues[16] found that most medical imaging students in South Africa had a limited understanding of ES while their colleagues in a Zimbabwean study[3] had little understanding of how their medical imaging practices could affect climate change. These findings further underscore the necessity of integrating ES in MRS education due to the reported significant contributions of MRS practices to environmental challenges.[9]

A MRS education that includes ES concepts may serve as a catalyst for developing a sustainability mindset among medical radiation professionals and students by integrating collaborative education and training.[9] This study explores the MRS education landscape through analysis of relevant guidelines/documents and peer-reviewed literature to assess whether elements of ES are integrated into the training of the future workforce. It aims to identify strategies for embedding ES concepts into MRS curricula and highlights areas for improvement. Additionally, the study seeks to identify barriers to integrating ES education and training in MRS curricula and to explore strategies to enhance its inclusion. With these in mind, the study aims to answer the following questions:

1. What are the current ES practices in MRS education?
2. What factors affect the successful integration of ES practices into MRS curricula?
3. What strategies can enhance the inclusion of ES training into MRS education?

Methods

Study design

The 'READ' approach which involves (1) readying the relevant materials, (2) extracting key data, (3) analysing the data, and (4) distilling the findings[17] was used to undertake this qualitative document analysis.[18] This approach was used to examine both peer-reviewed and grey literature regarding environmentally sustainable MRS practices and how these are incorporated into education and training activities. This approach was chosen as it follows Bowen's[18] requirement for document analysis to include the examination and interpretation of data to derive meaning, gain understanding, and develop empirical knowledge. Document analysis is regarded as an indispensable method for health policy research[17] and is therefore appropriate for examining the current ES practices in MRS education and training.

Inclusion and exclusion criteria

This study included peer-reviewed and grey literature, position statements, and policy guidelines on environmentally sustainable health professions education since they are deemed relevant for inclusion in health policy studies.[17] A study/document was included if it was written in the English language and reported ES practices in MRS education, challenges affecting the introduction of ES concepts in MRS education, and/or strategies for improvement. Additionally, eligible documents or studies were included if they were published between 2015 and February 2025. This period was chosen to ensure recency of the information on the topic under consideration. Thus, articles and/or documents were excluded if they did not focus on ES practices in MRS education. Additionally, eligible short commentaries[19–22] and editorials[23,24] were excluded to enhance the credibility and reliability of the findings.

Literature search

A literature search was conducted in January 2025 and revised in February 2025 using Scopus and PubMed. An additional search was conducted via medical radiation-specific journals (Radiography, Journal of Medical Imaging and Radiation Sciences, Journal of Medical Radiation Science, Journal of Radiotherapy in Practice, Acta Radiologica, Radiologic Technology, BMC Medical Imaging, and Journal of Nuclear Medicine) and professional websites (International Society of Radiographers and Radiologic Technologists, Society of Radiographers, Medical Radiation Practice Board of Australia, American Society of Radiologic Technologists, and Canadian Association of Medical Radiation Technologists) to identify profession-specific literature and information. These journals and professional websites were selected for their extensive contributions to the profession. Additionally, Google Scholar was used to identify relevant literature through snowballing.

The search strategy included the keywords "sustainability", "environmental sustainability", "environmental waste management", "radiography", "radiologic technology", "radiation therapy", "radiotherapy", "sonography", nuclear medicine" and "education" in combination with Boolean operators (AND/OR) and the truncation (*) character to increase sensitivity of the search across the included databases. The full search terms have been provided as a Supplementary File.

Data extraction, analysis, and synthesis

The identified documents were imported into the Rayyan systematic review platform[25] for initial title and abstract screening performed independently by JLA and GA, followed by full-text screening against the eligibility criteria. Discussion with the other members of the research team helped to refine the inclusion criteria. Relevant information on the included data was then extracted. The data extraction table included information on the author(s), originating country, study type and design, sample size, study aim(s), key notes, and outcome measure(s) based on the three research questions. A qualitative content analysis was performed through a thorough reading and re-reading of the full texts. This involved an initial deductive analysis to establish the basis for a final inductive analysis[26] of the included studies/documents. The extraction, analysis, and synthesis enabled the authors to achieve data saturation by 'distilling' the data through continuous identification and development of appropriate themes that address the study objectives until no further relevant themes could be identified from the analysis.

