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Embedding Lean Healthcare Training for Sustainability in Health Sciences Education: A Cross-Sectional KAB Model with Cultural–Leadership Moderation

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Abstract: *The imperative for sustainable healthcare is intensifying as health systems contribute to climate change, resource depletion and waste. Lean Healthcare (LH), with its focus on value, waste elimination and continuous improvement, offers a potential pathway toward environmental sustainability when integrated into health sciences education. However, most educational evaluations focus only on knowledge, attitude and behaviour (KAB) gains and overlook whether learners translate Lean principles into sustainability-oriented practices. This cross-sectional study used a newly developed Sustainability Outcomes in Healthcare Education (SOHE) scale to investigate whether students' Lean-related knowledge, attitudes and behaviours predict sustainability outcomes. A total of 118 health sciences students completed a survey comprising validated KAB subscales and SOHE items. Hierarchical multiple regression tested the main effects of Knowledge, Attitude and Behaviour on SOHE and examined whether the perceived learning Culture and Leadership moderated the Behaviour → SOHE relationship. All subscales showed acceptable reliability ($\alpha \geq 0.80$). Behaviour was the strongest predictor of SOHE ($\beta \approx 0.46$, $p < .001$), while Knowledge and Attitude showed weaker positive associations. Interaction terms revealed that supportive Culture and Leadership significantly strengthened the Behaviour → SOHE relationship ($\beta \approx 0.15–0.17$, $\Delta R^2 \approx 0.03$), indicating that when students perceive a culture of continuous improvement and strong leadership support, the translation of Lean behaviours into sustainability outcomes is amplified. Nursing students reported slightly higher SOHE scores than medical students. These findings suggest that embedding Lean training within supportive educational contexts can cultivate sustainability competencies in future clinicians and that curriculum designers should intentionally align process-improvement pedagogy with environmental stewardship.*

Keywords: Earnings Management; Accrual-Based Earnings Management (AEM); Real Earnings Management (REM); Chinese Listed Companies; Corporate Performance; Ownership Structure; State-Owned Enterprises (SOEs); Agency and Signaling Theories

1. Introduction

The environmental footprint of healthcare

Healthcare services are among the largest contributors to greenhouse gas emissions and resource consumption through energy-intensive operations, single-use devices and complex supply chains (Hilverda et al., 2023). While healthcare's mission is to provide safe and

effective care, the sector is increasingly being held accountable for its environmental footprint and urged to pursue more sustainable models of practice(Van Zyl-Cillié et al., 2024). International agencies, including the World Health Organization, together with the United Nations Sustainable Development Goals, have called for urgent efforts to decarbonise healthcare systems and to embed principles of environmental sustainability into the training of future health professionals (Brancalion et al., 2024). Despite these calls, recent surveys highlight a persistent gap: fewer than 2% of medical students report receiving formal instruction in sustainable healthcare, even though over 90% agree that topics such as climate change and sustainability should be part of the curriculum (Gupta et al., 2022). In line with this, a concept analysis of eco-conscious nursing emphasises that environmental stewardship, combined with strong educational foundations and institutional support, serves as a critical precursor to achieving sustainable practice (Lučić & Uzelac, 2024).

Healthcare services contribute substantially to greenhouse gas emissions and resource consumption through energy-intensive operations, single-use devices and complex supply chains (Hilverda et al., 2023). As the sector strives to deliver high-quality care, there is growing recognition of its environmental footprint and the need for sustainable healthcare (Van Zyl-Cillié et al., 2024). Agencies such as the World Health Organization and the United Nations Sustainable Development Goals call for decarbonising healthcare and integrating environmental sustainability into health professional training (Brancalion et al., 2024). However, surveys across medical schools reveal that fewer than 2% of students feel they have been taught sustainable healthcare, while over 90% believe the curriculum should address climate change and sustainability (Gupta et al., 2022). A concept analysis of eco-conscious nursing underscores that environmental stewardship, education and institutional support are antecedents of sustainable practice (Lučić & Uzelac, 2024).

Previous educational evaluations of Lean training have focused primarily on changes in Lean-related knowledge, attitudes and behaviours. Few studies have examined whether Lean learning translates into environmentally sustainable behaviours among students or healthcare professionals. This study addresses that gap by developing a Sustainability Outcomes in Healthcare Education (SOHE) scale and testing a moderated KAB model. Specifically, it asks: To what extent do students' knowledge, attitudes and behaviours regarding Lean predict sustainability outcomes? and Do perceptions of a supportive learning culture and leadership strengthen the Behaviour and therefor SOHE relationship? By positioning SOHE as the dependent variable and testing moderation rather than mediation, this research contributes novel insights into the interplay between process-improvement learning and sustainability in health sciences education.

