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Virtual education strategies in the context of sustainable health care and medical education: A topic modelling analysis of four decades of research

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Abstract

Background: The growing importance of sustainability has led to the current literature being saturated with studies on the necessity of, and suggested topics for, education for sustainable health care (ESH). Even so, ESH implementation has been hindered by educator unpreparedness and resource scarcity. A potential resolution lies in virtual education. However, research on the strategies needed for successfully implementing virtual education in the context of sustainable health care and medical education is sparse; this study aims to fill the gap.

Methods: Topic modelling, a computational text-mining method for analysing recurring patterns of co-occurring word clusters to reveal key topics prevalent across the texts, was used to examine how sustainability was addressed in research in medicine, medical education, and virtual education. A total of 17 631 studies, retrieved from Web of Science, Scopus and PubMed, were analysed.

Results: Sustainability-related topics within health care, medical education and virtual education provided systematic implications for Sustainable Virtual Medical Education (SVME)–ESH via virtual platforms in a sustainable way. Analyses of keywords, phrases, topics and their associated networks indicate that SVME should address the three pillars of environmental, social and economic sustainability and medical practices to uphold them; employ different technologies and methods including simulations, virtual reality (VR), artificial intelligence (AI), cloud computing, distance learning; and implement strategies for collaborative development, persuasive diffusion and quality assurance.

Conclusions: This research suggests that sustainable strategies in virtual education for ESH require a systems approach, encompassing components such as learning content and objectives, evaluation, targeted learners, media, methods and strategies. The advancement of SVME necessitates that medical educators and researchers play a central and bridging role, guiding both the fields of sustainable health care and medical education in the development and implementation of SVME. In this way, they can prepare future physicians to address sustainability issues that impact patient care.

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1 | INTRODUCTION

In the last five decades, sustainability has been widely recognised as an essential tenet guiding innovation. The seminal 1972 report, *The Limits to Growth*,¹ simulated the interactions between economic and population growth on the one hand and resource depletion and environmental degradation on the other hand. Without immediate and decisive action, the authors argued, the existing trajectory would lead to global collapse in the near future. In the 30 years that followed, interest in sustainability grew, but it was not until the 2000s that the discourse moved beyond environmental concerns to social and economic issues.²⁻⁴ Now, three accepted dimensions of sustainable development are as follows: *environmental sustainability* (focusing on preserving natural resources, reducing environmental harm and maintaining biodiversity), *social sustainability* (focusing on equitable access to basic needs, protection of human rights, social equality and responsible community engagement) and *economic sustainability* (focusing on responsible use of economic resources and creating a stable and sustainable economy for present and future generations).³

A growing body of medical research has demonstrated the need for a paradigm shift towards medical practices and systems that promote environmental, social and economic sustainability.⁵⁻⁷ In recognising the interdependence between human health and the health of the planet, a holistic planetary health approach can provide guidance at patient, service and system levels by identifying, for example, such priorities as empowering patients and addressing social determinants of health.^{8,9} Despite ongoing challenges posed by societal and cultural attitudes, political obstacles and economic limitations, increasing attention and investment are being directed towards advocacy, research and education for more sustainable medical practices.

As an inevitable response to the movement towards sustainable medicine, organisations have called for education for sustainable health care (ESH).^{10,11} The Association for Medical Education in Europe (AMEE) and the General Medical Council (GMC) have taken the position that medical school graduates should be equipped to promote sustainability in health care delivery, thus reducing negative environmental impacts, and promoting social and economic sustainability.¹¹⁻¹⁶ The UK Medical School Council has identified specific ESH topics that should be covered, including planetary health, the health impacts of the climate crisis, the impacts of health care on the environment and professionalism and leadership for structural change.¹⁷

Although the current literature is saturated with studies advocating the incorporation of ESH in medical education (ME) and also with studies on learning objectives and topics for ESH,^{12-14,16,18} few universities have actually integrated ESH content into their curricula. A recent survey by the International Federation of Medical Students' Associations found that 31% of medical schools across 112 countries have no ESH content in their curriculum, and only 14% have dedicated any time to the topic.¹⁹ In another

international survey, only 11% of nearly 3000 medical schools were found to provide ESH content in their curriculum.²⁰ Similar findings have been found at Monash University in Australia, where 81% of instructors surveyed indicated that they do not include ESH in their offerings, and 68% said they are uncertain how to teach it.²¹ A number of studies point out the lack of faculty expertise and resources as factors impeding the development and implementation of high-quality ESH curricula.^{7,22}

Given the unpreparedness of medical educators to teach sustainability and the scarcity of physical resources for ESH curriculum development, virtual education (VE) can serve a feasible solution, both for acquainting curricular stakeholders with ESH and for ultimately incorporating ESH into medical curricula. VE harnesses the potential of various technological advancements to overcome the constraints of expense, time, space and logistics traditionally inherent in education. Thus, VE can potentially facilitate the dissemination of ESH to a broader group of learners and also foster interinstitutional collaboration among medical educational institutions.²³

To optimise VE's efficacy for ESH within the context of health care and ME, an integrated strategy is crucial. This would mirror trends in public and professional discourses on sustainability. Both the seminal book 'The Limits to Growth' (1972, updated in 2004)¹ and the UN's shift from Millennium Development Goals (MDGs) in 2000 to Sustainable Development Goals (SDGs) in 2015 underscore the importance of a holistic approach for effective policy-making towards sustainable development. Similarly, an effective approach to the development and implementation of ESH using VE requires a holistic approach that takes into account potential contradictions, inherent tensions and trade-offs³ arising from the different values and interests in health care and ME. This necessitates more comprehensive strategies that reflect multifaceted systematic considerations, including educational objectives and content, targeted learners, media and technology, as well as integration strategies.¹⁴ To date, research into such comprehensive strategies has been sparse,^{12,20} with some studies attributing the failure of widespread ESH curricular implementation on virtual platforms to vague concepts and constructs.³ To bridge this gap, the authors constructed the following research questions (RQ):

- RQ1. What are the prevalent topics represented in Sustainable Health Care (SH) research;
- RQ2. What are the prevalent topics represented in Sustainable Medical Education (SME) research;
- RQ3. What are the prevalent topics represented in Sustainable Virtual Education (SVE) research; and
- RQ4. What overarching dimensions and strategies for Sustainable Virtual Medical Education (SVME) can be derived from the analysis of SH, SME and SVE research.

Answering these questions was intended to yield nuanced, systematic SVME strategies intersecting health care, ME and VE. For a

clear starting point, we define SH as medical practices and systems that promote environmental, social and economic sustainability; SME as ESH with sustainable means; SVE as education that utilises digital technology in a way that is environmentally, socially and economically sustainable; and SVME as the sustainable use of VE for ESH.