Results

A total of 2330 documents/articles were identified, 11 of which met the inclusion criteria (Fig. 1). The included documents/articles originated in the United Kingdom (n = 3),[10,27,28] Australia (n = 4),[29–31] Zimbabwe (n = 2),[3,32] across resource-limited settings (n = 1),[33] and global perspective (n = 2).[9,34] Five professional and regulatory documents were included.[10,27,28,30,31] The remaining six studies were peer-reviewed journal articles including four narrative review papers[9,29,33,34] and two quantitative cross-sectional studies.[3,32] Of note, none of the review articles included any of the quantitative cross-sectional studies. Details of the included studies/documents have been provided in Table 1.

Thematic findings

The content analysis identified three themes: (i) current ES practices in MRS education, (ii) barriers to improving ES practices

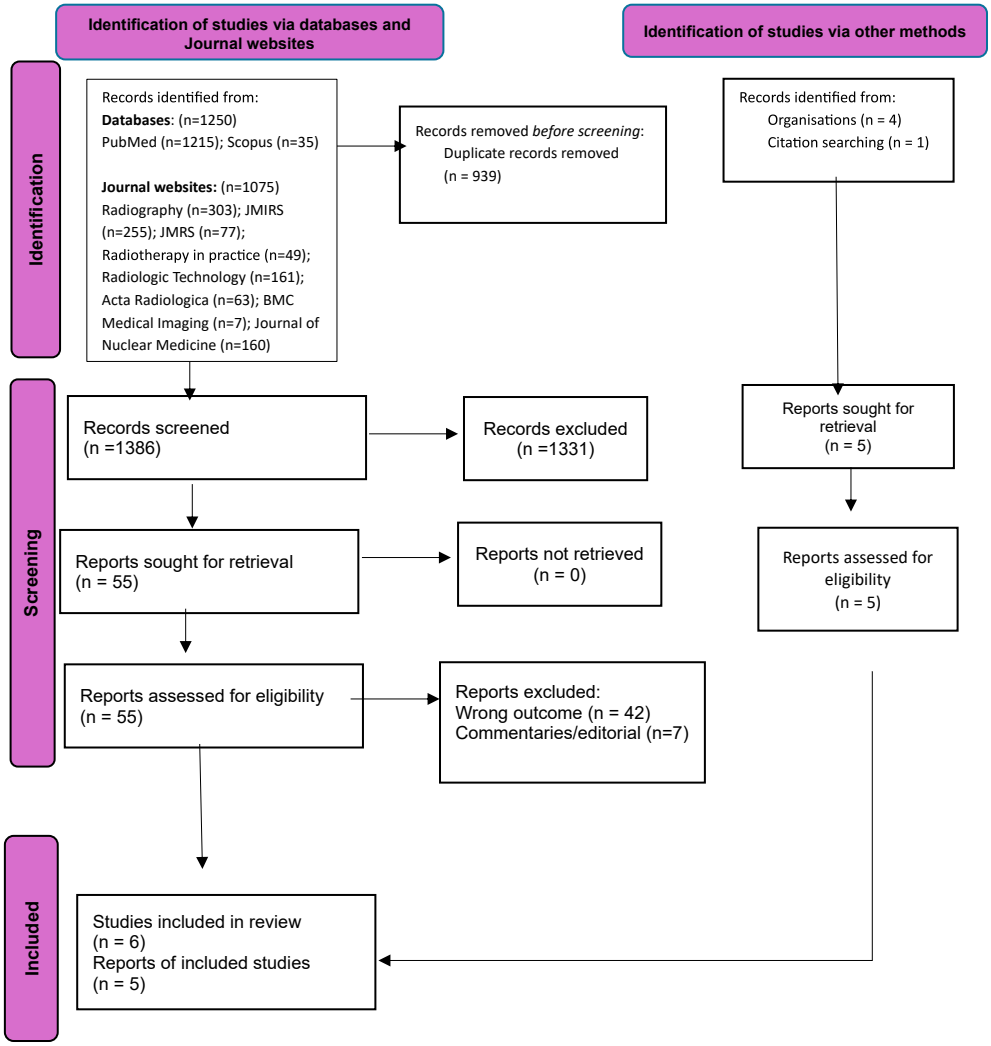

Figure 1. Flow diagram for the literature search.