2. Literature Review

2.1 Lean healthcare and quality improvement

Lean Management (LM) evolved from Toyota production methods and aims to maximise value by eliminating non-value-adding activities and creating efficient, standardised flows (Lemery, J. et al., 2024). In healthcare, Lean Healthcare (LH) is used to improve quality, safety and efficiency by reducing waste, streamlining care pathways and focusing on activities that patients value (Kunnen et al., 2023). Lean implementations yield benefits such as reduced patient waiting times, process standardisation and cost reductions (Mitchell et al., 2025) and require structural change and a culture of continuous improvement (Shaban et al., 2024). LH emphasises respect for people, professional training and frontline engagement (Gupta et al., 2022). Successful adoption depends on management support, clear goals and continuous

measurement (Lučić & Uzelac, 2024), whereas superficial tool implementation without cultural change often fails (Chen et al., 2024).

2.2 Lean and sustainability

Lean's strong emphasis on eliminating waste and streamlining processes makes it a natural fit with the goals of environmental sustainability. Yet in practice, many healthcare organisations still tend to prioritise financial savings and operational efficiency over ecological benefits. Green Lean Six Sigma (GLSS) training in Dutch healthcare has illustrated that when environmental criteria are intentionally built into Lean initiatives, tangible gains follow — reductions in product use, lower energy consumption, decreased costs and travel, as well as greater attention to green procurement and staff awareness of sustainability issues (Gupta et al., 2022). Despite these encouraging results, a number of obstacles continue to hold back sustainability projects, including time pressures on staff, the challenge of selecting suitable projects, and limited management support (Flynn et al., 2018). Reviews of Lean sustainability indicate that sustaining improvement beyond initial gains is challenging, especially in complex organisations with hierarchical structures(Gupta et al., 2022). A scoping review of Lean leadership concluded that leadership activities, stakeholder involvement and strategic alignment are essential for continuous improvement maturity(Aij & Rapsaniotis, 2017).

2.3 Knowledge–Attitude–Behaviour (KAB) framework

The KAB model proposes that knowledge acquisition influences attitudes, which in turn shape behaviour. Evidence from health education supports this sequential process: education programmes based on the KAB model improved haemodialysis patients' knowledge and self-management behaviour through stages of knowledge acquisition, belief generation and behaviour formation (Liu et al., 2016). A cross-sectional survey of psychiatric nurses found that knowledge and attitude together explained 61.8% of the variance in evidence-based practice behaviour (Lučić & Uzelac, 2024). These findings suggest that knowledge and attitude are precursors to behavioural change and justify using the KAB model to evaluate Lean training outcomes.

2.4 Role of culture and leadership

Organisational context profoundly influences Lean implementation. Intra-organisational factors such as teamwork, leadership commitment, communication, resources and people engagement shape Lean transformation (Reponen et al., 2021). Strong leadership and high managerial commitment are recognised facilitators of Lean maturity, while lack of knowledge, resources and customised training hinder progress (Hilverda et al., 2023). A scoping review identified 58 leadership activities grouped into nine themes and emphasised that leaders must align their style with organisational strategy, involve stakeholders and promote employee autonomy (Aij & Rapsaniotis, 2017). Lean leaders act as coaches, focusing on empowerment, trust and respect for people (Kunnen et al., 2023). Moreover, cultivating a culture of continuous improvement, employee empowerment and waste minimisation is integral to patient-centred lean healthcare (Aij & Rapsaniotis, 2017). Education programmes should therefore consider culture and leadership as moderators that can amplify or dampen the impact of Lean behaviours on sustainability outcomes.