2 | METHODS

We conducted topic modelling, a computational text mining methodology to uncover hidden topics within a collection of texts. Topic modelling is guided by the assumptions that text documents are organised into *bags of words* and that words can be clustered in a meaningful way by the patterns they co-occur across documents. Using a computer algorithm, topic modelling captures the substantially meaningful *aboutness* of documents, providing a bird's eye view of research in a field.^{24,25} Topic modelling is thus known as an optimal method for discovering thematic trends in a large volume of textual data and predicting future directions.²⁶

In general, more traditional approaches to revealing major topics and trends within a field involve manual reviews of published literature, such as a systematic review, scoping review or narrative review. These techniques require considerable effort when iteratively reviewing a large volume of full articles since they involve highlighting, coding and grouping data into salient themes and manually extracting and updating topics. The scoping review method and topic modelling share the same objective: exploring the scope of a body of literature on a given topic and giving its clear indications.²⁷

The reason why we chose topic modelling over a manual review methodology is threefold. First, we wished to examine how sustainability was addressed in publications on SH, SME and SVE that spanned an extended period of time. Manual review of such a large volume of studies would have been extremely labour-intensive and time-consuming, making an automated approach vastly preferable. Second, we felt that topic modelling would provide a relatively unbiased overview of a broad research landscape²⁶ because it would not rely primarily on the researcher's own predefined concepts and categories.²⁸ In fact, though manual reviews seek to overcome systematic error in searching, selecting and synthesising studies, numerous sources of bias are possible, such as favouring older articles or impact measures, omitting recently published articles or skewing selection through various predispositions towards particular themes.²⁶ Lastly, we believed that automating certain aspects of process of topic modelling would allow us to make implicit conceptual notions of discourse visible and zoom in on detailed specifics across texts, which extends human readers' analytic capacities.^{24,28} The methodological steps of topic modelling included the following: (1) data collection, (2) pre-processing, (3) keyword and phrase frequency analysis, (4) topic modelling and (5) link analysis.

2.1 | Data collection

In order to retrieve peer-reviewed journal articles containing the topics of (1) SH or medicine (SH), (2) SME and (3) SVE, we searched three databases: Web of Science (1996~), Scopus (1987~) and PubMed (1982~). We developed search strategies incorporating Medical Subject Headings (MeSH) and Major Topic of PubMed indexing systems. We chose studies containing 'sustainable' or 'sustainability' in the title, abstract and keywords at the same time, in order to ensure the sole inclusion of papers with a fundamental focus on sustainability. All studies were written in English and published up to 10 January 2023, without any restricted start date. Analysing this extensive set of studies was made possible only due to the capabilities of topic modelling. We restricted our analysis to journal articles and conference proceedings, as they are typically conducive to in-depth discussion of a subject. Conversely, other types of literature, such as editorials, letters, commentaries and erratum, were excluded due to their propensity for superficial mention of a topic. The search queries and the glossary of methodological terms are provided in the supporting information Appendices 1 and 2.

2.2 | Pre-processing

We pre-processed raw textual data and created a Term-by-Document Matrix (TDM) using the text mining software QDA Miner 6 with WordStat 9 (Montreal, QC, 2022). Pre-processing involved removing punctuation, numbers and whitespaces as well as stop-words including articles (e.g. *a*, *an* and *the*), prepositions (e.g. *with*, *to* and *on*), conjunctions (e.g. *and*, *or* and *but*) and pronouns (e.g. *she*, *he* and *they*). We also carried out lemmatization, a procedure that converts a word's inflected forms into a single base form (e.g. *run* for *runs*, *ran* and *running*). We excluded terms commonly used in research literature (e.g. *introduction*, *method*, *results* and *findings*), because they have the potential to obscure central themes.

2.3 | Keyword and phrase frequency analysis

We examined the frequencies of keywords and phrases in each area. We looked at the TF-IDF (Term Frequency weighted by Inverse Document Frequency) index, which is based on two assumptions: (1) the frequency of a term in a document determines how well it characterises its content and (2) the number of documents in which a term appears indicates how discriminating the term is. In other words, as the frequency of occurrence of a term *within* a document increases, it becomes more representative of the document's content. Conversely, as the frequency of occurrence of a term *across* multiple and diverse document collections increases, its ability to differentiate between the content of those documents decreases. Consequently, as the frequency of a word within a document increases and the

number of documents containing it decreases, the TF-IDF value of the word is heightened.

2.4 | Topic modelling

A topic represents a cluster of words that frequently appear together and are centred on a set of key terms, similar to the way individuals create written works related to specific themes or concepts.²⁹ The analysis of recurring patterns of co-occurring words reveals clusters of words that are prevalent across the texts and subsequently converts these clusters into discrete topics.^{29,30}

We employed the Non-Negative Matrix Factorization (NMF) method to decompose the original matrix V (consisting of n texts and m words) into two factors: W , composed of n texts and k topics, and H , consisting of k topics and m words. This process resulted in the creation of final topic lists, represented by the matrices W and H , with the frequency of documents classified as utilising each topic. NMF is more efficient in creating understandable and cohesive topics than other methods, such as Latent Dirichlet Allocation (LDA).^{31–34}

Using relevant guiding studies^{26,35} and preliminary examinations, we determined that the optimal number of topics for highly interpretable and diverse topics was 40, among which top 12 topics for each area were reported based on Normalised Pointwise Mutual Information (NPMI), which relies on the frequency of word co-occurrences and correlates with topic interpretability.³⁶ The interpretation of identified topics in topic modelling usually relies on the context in which the word or words are embedded, the research questions, current literature and researchers' expertise in the area.^{28,37,38} In instances where the precise meaning and context of some terms were ambiguous to interpret or the interpretations of independent researchers did not coincide, we jointly consulted the original text using the *word-in-context* function of

the software (Appendix 3) and also used a framework consisting of the following: (1) three interacting fields (SH, SME and SVE), (2) three pillars of sustainability (environmental, social and economic) and (3) the system components of VE (learning content and objectives, evaluation, targeted learners, media, methods and strategies).

2.5 | Link analysis

We performed link analyses by centering the most significant terms to discover contextual connections between extracted keywords and phrases and associated network diagrams showing the textual elements (nodes) and their association strength (links with numerical values) based on co-occurrence. We used force-based multidimensional scaling (MDS) with a tolerance of 0.000001 and a maximum iteration of 500. The co-occurrence measure between a pair of nodes served as an indicator of semantic proximity.³⁹ The more two items co-occurred in source documents, the higher their level of semantic proximity. The weight value ranged from 0 to 1, where 0 indicates no possibility that the two items could occur together in a source document.

3 | RESULTS

3.1 | Research overview

We retrieved and analysed a total of 17 631 articles containing the terms *sustainability* or *sustainable development* in the fields of medicine, ME and VE after removing duplicates from the initial search result of 19 321 articles. Table 1 shows the quantity of articles by field, the frequency of *sustainability* and *sustainable* and the ratio of term occurrence per 10 000 words (the intensity of the discussion).

TABLE 1 Total quantity of articles, occurrence of selected words and rate of selected words per 10 000 words.

	Quantity of Articles	Occurrence of words <i>sustainability</i> and <i>sustainable</i>	Rate of occurrence of words <i>sustainability</i> and <i>sustainable</i> per 10,000 Words*
Medicine	15,082 (85.5%)	25,475	69,985
Medical Education	626 (3.6%)	1,546	89,446
Virtual Education	1,923 (10.9%)	7,874	161,081

*The rate of occurrence of words *sustainability* and *sustainable* per 10 000 words refers to the density of the discussion.