Table 1
Summary of included documents/studies.

Author name, country	Study type and design	Sample size	Aim	Key notes	Outcome measure		
					Current practice	Barriers	Improvement strategies
Ohene-Botwe et al.,[33] low-resourced settings	Narrative review	Not indicated	Discussed factors contributing to carbon footprint and provided strategies to promote sustainability activities in radiography practice and education in low-resourced settings.	Awareness on environmental sustainability concepts in resource-limited settings can be improved through enhanced research activities, workshops, conferences, and seminars.	None	None	Raising awareness and adopting environmentally sustainable educational practices
Chau et al.,[34] global	Narrative review	Not indicated	Discussed how radiography education addresses three SDGs	Radiography education has contributed to the sustainable development goals through research and collaboration, and interdisciplinary teaching and learning. Opportunities for enhancement include the integration of sustainable-oriented modules into curricula.	Teaching, learning, and research and collaboration	None	Raising awareness through planetary health concepts
Chinene et al.,[3] Zimbabwe	Quantitative cross-sectional study	96 radiography students	Examined Zimbabwean radiography students' perception of sustainable radiography education	Radiography students indicated some level of sustainability practices in their curriculum, although they indicated a lack of confidence in answering sustainability-related exam questions. Awareness creation was suggested to help improve the current level of sustainable practices in radiography education.	Teaching, learning, and research and collaboration	Lack of knowledge and awareness	Raising awareness through planetary health concepts and adopting environmentally sustainable educational practices
Chinene et al.,[32] Zimbabwe	Quantitative cross-sectional study	92 radiography students	Examined Zimbabwean radiography students' perception of waste management	Radiography students acknowledge the importance of incorporating sustainability in the curricula. However, the lack of awareness and resources were noted as potential barriers.	Ethical and professional practices	Lack of knowledge and awareness, lack of capacity	Raising awareness
Currie et al.,[29] Australia	Narrative review	Not indicated	Examined challenges to sustainability practices in nuclear medicine	Sustainable practices are limited by resource scarcity, including workforce shortage. There is the need to develop strategies to improve the wellbeing and retention of the workforce.	Ethical and professional practices	Lack of capacity	Adopting environmentally sustainable practices
Council of Deans of health (CoDH),[10] United Kingdom	Guidelines	Not applicable	Explored strategies for integrating sustainable practices in health professions education curricula	Outlined various sustainable pedagogies such as case studies, problem-based learning, experiential learning, interdisciplinary learning, etc.	Teaching, learning, and research and collaboration, ethical and professional practices	None	Adopting environmentally sustainable practices
Health and care professions council (HCPC),[28] United Kingdom	Guidelines	Not applicable	Outlines safe and effective practice requirements for radiographers to protect members of the public.	Radiographers need to understand the various determinants of health and wellbeing (social, economic environmental factors)	Ethical and professional practices	None	Adopting environmentally sustainable practices
Health and care professions council (HCPC),[27] United Kingdom	Guidelines	Not applicable	Provided guidance on standards of health professions education and training	Learning outcomes should be geared towards sustainable performances including ethical, professional, fitness-for-purpose, etc	Teaching, learning, and research and collaboration, ethical and professional practices	None	None
Medical radiation practice board of Australia (MRPBA),[30] Australia	Guidelines	Not applicable	Outlines accreditation standards for medical radiation programs	The learning objectives of medical radiation programs are tailored to sustainable performances including ethical, legal, professional requirements, etc	Teaching, learning, and research and collaboration, ethical and professional practices	None	None
Medical radiation practice board of Australia (MRPBA),[31] Australia	Guidelines	Not applicable	Outlines professional capabilities for medical radiation practitioners	Students should be able to practise safely and competent to ensure the health and wellbeing of themselves and others.	Ethical and professional practices	None	None
Ramlaul and Khine,[9] global	Narrative review	Not indicated	Explored strategies to incorporate sustainability practices in radiography curricula	Outlined various strategies for integrating sustainable practices into radiography curricula. These include sustainable pedagogies (problem-based learning, case studies, interdisciplinary learning, etc).	None	None	Adopting environmentally sustainable educational practices