2.5 Lean healthcare in education and practice

Lean thinking has been widely adopted in healthcare to improve efficiency and quality. Early adoptions emphasised standardising processes, creating flow and eliminating waste, resulting in increased productivity and reduced patient waiting times (Aij & Rapsaniotis, 2017). Lean programmes in hospitals often involve training health professionals to use tools such as 5S,

value stream mapping and daily huddles, encouraging frontline staff to participate in improvement projects. Reviews show that Lean adoption must go beyond tool use to encompass a process-oriented culture, aligning departmental functions with overall patient value and requiring clear leadership and strategic alignment (Sijm-Eeken et al., 2024). An integrative review of Lean contributions to nursing and healthcare processes highlights that success depends on formal instructions, standardised work environments, professional training and respect for people, which collectively improve quality and patient safety (Hägg-Martinell, 2025). Importantly, Lean healthcare adds maturity to management by fostering a process-oriented culture that encourages people's engagement to deliver benefits to the institution (Liu et al., 2016). However, the same review emphasises that Lean implementation demands structural change, a clear goal, assignment of responsibilities and measurement of performance (Li et al., 2022).

Realist and integrative reviews highlight persistent challenges in sustaining Lean improvements. Implementation often falters when organisations adopt tools superficially without embedding Lean thinking into culture and leadership (Liu et al., 2016). Success depends on factors such as team cohesion, change readiness, leadership commitment, communication and resource availability (Reponen et al., 2021). Leadership plays a central role: systematic reviews show that a large proportion of Lean success depends on senior management creating an environment for continuous improvement, characterised by empowerment, trust, humility and respect for people (Flynn et al., 2018). When leaders act as coaches and align strategy, stakeholder involvement and employee autonomy, Lean maturity is enhanced (Hilverda et al., 2023). Conversely, lack of knowledge among leaders, inadequate resources and weak commitment can inhibit Lean maturity (Aij & Rapsaniotis, 2017).

2. 6 Lean and sustainability in healthcare

While Lean has always been associated with reducing waste, its direct impact on environmental sustainability is still seldom assessed in healthcare settings. The GLSS programme, which built environmental considerations into Lean training for healthcare professionals, showed promising results: many participants went on to apply the approach, and a notable number completed projects that lowered product use, cut energy consumption, reduced costs and travel, and encouraged greener procurement practices (Flynn et al., 2018). Yet, as with many improvement efforts, persistent barriers were reported — staff struggled with limited time, uncertainty over which projects to prioritise, and a lack of consistent managerial support (Mitchell et al., 2025). These findings highlight both the potential and the challenges of aligning Lean training with sustainability outcomes.

A concept analysis of eco-conscious nursing further reinforced this perspective. The authors highlighted that sustainable nursing practice is rooted in environmental stewardship, responsible healthcare practices, and a commitment to lowering ecological impact (İlaslan & Şahin Orak, 2024). They identified key prerequisites — including adequate education, heightened awareness, and strong institutional backing — and pointed out that when these conditions are present, improved environmental health tends to follow. Nurses' close contact with patients also places them in a unique position to act as change agents. However, the analysis noted that limited training opportunities, low awareness, and structural obstacles within organisations remain significant barriers to advancing sustainability, even though nursing education is increasingly recognised as central to this agenda (İlaslan & Şahin Orak, 2024). ffective waste management and energy-efficient practices were also emphasised, not only as strategies for reducing environmental harm but also for lowering hospital-acquired infection rates and cutting costs (İlaslan & Şahin Orak, 2024). Complementing this, a recent

study of simulation-based education cautioned that simulation labs are highly resource-intensive and reliant on single-use materials. The authors urged educators to calculate the carbon footprint of such activities and adopt practical measures to reduce waste, designing scenarios that embed sustainability principles from the outset (Mitchell et al., 2025).

2.7 Knowledge–Attitude–Behaviour model in health education

The KAB model has been widely applied to health education and sustainability. A study with haemodialysis patients demonstrated that KAB-based interventions improved knowledge and self-management behaviours by guiding participants through stages of knowledge acquisition, belief formation and behaviour change (Wang et al., 2025). Similarly, a cross-sectional survey of psychiatric nurses found that knowledge and attitude explained a large share of the variance in evidence-based practice behaviour, highlighting the predictive validity of the KAB framework (İlaslan & Şahin Orak, 2024). Research on sustainable household capability among young adults confirmed that sustainable knowledge positively influences attitudes, which in turn predict behaviour, supporting the KAB model in sustainability contexts (Lučić & Uzelac, 2024). In the context of Lean training, these findings imply that students' knowledge of Lean principles and positive attitudes towards continuous improvement should translate into behaviours that manifest as process improvement and, potentially, sustainability outcomes.