The medicine field had the highest number of articles, followed by the VE field, with the lowest number of articles in the ME field. VE articles had the greatest intensity of the use of sustainability-related terms, while ME articles containing the terms had relatively less emphasis on sustainability issues.

The earliest journal article across the three fields was published in 1982 by Loraine (1982). A consistent rise in the number of sustainability-related articles has continued through 2022 (Figure 1). A marked growth in the number of such articles has occurred since 2015. Notably, half of the total number of articles published in the last 41 years were published in the last 8 years ($n = 8508$, 50%).

3.2 | RQ1. Prevalent sustainability topics explored in health care research

Our first research question concerned the prevalence of topics related to SH research. The most frequently occurring keywords, phrases, topics and their interconnections in the field of SH are as shown in Tables 2 and Figure 2. The results highlight the central theme of sustainability at environmental, social and economic dimensions and the medical practices to achieve them, particularly in relation to health care service and systems, patient empowerment, preventive measures and workforce training. In terms of environmental sustainability (32.7%), *climate change* was most frequently mentioned, with a particular emphasis on *waste* and *waste management*.^{40,41} This leads to a practical movement towards low carbon alternatives and operational resource use (minimising waste, energy and travel). Phrases related to the social sustainability reveal frequent references to equitable access to health care services and the social determinants of health, with a particular emphasis on vulnerable patient groups such as *children*, *women*, *pregnant women* and *infants* (11.5%), along with populations in *low-income countries* (11.5%). These phrases also point to social responsibility issues among medical professionals, institutions and health systems (23.1%).^{8,10} In terms of economic sustainability (5.8%), phrases such

as *cost effectiveness* and *long-term* suggest a focus on the efficiency and effectiveness of health care in ways of prevention (3.8%) and patient empowerment (11.5%), which ultimately aim to reduce health care costs. Reducing medical activity and educating and encouraging patients, particularly those with chronic diseases (reflected in phrases such as *blood pressure*, *weight loss* and *physical activity*) and streamlining clinical pathways are examples of SH practices that are both economically and socially sustainable.⁴² The topics of training of medical workforce (3.8%) also were present, which leads to sustainability topics in the field of ME.

3.3 | RQ2. Prevalent sustainability topics explored in ME research

Tables 3 and Figure 3 display the most frequently occurring keywords, phrases, topics and their interlinkages in SME articles. The three pillars of sustainability and upholding medical practices were recurrent topics in SME but with different emphases. The first cluster of topics encompasses concepts related to environmental (9.6%), social (7.7%) and economic (5.8%) sustainability. The second cluster includes topics in the medical field, including health care services and systems (19.2%), patient empowerment (7.7%) and prevention (1.9%). Words related to public health appeared more frequently (7.7%) than in SH. The third cluster shows words related to education (30.8%), including such common terms as *curriculum*, *clinical training* and *medical workforce*. The topic of *evaluation* (11.5%) indicates both the assessment of learner acquisition of knowledge, skills and attitudes and the evaluation of programme effectiveness. Of the phrases notable as SME strategies, the following four emerged as most prominent: *standard*, *evaluating effectiveness*, *training with simulations* and *collaborative training for global health*. In the link analysis, a central cluster of *knowledge*, *clinical skills* and *reasoning skills* was noted along with a cluster of words related to social sustainability, including *value*, *responsibility* and *rural practice* at the bottom.

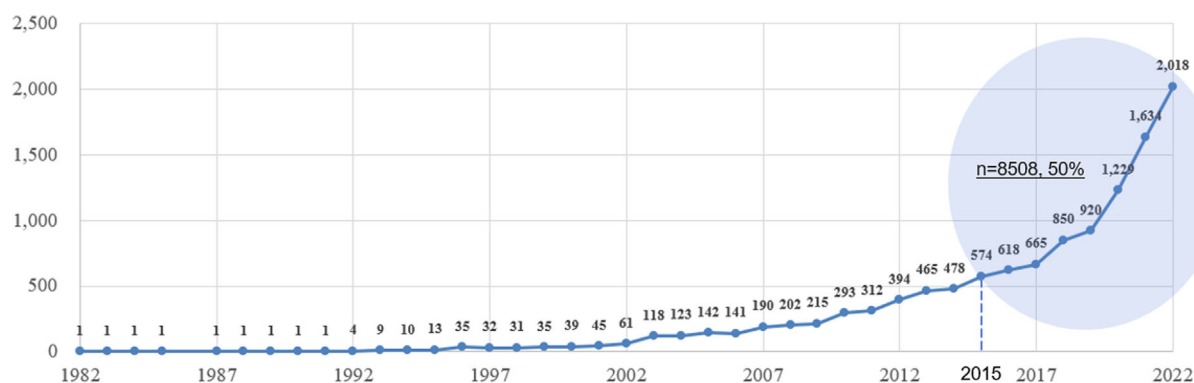


FIGURE 1 Growth of sustainability-related articles in medicine, medical education, and virtual education. (The earliest article was published in 1982. There has been a steady increase in the number of sustainability-related articles, with notable growth since 2015. Half of the articles ($n = 8508$, 50%) were published in the last 8 years.). [Color figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com)]

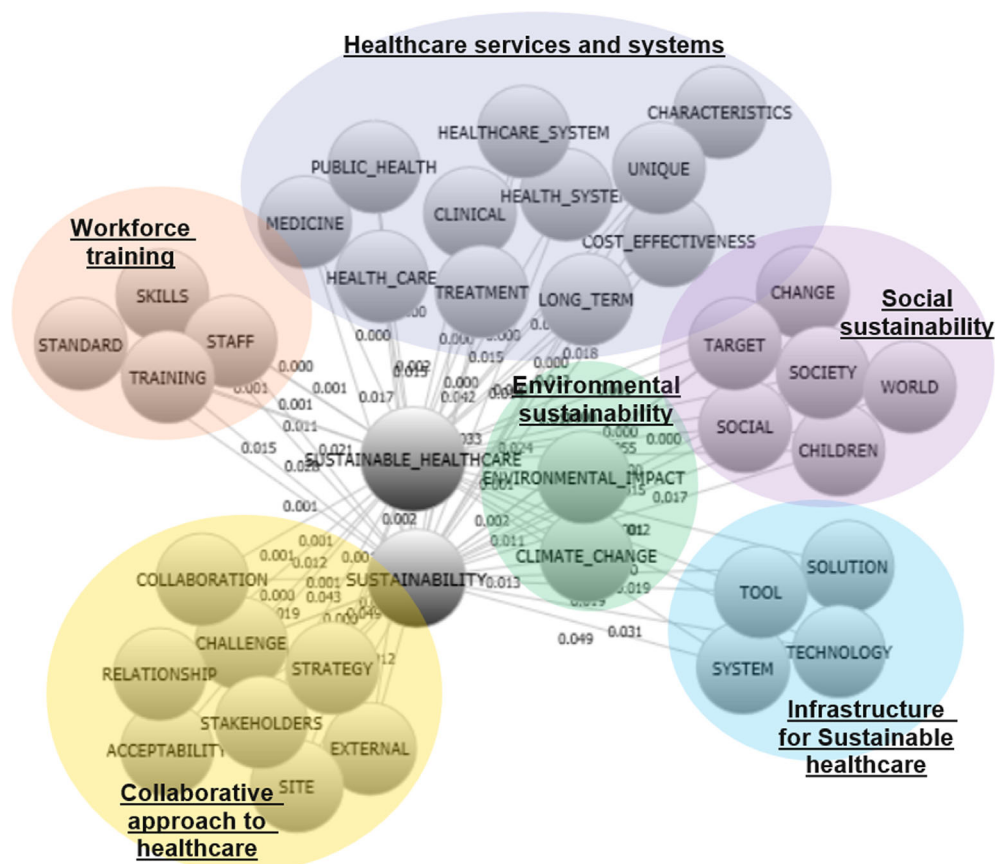
TABLE 2 Keyword, phrase and topics from SH articles ($n = 15\,894$).