in MRS education, and (iii) strategies for enhancing ES training in MRS education.

Nine of the articles and documents analysed reported the implementation of ES practices in MRS education, including (i) teaching, learning, and research & collaboration activities,[3,10,27,30,34] and (ii) ethical and professional practices.[10,27–32] Meanwhile, three of the documents identified two primary barriers to ES in MRS education: (i) lack of knowledge and awareness regarding ES concepts[3,32] and (ii) lack of capacity in terms of resources and time constraint.[29,32] Two strategies for improving ES in MRS education identified from eight documents were: (i) raising awareness through planetary health concepts[3,32–34] and (ii) adopting environmentally sustainable educational practices.[3,9,10,28,29,33] The themes and subthemes are presented in Fig. 2.

Discussion

This study sought to evaluate the current ES practices in MRS education and identify areas for improvement. The results of this study demonstrate a strong integration and good application of environmentally sustainable practices in MRS education, evidenced in most of the included documents. Nonetheless, understanding of the concept and its applicability in MRS curricula is less appreciated by educators and students alike. The discussion will therefore throw light on the current ES practices in MRS education and the strategies that could help address the barriers surrounding their application.

Theme 1: current sustainable practices in medical radiation education

MRS education and training incorporate environmentally sustainable practices through (i) teaching, learning, and research & collaboration activities and by (ii) educating students in line with professional and regulatory requirements.[27,28,30,31] These ensure that graduates possess relevant professional skill sets that will enable them to practise sustainably. These two identified subthemes are discussed below.

Teaching, learning, and research & collaboration activities

Higher education institutions are in an advantageous position to advance ES practices through teaching, learning, and research and collaboration activities. Among the many teaching and learning strategies used in MRS education is problem-based learning,[35] which has been reported as a pedagogical strategy to enhance ES.[9,10] Problem-based learning enables educators and learners to address multidisciplinary inquiry-based challenges, including those of ES.[36] This may be achieved through scenario-based activities such as case studies. MRS students' clinical placements offer the opportunity to enhance problem-based learning and case studies, as students are exposed to real world imaging and therapeutic procedures. These pedagogical approaches are essential for developing MRS students' decision-making and problem-solving abilities by enhancing their communication, critical thinking, and collaboration skills, thus challenging them to be sustainable practitioners.[9] The integration of simulation-based learning in MRS education has also been reported as a good step towards ES.[37] Chau et al.[38] reported that simulation activities can have a role in effectively preparing students for clinical practice by improving their knowledge, skills, and attitudes in a risk-free environment. Another area where MRS education has improved environmentally sustainable practices is (collaborative) research.[34] Various MRS education programs incorporate research activities, beginning at the undergraduate level. Additionally, recent bibliometric analyses[39,40] revealed that medical radiation research traverses the academic landscape, although only a few clinical practitioners were involved in research. These research activities enhance evidence-based clinical practice,[41] including environmentally sustainable practices. Thus, medical radiation practitioners' limited engagement in research may result in them not following contemporary practices. This may negatively affect patient safety and outcomes. Indeed, Connor et al.[42] emphasised that lack of evidence-based practice may lead to continual reliance on outdated and unsustainable practices. Iweka et al.'s[39] bibliometric study further showed multi-country research collaboration. This presents a good opportunity for medical radiation practitioners to collaborate with colleagues in other geographic locations (both researchers and clinicians) on