2.8 Culture and leadership as moderators

Organisational culture and leadership can amplify or attenuate the translation of Lean behaviour into sustainability outcomes. Intra-organisational factors such as teamwork, change readiness, leadership commitment and resource availability shape Lean transformation (van Dun et al., 2024). Lean leaders must adopt hybrid leadership styles, empower employees, involve stakeholders and align initiatives with organisational strategy (Hilverda et al., 2023). Reviews emphasise that leadership is central to Lean maturity; strong leadership and high commitment facilitate continuous improvement, whereas lack of knowledge and resources inhibit progress (Snyder et al., 2024).Patient-centred Lean management further stresses the cultivation of a culture of continuous improvement, employee empowerment and waste minimisation to enhance patient value (van Dun et al., 2024). Without supportive culture and leadership, Lean behaviours may not translate into sustained improvements or environmental benefits. This study therefore tests Culture and Leadership as moderators of the Behaviour and SOHE path.

Despite recognition that Lean can contribute to environmental sustainability, few studies explicitly measure sustainability outcomes in educational settings. Existing research often stops at assessing KAB changes or process improvements. There is a paucity of empirical evidence linking Lean learning outcomes to environmental or sustainability behaviours. This study addresses this gap by developing an SOHE scale and testing whether Lean-related behaviours predict sustainability outcomes and whether organisational context moderates this relationship.

Figure 1 illustrates the proposed framework. Knowledge, Attitude and Behaviour are independent variables; Sustainability Outcomes in Healthcare Education (SOHE) is the dependent variable. Culture and Leadership are conceptualised as moderators of the Behaviour and SOHE relationship. The following hypotheses are tested:

- **H1:** Knowledge, Attitude and Behaviour are positively associated with SOHE, with Behaviour expected to have the strongest effect.
- **H2:** Culture moderates the relationship between Behaviour and SOHE; the positive association is stronger under a supportive learning culture.
- **H3:** Leadership moderates the relationship between Behaviour and SOHE; the positive association is stronger when leadership is supportive and empowering.
- **H4:** Nursing students report higher SOHE scores than medical students.

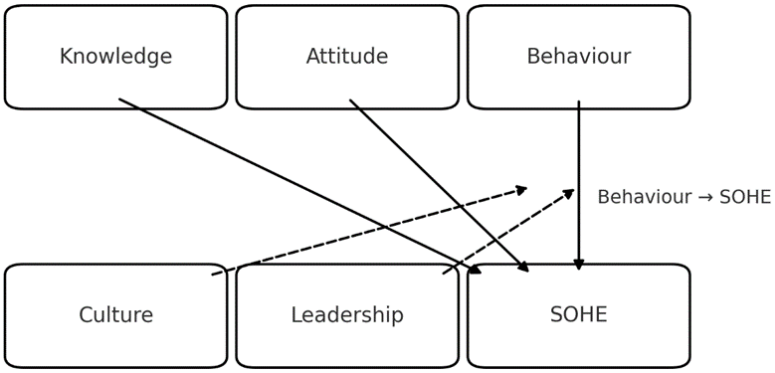

Figure 1: Conceptual framework

3. Methodology

3.1 Research Design

This cross-sectional, descriptive–correlational study was conducted at a public health sciences college in Oman. Data were collected during a routine Lean training module integrated into the curriculum. Participation was voluntary, and no training intervention was delivered for research purposes; rather, the study examined existing Lean-related competencies and sustainability perceptions among students.

3.2 Participants and sampling

The target population comprised undergraduate students from nursing and medical programmes. Using convenience sampling, 118 students completed the survey (doubling the sample size from a previous pilot study). Inclusion criteria were enrolment in the Lean module and consent to participate. The sample included 64 nursing students and 54 medical students, with a gender distribution of 70% female and 30% male. Prior Lean experience was low (<10%), ensuring that responses reflected educational exposure rather than professional practice. Table 1 shows distribution of participants by gender, discipline (nursing vs. medical), and year of study.