Keyword	TF-IDF	Case %*	Phrase	TF-IDF	Case %*
1 treatment	4306.1	16.98%	1 health care	2524.8	7.59%
2 system	4141.6	22.05%	2 long term	2131.9	10.54%
3 children	3661.0	6.47%	3 public health	2041.1	7.59%
4 technology	3598.6	16.70%	4 physical activity	1906.4	3.04%
5 strategy	3474.0	23.09%	5 health system	1883.4	4.75%
6 challenge	3224.1	23.52%	6 climate change	1850.2	5.35%
7 change	3111.1	15.32%	7 mental health	1832.4	2.63%
8 water	3092.9	8.94%	8 cost effectiveness	1703.7	6.92%
9 waste	3048.7	7.11%	9 primary care	1339.2	2.33%
10 soil	2970.4	5.32%	10 middle income country	1187.6	3.62%
11 clinical	2718.9	11.21%	11 weight loss	1181	1.49%
12 support	2646.4	14.39%	12 wastewater treatment	1179.6	2.79%
13 training	2494.1	6.37%	13 human health	1058.5	3.88%
14 chemical	2492.1	9.09%	14 healthcare system	1032.7	3.20%
15 species	2290.2	6.26%	15 environmental impact	1029	3.42%
16 social	2222.0	9.31%	16 decision making	1001.5	2.91%
17 women	2013.3	3.65%	17 health service	996	2.73%
18 vaccine	1900.2	2.17%	18 waste management	973	1.91%
19 long-term	1874.3	8.72%	19 environmental sustainability	960	3.04%
20 climate change	1850.2	5.35%	20 global health	922	2.18%
Topic	Coherence (NPMI)	Frequency	Cases	Case %*	
1 clinical treatment	0.273	5,228	2,674	17.73%	
2 sustainable water management	0.337	3,773	1,664	11.03%	
3 green biotechnology, gene biology	0.287	2,573	1,684	11.17%	
4 climate change	0.230	2,592	1,368	9.07%	
5 sustainable agriculture/food industry	0.308	2,316	1,270	8.42%	
6 sustainable workforce	0.294	2,519	1,262	8.37%	
7 pregnant women, young children, infant	0.320	2,907	1,104	7.32%	
8 sustainable weight management	0.379	2,457	1,005	6.66%	
9 sustainable energy	0.363	1,377	893	5.92%	
10 sustainable waste management	0.324	1,791	831	5.51%	
11 healthcare services/systems	0.289	1,422	791	5.24%	
12 prevention vaccination	0.289	1,921	726	4.81%	
Summarized Implications					
Dimensions (Case %)*	Topic Contexts				
Environmental sustainability (32.7%)	<i>waste, soil, chemical, species, climate change, environmental impact, sustainable water/waste management</i>				
Social sustainability (23.0%)	<i>children, women, pregnant women, infant, middle income country, global health</i>				
Economic sustainability (5.8%)	<i>cost effectiveness, long-term</i>				
Healthcare services/systems (23.1%)	<i>healthcare, clinical treatment, primary care, health system, healthcare system</i>				
Patient empowerment (11.5%)	<i>weight loss, sustainable weight management, physical activity, mental health</i>				
Prevention (3.8%)	<i>prevention, vaccination</i>				
Workforce training (3.8%)	<i>training, sustainable workforce</i>				

Abbreviations: SH, Sustainable Healthcare; NPMI, Normalised Pointwise Mutual Information; TF-IDF, Term Frequency weighted by Inverse Document Frequency.

*Case % refers to the percentage of studies (cases) in which corresponding keyword, phrase or topic appears.

FIGURE 2 Contextual connections among terms from sustainable health care articles. [Color figure can be viewed at wileyonlinelibrary.com]



3.4 | RQ3. Prevalent sustainability topics explored in VE research

As shown in Table 4 and Figure 4, the analysis of keywords, phrases, topics and their networks in SVE articles also yielded topics related to environmental sustainability (13.5%) and social sustainability (5.7%). Words related to social sustainability, like *equity* and *social responsibility*, were more explicit than words from medicine and ME articles. The most frequently appearing terms were those associated with technology, such as virtual reality (VR), augmented reality (AR), information and communication technology (ICT) and cloud computing (28.8%), which can be used to raise learners' awareness of environmental issues and promote their pro-environmental attitudes and behaviours with immersive, hands-on learning experiences—without a need to travel.⁴³ We observed a substantial presence of words related to the form of VE, such as the conventional forms *e-learning*, *online and distance learning*, as well as the more recent emergence of terms like *massive open online courses* (MOOCs) (9.6%). Terms surrounding the advantages of VE, such as *traditional, face-to-face, competitive advantage over traditional classroom lecture* and *COVID pandemic*, were observed as well (9.6%).

The presence of terms relating to macro- and micro-strategies was notable, both among institutions and within institutions implying collaborative strategies for developing and implementing VE. This finding was exemplified by phrases such as *funded cooperation*, *stakeholders* and *collaboration* (3.8%) along with phrases on educational institutions, such as *university*, *higher education institutions* and

postgraduate education (9.6%). The strategies involve minimising resource consumption, encompassing not only tangible resources such as travel and administrative burden but also intangible resources, including human capital, which would not have been incurred if traditional resource-intensive methods had been employed.^{12,21} The use of keywords related to innovation, such as *behavioural change* and *digital transformation*, also was observed (3.8%).

3.5 | RQ4. The synthesis of SVME dimensions and strategies

The keywords, phrases, topics and networks extracted from the SH, SME and SVE studies provided dimensions and strategies of SVME in regard to learning content, media and methods and strategies. Figure 5 illustrates how the implications of topics derived from SH, SME and SVE studies constitute SVME system elements. SH-derived topics provide the broader context of SVME, influencing the learning content and objectives of SVME. These topics encompass the three pillars of sustainability and the medical practices for achieving them, serving as the goals and means of SH. Through the SME aspect, these topics become the learning content, and the acquisition of related knowledge, skills and attitudes becomes the learning objectives. The SME research topics provide insights into learners and their evaluation. They imply that the target learners of SVME should encompass not only medical students but also health care professionals and staff within the entire workforce. The topic *workforce training* emerges