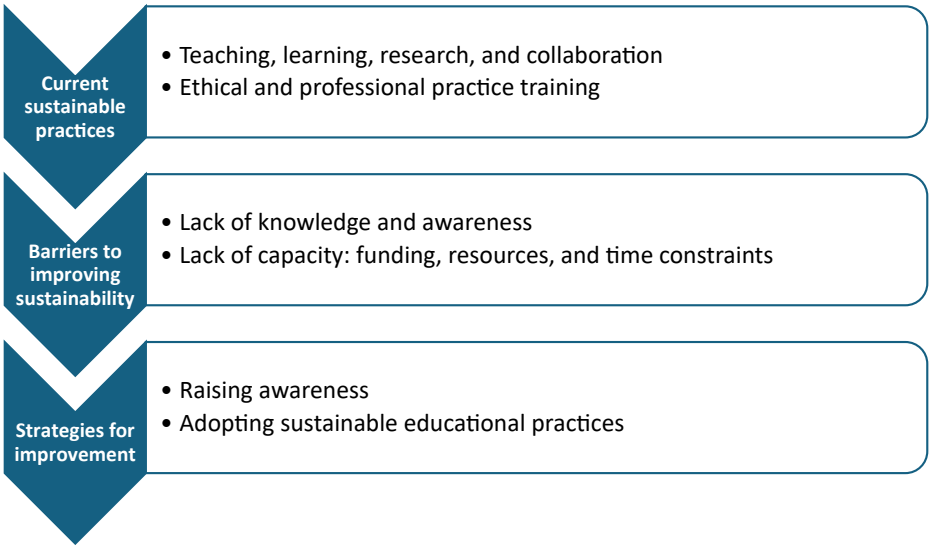

Figure 2. Identified themes and subthemes.

research projects and/or share ideas on relevant ES issues. As Chau et al.[34] emphasised, these multinational research collaborations improve the utilisation of resources and expertise, resulting in improved patient outcomes and potentially improving ES through the development of innovative MRS practice approaches.

Ethical and professional practice training

Learning objectives in MRS education are usually tied to professional and regulatory standards of practice requirements, including the need for professionals to practise sustainably. Thus, MRS educators adhering to these requirements ensure that students are fit for sustainable practices upon graduation.[27,30] For example, the Health and Care Professions Council's (HCPC) Standards of Education and Training[27] emphasise that a sustainably fit-for-purpose program is one "*… that meets the needs of learners who will be entering [the] profession, [including] making sure that learners are suitably prepared for [environmentally sustainable] practice …*" (p.16). Through problem-based learning, case studies, simulation (including role-play), and other teaching and learning pedagogies, students are taught to develop critical thinking skills that will enable them to practise responsibly, bearing in mind their ethical and professional requirements.[9] A key professional requirement that addresses ES in MRS practice is risk-benefit assessment,[28,31,43] encompassing justification, optimisation, and patient safety. These requirements are emphasised in MRS education, with programs including courses/units such as radiation physics and protection and patient management in the curricula. MRS students are therefore taught to effectively assess the patient's condition in line with the requested radiological or therapeutic procedure to select the most appropriate protocol. These courses/units therefore empower students to practise sustainably upon graduation by reducing low-value imaging and therapeutic procedures.[44] Evidence suggests that a reduction in low-value imaging does not only improve patient outcomes but also improves economic[45] and environmental (carbon footprint) sustainability.[46,47]

Theme 2: barriers to improving sustainable practices in medical radiation science education

There is potential for improving the ES concepts taught in MRS education. However, lack of knowledge and awareness of ES practices by academic staff and students and lack of capacity (in terms of funding, resources, and time constraints) hinders the ES agenda in health professions (including MRS) education.[6,15,29,48,49] These two impeding factors are herein discussed.