Table 1: Demographic Characteristics of Participants (N = 118)

Characteristic	Category	N (%)
Gender	Female: 70%, Male: 30%	83 (70), 35 (30)
Discipline	Nursing: 64 (54%), Medical: 54 (46%)	64 (54), 54 (46)
Year of Study	Mostly Year 3–4 undergraduates	N/A

3.3 Measures

Knowledge was assessed using three subscales from an existing Lean training instrument—Content knowledge, Training quality and Assessment knowledge (each 5 items). Items asked about understanding Lean principles, confidence in training delivery and awareness of assessment criteria. Attitude comprised two subscales capturing mindsets toward Lean and perceptions of continuous improvement culture (5 items each). Behaviour included 12 items covering application of Lean tools, seeking feedback and role modelling continuous improvement. Culture was measured by 5 items reflecting teamwork, collaboration, openness and shared learning. Leadership used 5 items assessing visible support, empowerment, accountability and encouragement from faculty and clinical supervisors. Items were rated on a five-point Likert scale (1 = strongly disagree to 5 = strongly agree). The SOHE scale was newly developed for this study; it contained nine items across three domains—environmental waste practices (e.g., appropriate waste segregation; avoiding unnecessary single-use items), resource stewardship and flow (e.g., preparing only necessary materials; sequencing tasks to reduce rework), and patient-value orientation (e.g., prioritising steps that improve patient outcomes). Higher scores indicated stronger sustainability outcomes. Face validity was established through expert review and pilot testing.

3.4 Procedures and ethics

The study received approval from the institutional research ethics committee. Students were informed of the study purpose, assured of confidentiality and anonymity, and provided digital consent before completing the online questionnaire. Surveys were administered during class and took approximately 15 minutes. Participation was voluntary, and students could withdraw at any time without penalty. Data were stored securely and analysed in aggregate form.

3.5 Data analysis

Data were analysed using SPSS v.26. First, reliability of each scale was examined using Cronbach's alpha. Descriptive statistics (means, standard deviations) were calculated. Independent samples t-tests compared SOHE scores by discipline (nursing vs. medical). Pearson correlations assessed bivariate associations among variables. Hierarchical multiple regression was performed to test hypotheses. In Model 1, demographic controls (gender, programme) were entered. Model 2 added Knowledge, Attitude, Behaviour, Culture and Leadership main effects. Model 3 added interaction terms Behaviour×Culture and Behaviour×Leadership (variables were mean-centred). Moderation was evaluated by examining the significance of interaction coefficients and incremental variance explained (ΔR^2). Simple slopes analyses plotted the Behaviour and SOHE relationship at ±1 standard deviation of the moderator. Statistical significance was set at $p < .05$.

4. Results

4.1 Reliability and descriptive statistics

All scales demonstrated good internal consistency: Knowledge ($\alpha = .84$), Attitude ($\alpha = .83$), Behaviour ($\alpha = .85$), Culture ($\alpha = .81$), Leadership ($\alpha = .82$) and SOHE ($\alpha = .88$). Mean scores were moderate to high (Knowledge = 3.7 ± 0.6; Attitude = 3.6 ± 0.7; Behaviour = 3.5 ± 0.7; Culture = 3.6 ± 0.8; Leadership = 3.5 ± 0.8; SOHE = 3.4 ± 0.8). Nursing students reported marginally higher SOHE scores (3.5 ± 0.7) compared with medical students (3.3 ± 0.8), $t(116) = 2.00$, $p = .047$, supporting H4. Table 2 shows results of reliability Cronbach's alpha.

Table 2: Reliability of Study Scales

Scale	No. of Items	Cronbach's α
Knowledge	15	0.84
Attitude	10	0.83
Behaviour	12	0.85
Culture	5	0.81
Leadership	5	0.82
SOHE	9	0.88

Correlations showed that Behaviour had the strongest relationship with SOHE ($r = .58$, $p < .001$), followed by Culture ($r = .45$) and Leadership ($r = .42$). Knowledge ($r = .28$) and Attitude ($r = .32$) were positively correlated with SOHE but at lower magnitudes. These patterns supported H1.

4.2 Regression and moderation analyses

In hierarchical regression, Model 1 (controls) explained 4% of the variance in SOHE. Adding Knowledge, Attitude, Behaviour, Culture and Leadership in Model 2 increased explained variance to 40% ($p < .001$). Behaviour emerged as the strongest predictor ($\beta = .46$, $p < .001$), Culture ($\beta = .22$, $p = .002$) and Leadership ($\beta = .18$, $p = .014$) also contributed significantly. Knowledge ($\beta = .11$, $p = .08$) and Attitude ($\beta = .13$, $p = .06$) had weaker, non-significant effects when controlling for other variables, consistent with H1.