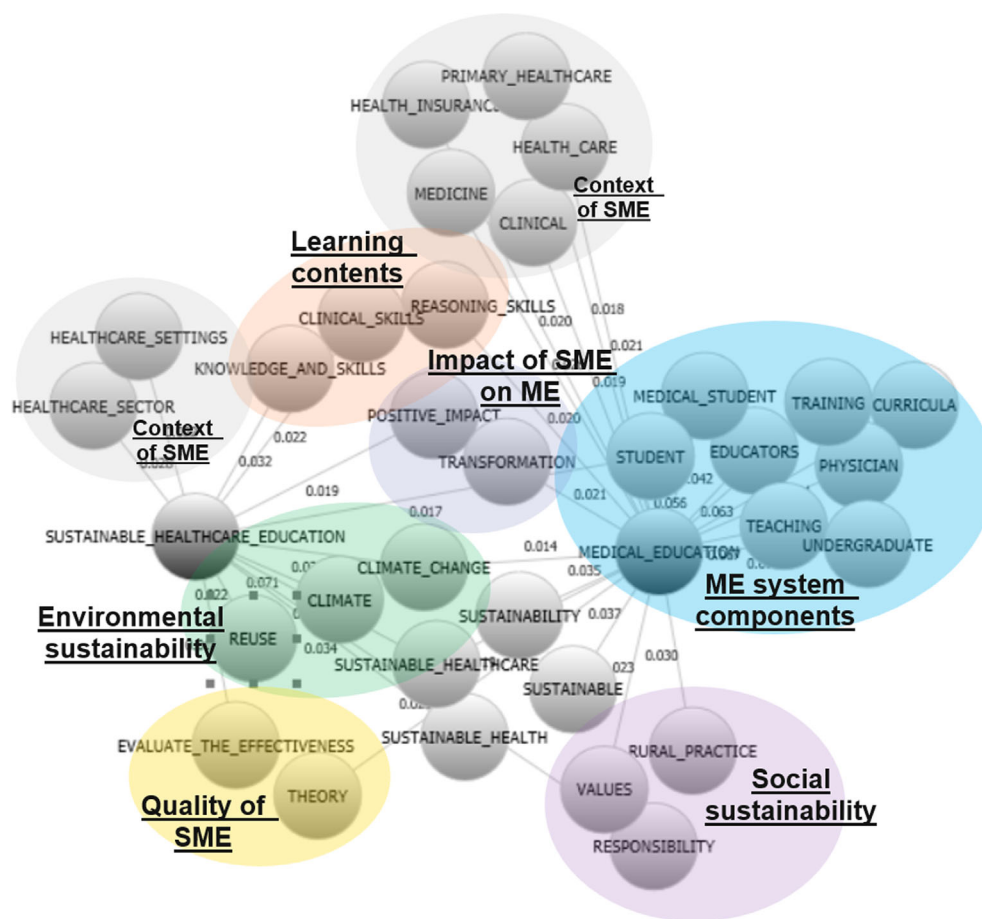
TABLE 3 Keyword and phrase analysis of SME articles (n = 729).

	Keyword	TF-IDF	Case %*		Phrase	TF-IDF	Case %*
1	training	218.5	41.37%	1	health care	179	18.21%
2	treatment	166.2	15.18%	2	public health	134	10.86%
3	clinical	153.6	22.20%	3	health system	99.3	8.79%
4	physician	151.9	12.78%	4	healthcare professional	93.3	8.94
5	teaching	148.5	10.38%	5	mental health	89.6	3.04%
6	strategy	146.2	23.00%	6	long term	84.7	11.18%
7	university	135	12.94%	7	climate change	82.7	4.63%
8	staff	120.4	11.66%	8	sustainable healthcare	82.3	3.19%
9	waste	117.4	4.47%	9	primary care	81.5	6.07%
10	public_health	115.3	8.95%	10	training program	72.6	7.03%
11	social	112.8	12.94%	11	environmental sustainability	68.8	3.19%
12	skills	105.6	11.18%	12	middle income country	68.7	6.23%
13	technology	104.7	11.18%	13	physical activity	66.8	3.04%
14	women	101.6	4.79%	14	clinical practice	66.3	5.91%
15	surgical	100.3	7.03%	15	sustainable development goal	65.7	7.03%
16	simulation	100.2	2.72%	16	patient care	62.1	4.47%
17	standard	93	9.27%	17	decision making	60.7	4.47%
18	team	88.8	7.51%	18	cost effectiveness	57.1	5.75%
19	workforce	88.4	6.39%	19	waste management	53.8	2.08%
20	curricula	87.7	7.51%	20	palliative care	52.5	0.96%
Topic				Coherence (NPMI)		Frequency	Case %*
1	self-care patient empowerment			0.563		368	25.08%
2	collaborative training for global health			0.305		252	22.04%
3	health_insurance/primary_healthcare			0.522		221	20.13%
4	prevention vaccination			0.602		286	19.97%
5	sustainable healthcare education			0.345		302	18.05%
6	digital_health/patient_centered_care			0.500		186	14.86%
7	training with simulations			0.277		226	13.90%
8	maternal_health			0.550		167	11.98%
9	clinical_training			0.474		131	11.66%
10	community heatlh			0.553		142	9.74%
11	evaluate_the_effectiveness			0.490		96	7.83%
12	waste management			0.332		96	5.43%
Summarized Implications							
Dimensions (Case %)*				Topic Contexts			
Environmental sustainability (9.6%)		waste, climate change, environmental sustainability, waste management, (planetary health)					
Social sustainability (7.7%)		middle-income country, maternal_health, public health, community health					
Economic sustainability (5.8%)		cost effectiveness, long-term					
Healthcare service/system (19.2%)		primary care, physician, treatment, clinical practice, sustainable healthcare					
Patient empowerment (7.7%)		self-care patient empowerment, mental health, physical activity (blood pressure, weight loss, health education)					
Prevention (1.9%)		vaccination, health promotion					
Education program and learners (30.8%)		curricula, clinical_training, training program, healthcare professional, workforce, staff					
Program evaluation (11.5%)		evaluate_the_effectiveness, knowledge and skills, clinical skills, reasoning skills, value, responsibility					
Technology (5.8%)		simulation, training with simulations, digital_health, (e-learning)					

Abbreviations: SME, Sustainable Medical Education; NPMI, Normalised Pointwise Mutual Information; TF-IDF, Term Frequency weighted by Inverse Document Frequency.

*Case % refers to the percent of studies (cases) in which corresponding keyword, phrase or topic appears.

FIGURE 3 Contextual connections among terms from sustainable medical education articles. [Color figure can be viewed at wileyonlinelibrary.com]



towards the end of the SH field, linked to the SME topic. This finding not only situates SVME within the context of SH but also denotes the intended learners of SVME. The topic *technology* from SME studies overlaps with SVE research topics, which contributes to the shaping of SVME tools, methods, and strategies. The resulting SVME guidelines and strategies are summarised in Table 5.

4 | DISCUSSION

The primary purpose of this study was to identify sustainability topics in a large volume of studies in order to explore strategies for implementing ESH via virtual platforms in ME. We extracted keywords, phrases, topics and their networks from studies on sustainability in the fields of health care, ME and VE. This process revealed relevant concepts with practical implications within each area. Grounded in the results of each research question, we discerned new definitions of sustainability within each field, consequently leading to the extrapolation of VE strategies in the context of SH and ME.