Lack of knowledge and awareness

The calls for including ES practices in MRS curricula may be constrained by educators' lack of confidence to teach environmentally sustainable healthcare to students.[6] Similarly, MRS students may not be confident in answering ES-related examination questions,[3] potentially resulting from a lack of knowledge, awareness, and practical guidance on environmentally sustainable educational activities.[6,32] This lack of knowledge and awareness is not peculiar to students and educators as previous review[33] and studies[15,50–52] identified high levels of these shortfalls in the clinical workforce, underscoring the need to educate both students and professionals on ES practices.[53]

Lack of capacity: funding, resources, and time constraints

MRS programs in low-resource settings may be unable to benefit from these sustainable learning activities due to inadequate funding that may limit the availability of waste management resources.[15,32] The lack of capacity may also affect the ability of educators to incorporate problem-based learning into the curricula[54] due to factors such as high student-staff ratio and educators' lack of expertise in problem-based learning processes.[55] To enhance ES practices in MRS education, there is a need to identify and apply appropriate strategies that may address these barriers. Some of these strategies are discussed below.

Theme 3: strategies for enhancing sustainability training in medical radiation education

ES practices in MRS education may be improved through strategies such as awareness creation and the adoption of ES educational practices.

Raising awareness through planetary healthcare concepts

To combat issues of lack of knowledge, awareness, and confidence, leadership of educational programs need to engineer practical activities that will strengthen the connection between clinical practice and ES.[10] This can be achieved by adopting evidence-based guidance, such as by Webster and Marshall,[56] on how to raise ES-related topics of discussion. Ramlaul and Khine[9] suggest that this could be achieved by incorporating ES topics into existing pedagogies, a strategy re-echoed in a recent European Federation of Radiographer Societies (EFRS) position statement on sustainability for the radiography profession.[24] The authors[24] called on educators to include ES and planetary health-related concepts in training programs. Importantly, evidence shows a fundamental requirement for health professions students to appreciate core ES concepts and how these apply to them in practice.[8] This will enable students and, by extension, the workforce to understand how their clinical activities may affect global health and wellbeing. Considering this, incorporating ES as a core learning module in MRS education curricula[57] will essentially provide a "lens" for educators and learners to acknowledge their significant roles in ES.[58]

Furthermore, there is a need to increase research activities[6,33] in MR education programs. Although evidence suggests good research activities in MRS, there is a dearth of research focusing on ES within the profession.[2,59] As a result, Ohene-Botwe et al.[33] called for increased ES-related research to address issues of planetary health. A continuous inclusion of research within MRS education coupled with an initiation of ES interest groups for students[6] may help improve their knowledge and interest in eco-related research. A recent study[32] reported lack of awareness of ES student groups among MRS students. MRS educators are therefore encouraged to begin discussion on how to initiate these planetary health advocacy groups. Moreover, the adoption of planetary health policies in MRS education may be hard to achieve in resource-constrained settings due to the limited policies on ES agenda in such countries.[60] The authors stressed the need for explicit policies and guidelines in MRS education and practice.

Adopting sustainable educational practices

To enhance students' understanding of planetary health concepts, it is essential to include ES into the curriculum.[3,15,32,34,57] Schwerdtle et al.[57] assert that this should be done in a spiral approach, by building upon foundational knowledge and increasing the complexity as students progress through the program. Specific strategies to achieve this include incorporating ES concepts into lectures, clinical placement portfolios, and rubrics.[32,61] The integration of ES into rubrics will help address issues of lack of confidence in answering ES-related exam questions.[3] Essential teaching and learning strategies that can improve ES awareness among MRS students include case studies, interdisciplinary studies, debates, student-centred learning, and experiential learning.[10,34] The strategies and significance of these

Table 2
Teaching and learning strategies to enhance environmental sustainability.