Model 3 added the interaction terms. The Behaviour×Culture interaction was significant ($\beta = .15$, $p = .012$) and increased explained variance by 2.7% ($\Delta R^2 = .027$). Simple slopes showed that the Behaviour–SOHE relationship was stronger at high Culture (+1 SD: slope = 0.61, $p < .001$) than at low Culture (−1 SD: slope = 0.30, $p = .04$), supporting H2. Similarly, the Behaviour×Leadership interaction was significant ($\beta = .17$, $p = .009$, $\Delta R^2 = .031$). At high Leadership (+1 SD), the slope of Behaviour and SOHE was 0.63 ($p < .001$), whereas at low Leadership (−1 SD) it was 0.27 ($p = .045$). These results supported H3, indicating that supportive culture and leadership amplify the translation of Lean behaviours into sustainability outcomes. Table 3 shows hierarchical multiple regression results testing the main effects of Knowledge, Attitude, Behaviour, Culture, and Leadership (Model 2) and the moderating effects of Culture and Leadership on the Behaviour–SOHE relationship (Model 3). Figure 2 and 3 shows simple slopes analysis showing that the positive relationship between Behaviour and SOHE is stronger when Leadership support is high compared to when Leadership support is low.

Table 3: Hierarchical Regression Predicting SOHE

Predictors	β	p-value	ΔR²
Model 1: Controls (Gender, Discipline)	-	-	0.04
Knowledge	0.11	0.08	0.36
Attitude	0.13	0.06	
Behaviour	0.46	<.001	
Culture	0.22	0.002	
Leadership	0.18	0.014	
Behaviour × Culture	0.15	0.012	0.027
Behaviour × Leadership	0.17	0.009	0.031

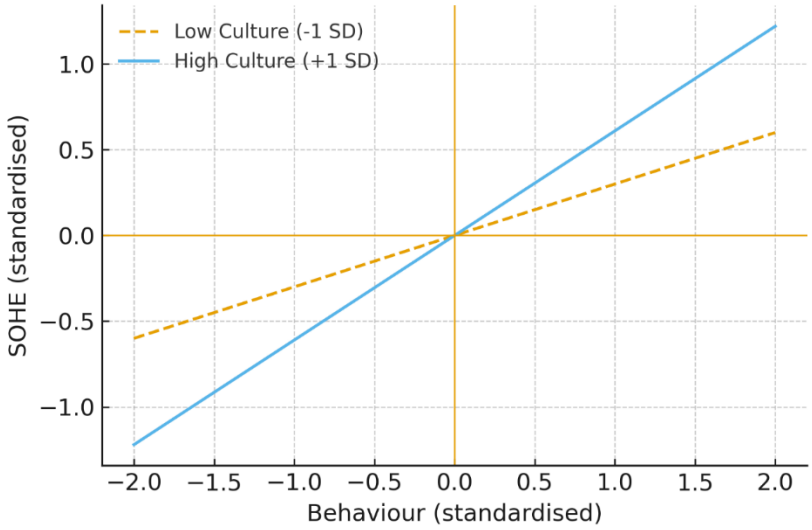

Figure 2: Moderation Effect of Culture on the Behaviour–SOHE Relationship

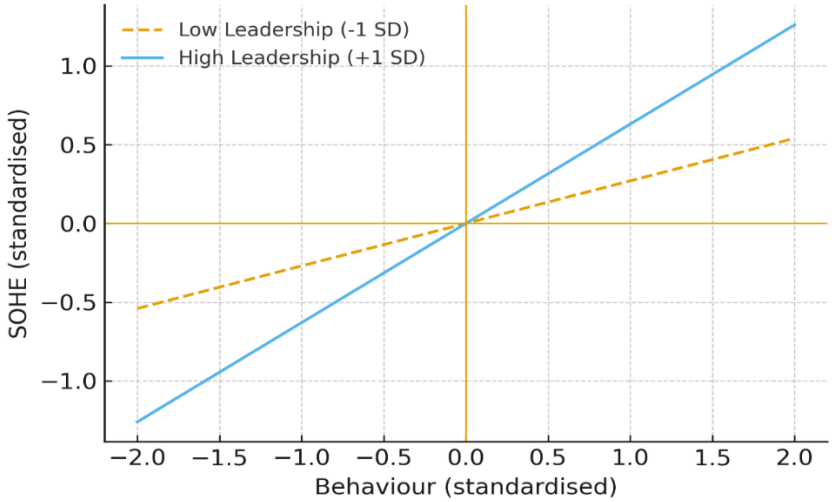

Figure 3: Moderation Effect of Leadership on the Behaviour–SOHE Relationship

5. Discussion

5.1 Interpretation of findings

This study provides empirical evidence that Lean training in health sciences education can foster sustainability outcomes when behaviours are enacted within supportive learning cultures and leadership contexts. Consistent with the KAB model, Behaviour was the strongest predictor of sustainability outcomes, whereas Knowledge and Attitude showed weaker associations once behavioural practice was considered. The importance of behaviour aligns with evidence from KAB research showing that knowledge and attitudes influence behaviour, which then predicts outcomes (Cheng et al., 2016; Mitchell et al., 2017). Our findings extend this model by linking Lean behaviours to environmental and patient-value outcomes, demonstrating the potential for Lean education to contribute to sustainability.