4.1 | SH redefined

In the health care area, three major topics emerged: (1) environmental sustainability within a medical context (supporting human and

planetary health by reducing the carbon intensity of services), social sustainability (providing equitable access to health care services) and economic sustainability (ensuring the long-term cost-effectiveness of health care services); (2) the means to achieve these three pillars of sustainability, including the transformation of health care services and systems, patient empowerment and prevention; and (3) non-medical means for SH, which is, essentially, workforce training. Based on the topics we identified, we can redefine SH as follows:

A holistic strategy that supports environmental responsibility (both human and planet-friendly), social equity (accessibility for all), and economic viability (cost-effectiveness in the long run) by reducing the carbon intensity of services, increasing patient empowerment, emphasizing prevention, transforming healthcare services and systems, and training a healthcare workforce equipped to understand and implement these priorities

This definition redefines the original three pillars of sustainability within the context of health care, incorporating enabling medical practices. Compared with previous definitions that primarily focused on environmental sustainability in health care (e.g. Gandhi et al, 2020¹¹), this is a more balanced and integrated definition. It stresses the necessity of cultivating a health care workforce trained to proficiently implement and advance such a sustainability paradigm. In essence,

TABLE 4 Keyword and phrase analysis of SVE articles ($n = 1923$).

Keyword	TF-IDF	Case % *	Phrase	TF-IDF	Case % *
1 university	700.2	22.41%	1 higher education	500.6	15.86%
2 technology	605.5	27.04%	2 e-learning	380.1	5.36%
3 social	399.2	18.46%	3 covid pandemic	267.8	7.33%
4 strategy	372.1	15.96%	4 machine learning	212.9	5.98%
5 higher_education	402.4	12.12%	5 environmental sustainability	203.6	4.21%
6 world	310.5	14.40%	6 digital technology	201.1	5.04%
7 skills	327.1	10.56%	7 online learning	200.3	4.52%
8 virtual	338.4	9.57%	8 social media	195.5	2.50%
9 tools	306.5	11.86%	9 higher education institutions	187.6	5.62%
10 solution	308.8	11.60%	10 artificial intelligence	180.2	4.32%
11 sustainable development_goal	308.1	10.97%	11 long term	178.7	6.08%
12 society	275.7	13.16%	12 climate change	170.5	4.00%
13 e-learning	380.1	5.36%	13 smart city	168	1.56%
14 urban	307.1	5.25%	14 distance learning	152.3	3.43%
15 tool	243.6	8.63%	15 decision making	147.1	4.47%
16 covid pandemic	260.1	7.23%	16 digital transformation	144.3	2.39%
17 collaboration	207.1	11.44%	17 learning environment	128.8	2.81%
18 stakeholders	225.7	8.22%	18 sustainable energy	126.3	1.66%
19 ICT	280.4	4.42%	19 face to face	125.6	3.33%
20 traditional	218.3	7.70%	20 virtual reality	122.1	2.24%
Topic	Coherence (NPMI)		Frequency	Case %*	
1 cloud computing	0.502		233	5.15%	
2 AI/machine learning/deep learning	0.493		185	5.46%	
3 postgraduate education	0.394		841	22.98%	
4 massive open online courses/MOOCs	0.360		166	2.39%	
5 competitive advantage over traditional classroom lecture	0.349		626	18.51%	
6 sustainable architecture/smart city	0.308		691	12.06%	
7 virtual reality (VR)/augmented reality (AR)	0.282		402	10.19%	
8 behavioral change & innovation	0.282		161	5.10%	
9 ICT	0.275		434	13.73%	
10 climate change	0.229		428	11.08%	
11 equity and social responsibility	0.224		429	13.73%	
12 funded cooperation	0.124		590	15.70%	
Summarized Implications					
Dimensions (Case %)*			Topic Contexts		
Environmental sustainability (13.5%)			climate change, climate change, sustainable energy, smart city		
Social sustainability (5.7%)			society, equity, social responsibility		
Technology for virtual education (28.8%)			VR AR, ICT, cloud computing, AI		
Virtual education type (9.6%)			e-learning, online & distance learning, MOOCs		
Educational institution (9.6%)			university, higher education institutions, postgraduate education		
Collaborative development (3.8%)			funded cooperation, stakeholders, collaboration		
Advantages of VE (9.6%)			traditional, face to face, competitive advantage over traditional classroom lecture, COVID pandemic		
Innovation (3.8%)			behavioral change & innovation, digital transformation		

Abbreviations: SVE, Sustainable Virtual Education; ICT, Information and Communication Technology; MOOCs, Massive Open Online Courses; NPMI, Normalised Pointwise Mutual Information; VE, Virtual Education; TF-IDF, Term Frequency weighted by Inverse Document Frequency.

*Case % refers to the percent of studies (cases) in which corresponding keyword, phrase or topic appears.

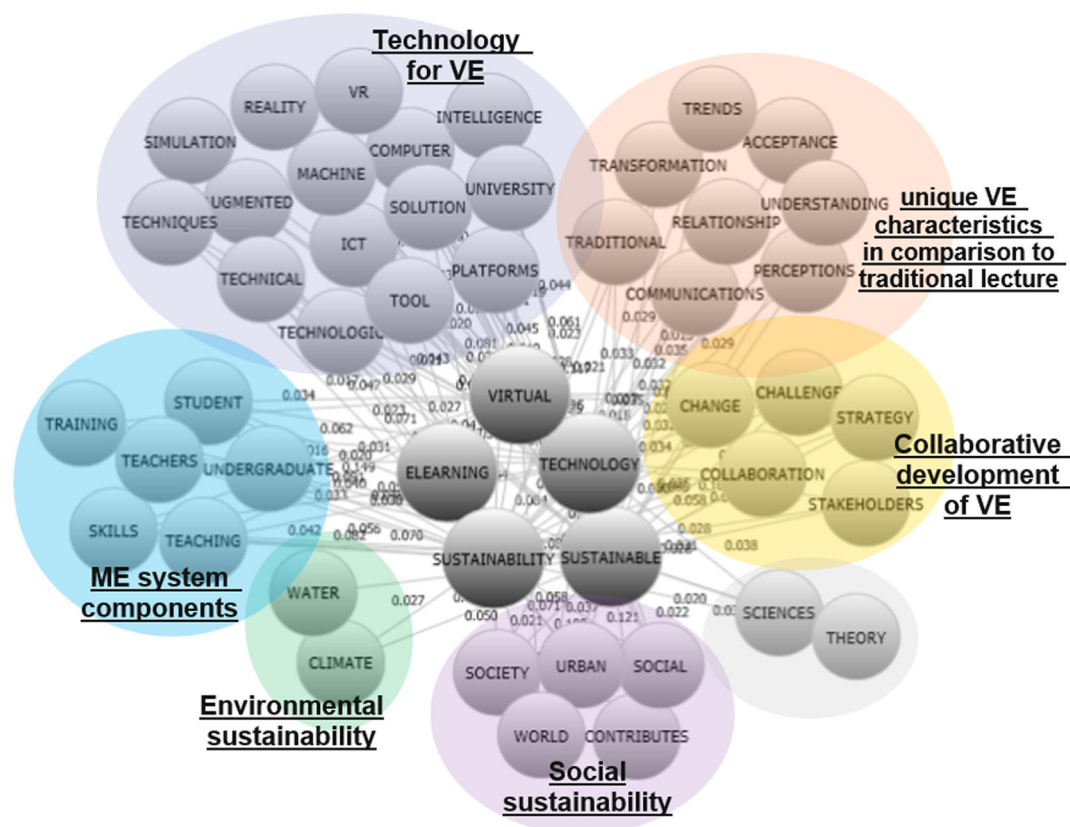


FIGURE 4 Contextual connections among terms from Sustainable Virtual Education (SVE) articles. [Color figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com)]

this feature introduces a new perspective that extends and shapes a nexus between SH and ME (Figure 5).