Teaching & learning approach	Application	Significance
Problem-based learning	Guide students to critically analyse sustainability related problems in groups.	Problem-based learning stands out as a superior educational strategy over conventional methods, offering develops students' essential problem-solving and decision-making abilities such as critical thinking, communication, and collaboration skills.[9]
Case studies	Presenting students with in-depth sustainability-oriented scenarios, such as dose and image quality optimisation strategies, for discussion and research. These scenarios/ cases could be obtained from clinical placement.	Provides research experiences for students, allowing them to explore the relationships between people and their environments[63] and to assess potential risks within real-life patient care scenarios.[9]
Interdisciplinary studies	Educating students in partnership with their colleagues from computer science, engineering, and other health profession disciplines.	Fosters deeper understanding of how medical radiation technologies, health, and sustainability interact with one another; also enhances multidisciplinary teamwork skills in medical radiation students.[63,64] the approach will also enable students to understand sustainability from different perspectives.[65]
Debates	Encouraging students to engage in fruitful discussions/ debates on sustainability issues such as the role of medical radiation practitioners in justification of radiological and therapeutic procedures.	Enables students to appreciate and understand their role as professionals in patient safety and environmental health issues.
Student-centred learning: Practical and skill-based learning	Encouraging students to engage in self-directed research projects on sustainability and reflective exercises.[10]	Enables students to appreciate how their actions could affect environmental health, including the patients they care for.
Experiential learning	Promoting good practice on waste management among learners,[10] through such activities as effective use of iodinated contrast media, proper disposal of used consumables.	Enables students to cultivate the habit of effective waste management resource utilisation.

pedagogical approaches have been summarised in Table 2. Furthermore, the use of problem-based learning[9,10] may enhance ES practices among MRS students. Despite recent advances and implementation of problem-based learning in other healthcare disciplines,[62] it has received little attention in MRS curricula.[35] As a relevant ES awareness strategy, MRS educators need to adopt and incorporate it in teaching and learning activities. The strategies for implementing problem-based learning have been outlined in a previous narrative review.[54]

Limitations and strengths

This review was limited by the inclusion of only English language articles/documents and the exclusion of studies situated in specific health professions disciplines other than MRS. Additionally, it is acknowledged that document analysis may not uncover all relevant aspects of the concept and how it could be advanced in MRS education. This and the fact that only two primary studies[3,32] were identified and included in this analysis underscore the need for additional empirical studies to provide a thorough insight into how ES practices can be enhanced in MRS education. Further, although this study followed a systematic document analysis approach, a formal quality appraisal of the included documents was not undertaken. As such, documents were treated with equal analytical weight regardless of document type or methodological rigour. As noted by Dalglish et al.,[17] the lack of quality appraisal in document analysis raises concerns over its trustworthiness. Nonetheless, the inclusion of both policy documents and peer-reviewed articles ensures triangulation within documents and enhances qualitative rigour as suggested by the authors.[17]

Conclusion

MRS education and training incorporate ES practices in line with the global call for sustainable health professions education. This document analysis revealed that academic programs follow professional standards of practice requirements including, among many things, patient safety through risk-benefit analysis. Opportunities for research and collaboration further add to the current ES practices in MRS education and training. Nonetheless, these practices could be enhanced by adopting ES-oriented pedagogies. However, the lack of confidence among educators and students due to inadequate knowledge and awareness, and the lack of capacity (in terms of funding, resources, and time constraints) were key limiting factors identified. These could be addressed through the provision of practical guidance to educators on how to incorporate ES into teaching, learning, and assessment activities such as problem-based learning, case studies, interdisciplinary learning, and rubrics. Further studies are required to explore how other sustainability concepts such as sustainable performance (including wellbeing and resilience training) could be integrated in MRS curricula to help address issues of workforce shortages and staff burnout.

Ethics approval and consent to participate

Ethics approval was not required for this type of study.

Availability of data

All data included have been cited in the study. No additional data was included.

Author contributions

JLA: Conceptualisation, Methodology, Investigation, Formal Analysis, Writing – Original Draft; **AK:** Conceptualisation, Supervision, Writing – Reviewing and Editing; **MC:** Conceptualisation, Writing – Reviewing and Editing; BOB: Conceptualisation, Writing – Reviewing and Editing; **BOM:** Conceptualisation, Writing – Reviewing and Editing; **CLS:** Conceptualisation, Supervision, Writing – Reviewing and Editing; **GA:** Conceptualisation, Investigation; **TNA:** Conceptualisation, Writing – Reviewing and Editing.

Declaration of Generative AI and AI-assisted technologies in the writing process

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Conflict of interest statement

The authors declare no competing interests.

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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.2025.103090.

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