The significant moderation effects highlight that organisational context matters. A culture of continuous improvement and visible leadership support strengthened the relationship between behaviour and sustainability outcomes, confirming that context can amplify or dampen Lean's impact. This aligns with reviews emphasising that leadership commitment, stakeholder engagement and team culture are crucial for Lean maturity (Hilverda et al., 2023; Aij &

Rapsaniotis, 2017). Without supportive culture or leadership, Lean behaviours may not translate into sustainability, echoing concerns that Lean implementations often fail when cultural change is absent (Amini et al., 2023; de Vries et al., 2024). Nursing students' slightly higher SOHE scores may reflect more emphasis on patient-centred care and environmental stewardship in nursing curricula or a higher proportion of female students, who may display greater pro-environmental behaviours.

5.2 Theoretical contributions

By positioning Sustainability Outcomes as the dependent variable and testing Culture and Leadership as moderators, this study advances Lean education research beyond the traditional focus on KAB or process metrics. It demonstrates that Lean behaviours can extend beyond operational efficiency to environmental stewardship and patient-value orientation. The findings support calls to integrate sustainability into Lean training and show that the KAB framework remains useful when extended to sustainability outcomes. The moderation results underscore the importance of contextual factors in behaviour–outcome relationships, suggesting that models of Lean education should incorporate organisational culture and leadership to fully capture the pathway to sustainability.

5.3 Practical implications and curricular recommendations

Educators and administrators can draw several lessons. First, Lean training should explicitly link process improvement to environmental and patient-value outcomes. The new SOHE scale provides a tool for measuring such outcomes. Second, building a culture of continuous improvement—through teamwork, transparency, feedback loops and empowerment—is essential. Incorporating daily huddles, reflection sessions and peer feedback can reinforce Lean behaviours and sustainability. Third, leadership development should accompany Lean curricula. Faculty and clinical supervisors must role-model Lean behaviours, provide resources and recognise sustainability initiatives. Leadership training should emphasise coaching, empowerment and alignment with organisational strategy, as highlighted in the Lean leadership literature (Hilverda et al., 2023; Aij & Rapsaniotis, 2017; Demir et al., 2022). Fourth, sustainability should be integrated across health sciences curricula. Environmental sustainability, climate health and resource stewardship should be included in learning outcomes and assessed through simulations, quality improvement projects and community engagement. Simulation-based education programmes should estimate carbon footprints and adopt strategies to reduce waste and incorporate sustainable principles (Mitchell et al., 2025; Warner et al., 2023). Finally, partnerships with hospitals and health organisations can provide authentic settings for students to apply Lean and sustainability principles.

5.4 Limitations

Several limitations warrant consideration. First, the cross-sectional design precludes causal inference; future research could use longitudinal or experimental designs to examine changes over time. Second, the sample was limited to one institution in Oman, which may limit generalisability to other contexts. Third, the SOHE scale, though showing good reliability, was newly developed; further validation across diverse settings is needed. Fourth, data were self-reported and may be subject to social desirability bias. Fifth, the study did not examine mediation pathways (e.g., knowledge → attitude → behaviour) or other potential moderators such as prior sustainability education or personal values. Future studies could incorporate objective measures of sustainability practices (e.g., waste audits) and explore additional individual and contextual factors.

6. Conclusion

Embedding Lean healthcare training in health sciences education offers an opportunity to cultivate sustainability competencies. This study shows that Lean-related behaviours contribute to sustainability outcomes and that supportive culture and leadership amplify this effect. By integrating sustainability into Lean curricula, fostering continuous improvement culture and developing leadership that prioritises environmental stewardship, educators can prepare future clinicians to deliver high-value, sustainable care. The moderated KAB framework provides a useful lens for evaluating such efforts and underscores the importance of contextual factors in achieving sustainability in healthcare education.

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

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