4.2 | SME defined

In the ME area, three groups of topics emerged: (1) three pillars of sustainability and their enabling medical practices directly aligned with topics from SH, which can constitute ESH content and learning objectives; (2) educational interventions to implement the content and objectives in curriculum intended for a specific learning population (e.g. *health care professionals, workforce and staff*); and (3) strategies to enhance the effectiveness of ESH such as programme evaluation (e.g. *effectiveness, knowledge, clinical skills, reasoning skills and values*), including the use of technology as a potential medium for delivery. SME could therefore be defined as follows:

A pedagogical approach designed to educate the entire healthcare-related workforce on sustainable healthcare priorities, including environmental responsibility (both human and planet-friendly), social equity (accessibility for all), and economic viability (cost-effectiveness in the long run), through the coordination of curricula, programs, technology, and the evaluation of program effectiveness

In the current ME literature, approaches to sustainability predominantly focused on what medical educators should teach to promote SH; this is commonly referred to as ESH (e.g. Bevan et al 2022²⁰; Hategan & Abdurrahman, 2021⁹; Thompson et al 2014¹⁶). This definition reflects the finding that ME researchers view teaching about sustainability not only as pertinent to the content of instruction but also as a practice necessitating sustainable methods of education. The last group of ME topics also implies that if ESH programmes are to be genuinely sustainable, they must engage in quality assurance through programme evaluation, as reflected in Goal 4 (Quality Education) of the UN SDGs. As shown in Figure 5, the above definition also places technology at intersection point of ME and VE.

4.3 | SVE defined

The primary topics emerging from the VE studies we analysed can be categorised into three groups: (1) VE's contributions to environmental and social sustainability, (2) the variety of technologies that can be used to enable VE and (3) VE strategies, for collaboration between educational institutions and for the diffusion of innovation. SVE can thus be defined as follows:

An pedagogical approach in which learning programs employ virtual platforms with advanced technologies

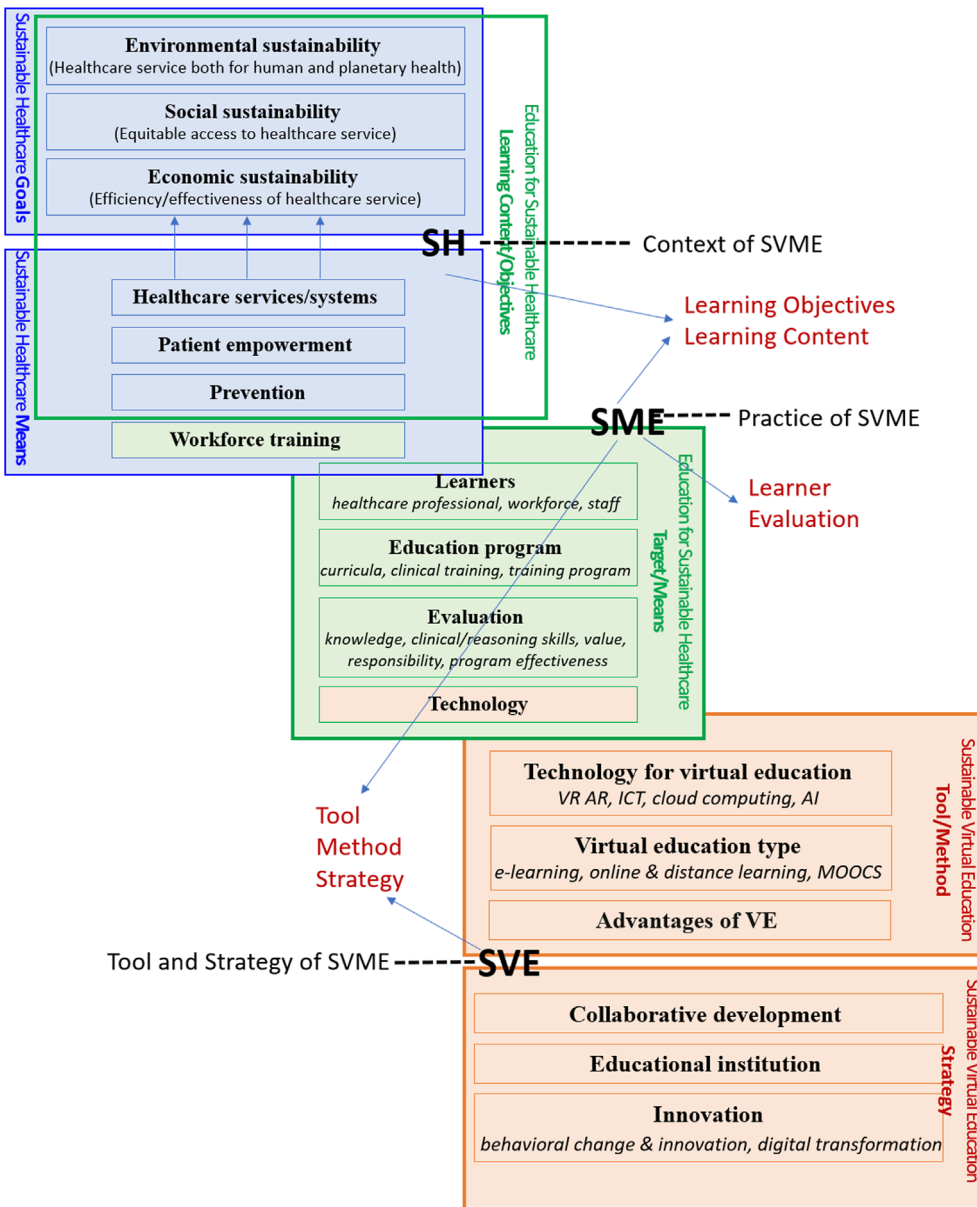


FIGURE 5 Topics from Sustainable Health Care (SH), Sustainable Medical Education (SME) and Sustainable Virtual Education (SVE) research articles for SVME system elements. [Color figure can be viewed at wileyonlinelibrary.com]

that provide unique affordances overcoming the limitations of current training methods, and which is enhanced by institutional collaboration and diffusion strategies

This definition augments the existing concepts of sustainability discussed in VE, namely, its utility from a sustainability perspective. For example, VE reduces the need for student travel to physical campuses and improving access to quality education for students in remote or underserved areas (e.g. Alonso-García et al 2019⁵¹). SVE also encompasses the strategies required for its own sustainability. This includes a judicious selection of technology that aligns learning objectives and relieves institutions of economic and logistic burdens. It also stresses cross-functional collaborations to effect development, adoption, and implementation and to engage stakeholder who can help drive diffusion of innovation.

4.4 | SVME: Definition and strategies

The redefined concepts of SH, SME and SVE yield implications for a definition of SVME and the strategies by which to promote it, as depicted in Table 5. Firstly, SVME content should encompass three widely accepted principles of environmental responsibility, social equity and economic viability actualized through such means as reducing the carbon intensity of services, supporting patient empowerment and prevention and advocating the transformation of health care services and systems Secondly, one objective of SVME should be to provide the entire health care workforce, at all levels, with the requisite knowledge, skills and attitudes necessary to comprehend and operationalise these principles and facilitating practices. Thirdly, SVME should be leveraged by a variety of media and methods, including simulations, VR, AR, AI, cloud computing, online and distance learning and MOOCs, while bearing in mind the unique affordance of

TABLE 5 Summarised directions and strategies for sustainable virtual medical education.

Sustainable Virtual Medical Education						
Sustainable Medical Education						
Sustainable Healthcare						
Learning Content	Education for Sustainable Healthcare (ESH) (Goal of Sustainable Healthcare)	Environmental Sustainability	- planetary health - waste management, - low carbon alternatives - operational resource use			
		Social Sustainability	- equitable access to healthcare services - the social determinants of health - health issues of vulnerable patients			
		Economic Sustainability:	- prevention - patient empowerment - streamlining clinical pathways			
Learning Objectives / Evaluation	Fundamental cognitive competencies	- knowledge - clinical skills - reasoning skills				
	Values & attitude	- social responsibility of medical professionals, institutions, and health systems - professionalism and leadership for sustainability				
Learner	Healthcare workforce and staff as well as community health workers (CHW)					
Media/Tool Method	- Type: e-learning, online learning, distance learning, and MOOCs - Technology: simulations, VR, AR, AI, cloud computing used both online and offline - Optimal use of technology considering its unique affordances					
The Strategies	Development strategy		Collaboration and partnership strategy to overcome limited local resources and expertise			
	Diffusion of innovation strategy		- behavioral change - persuasive communication - engagement of stakeholders			
	Quality assurance strategy		- satisfaction of stakeholders' needs - effective instructional design - accessibility - sustainability			

each medium. Finally, those implementing SVME should utilise collaborative institutional development, engage with the process of innovation diffusion and evaluate the effectiveness of SVME programmes based on learning objectives and outcomes. Accordingly, we can define SVME as follows:

A systematic integrated approach for educating sustainable healthcare that employs virtual platforms to embed environmental responsibility, social equity, and economic viability within medical education content

and practices, empower the healthcare workforce with pertinent sustainability-based knowledge, skills, and attitudes, utilise diverse media and innovative methods, and promote sustainability through collaborative development, innovation diffusion, and quality assurance of program effectiveness based on learning objectives and outcomes.

The study advances understandings of the role of SVME in SH and ME both in providing the first clear definition of SVME and in

proposing a systematic approach to making SVME methods themselves sustainable. A *systems (or systematic) approach* to teaching and learning addresses educational challenges by examining the various components of an educational system as interconnected and interdependent parts.^{44,45} Instead of focusing on curriculum or instruction in isolation, for example, a systems approach views these elements as part of a larger, integrated whole. The topics and new definitions identified in this study reflect such a systematic approach to SVME, which includes careful planning and development of learning content based on sustainability principles, the utilisation of sustainable technologies and practices and the evaluation of the effectiveness and sustainability of these educational experiences. The overarching purpose in this process is to ensure that SVME not only teaches about sustainability but also embodies sustainability in its methodologies and practices.

Another significant implication of our findings is that the discourse on SVME should be primarily driven by the field of ME. Although a considerably smaller quantity of sustainability research was identified in studies on ME ($n = 626$, 3.6%) versus medicine ($n = 15\,082$, 85.5%) or VE ($n = 1923$, 10.9%), the critical SVME strategies pertain to the ME strategies for quality assurance and innovation diffusion, which provide practical guidance for curriculum developers, educators, researchers and other stakeholders.

Achieving integrated sustainability in the field of medicine and ME may involve tensions between different dimensions of sustainability³ and lead to conflicts related to quality assurance. For example, SH may require the provision of cost-effective medical services, challenging both economic sustainability and social sustainability goals for economically challenged individuals—potentially leading to a decline in service quality. Similar conflicts can arise in SME and SVME when trying to provide cost-effective learning to a large number of learners, as seen in the emergency remote medical learning required by the COVID pandemic. The quality of health care, ME and VE should not be compromised over sustainability values, but quality assurance should be a guiding principle for SVME.^{3,9,46} High-quality education has been shown to positively impact individual and community development and serve not only as an end goal in itself but also as a means for promoting sustainability.⁴⁷ Instructional design, stakeholder needs and accessibility are all criteria that can be used to evaluate the quality of SVME. In fact, advanced technology alone cannot ensure successful learning outcomes without proper curricular design and instructional strategies, as argued by Clark^{48,49} in historical instructional media debates. A recent systematic review also found that effective virtual patient programmes for medical communication training were distinguished by their instructional design, not technical quality.⁵⁰ Thus, the needs and expectations of learners, educators, and society including the accessibility of programmes must be taken into account when defining quality in VE.⁴⁶

This study has methodological limitations, however, in terms of identifying detailed subtopics within each topic and understanding their precise meanings and implications, despite efforts to explore documents using the keyword-in-context function. In acknowledging this limitation, we recommend further validation through in-

depth investigations employing other quantitative and qualitative research methodologies. Nevertheless, grounded on the topic analysis of over 17 000 research spanning more than 40 years in the domains of SH, SME and SVE, this study redefined the notions of SH, SME and SVE and created a definition and strategies for SVME, a substantial contribution to the field of ME. It is our intention to contribute to the refinement of SVME concepts and strategies by measuring and enhancing the effectiveness of SVME and facilitating its continuous improvement. In this way, we hope to quantify, optimise and incrementally advance the efficacy of SVME.

5 | CONCLUSION

The emergent topics underscore that SVME requires a comprehensive systems approach that takes the following into account: learning content and objectives, evaluation, target learners, media/technologies and strategies to ensure development, diffusion of innovation and stringent quality assurance. Among these, quality assurance is a critical and non-negotiable guiding principle. The advancement of SVME necessitates that medical educators and researchers play a central and bridging role, guiding both the fields of SH and ME in the development and implementation of SVME. In this way, they can prepare future physicians to address sustainability issues that impact patient care. It is hoped that this research will encourage further investigation in this area that will lead to actionable steps to deliver ESH to future generations of physicians, who will certainly find this learning increasingly important to the health of their patients.

AUTHOR CONTRIBUTIONS

Jihyun Lee: conceptualization, data curation, formal analysis, funding acquisition, methodology, project administration, supervision, validation, visualisation, writing—original draft and writing—review and editing. **Hyeongjo Kim:** formal analysis, methodology, validation and writing—original draft, writing—review and editing. **Frederick Kron:** conceptualization, writing—revised drafts and writing—review and editing.

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None.

CONFLICT OF INTEREST STATEMENT

There are no conflicts of interest to declare.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request.

ETHICS STATEMENT

None.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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