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Digital Learning Readiness and Health Sustainability Awareness Among Nursing Students in Saudi Arabia and Egypt: A Multicenter Cross-Sectional Study

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Abstract

Digital learning readiness and health sustainability awareness are both relevant to preparing nurses for digitally mediated and environmentally sustainable care, yet their relationship has rarely been examined within one analytical model. In this multicenter cross-sectional study, 482 undergraduate nursing students from four universities in Saudi Arabia and Egypt completed the 15-item Digital Learning Readiness Scale (technical competency, self-directed learning, digital attitudes) and the 15-item Health Sustainability Awareness Scale (environmental health consciousness, resource stewardship, sustainable clinical practice). Overall readiness and awareness correlated positively ($r = 0.568$, $P < 0.001$). After adjustment for academic year, all three readiness dimensions were independently associated with sustainability awareness (final $R^2 = 0.383$; $\Delta R^2 = 0.241$), and self-directed learning showed the largest standardized coefficient among them ($\beta = 0.242$). Students with prior sustainability training reported higher awareness ($d = 1.54$), and the readiness associations persisted after adjustment for training. Resource stewardship was the lowest-rated sustainability domain. Both scales were internally consistent ($\alpha = 0.949$ and 0.952), although confirmatory factor analyses did not support the proposed three-factor structures. Because the data are cross-sectional and self-reported, these associations warrant testing in longitudinal and intervention studies with observed clinical sustainability behaviors.

Keywords: Digital learning readiness; Health sustainability awareness; Self-directed learning; Nursing education; Planetary health; Cross-sectional study

Introduction

Health care faces interrelated challenges of digital transformation and environmental sustainability. Preparing future nurses to evaluate emerging health information, use educational technologies, and recognize environmental determinants of health is relevant to safe and sustainable care. Educational approaches to planetary health emphasize that human wellbeing depends on ecological systems, while nursing scholarship highlights resource stewardship and the environmental impact of clinical work[1–3].

Digital readiness is not reducible to device ownership. Online-learning readiness includes technical self-efficacy, autonomous learning, and attitudes toward digital learning[4]. Connectivist perspectives further suggest that digitally capable students can locate and integrate information distributed across learning networks[5], and self-directed learning theory emphasizes identifying learning needs, sourcing evidence, and monitoring one's own progress[6]. These perspectives suggest a plausible association between digital learning readiness and sustainability awareness (Fig. 1), although they do not establish causality.

Within nursing education, sustainability-related knowledge and reported practices may diverge: understanding environmental health risks does not necessarily mean that students can enact resource-efficient behaviors under clinical supervision. Recent studies therefore distinguish environmental knowledge, sustainability attitudes, perceived competence, and clinical behavior. A Swedish cross-sectional study documented students' views on the relevance of climate change and sustainability to nursing education[7], and an integrative review synthesized challenges in integrating sustainability across nursing practice and education[8]. Prior information about climate change has been associated with students' climate–health awareness and behavior[9], and ecological-footprint awareness has been associated with renewable-energy perceptions ($r = 0.523$) among 400 nursing students[10]. These findings support distinguishing environmental-health awareness, resource stewardship, and self-reported sustainable clinical practice rather than assuming that one domain captures the others.

Other work highlights the complexity of psychological and pedagogical pathways. In 561 nursing students, eco-anxiety moderated associations between global-warming knowledge and sustainability attitudes[11], whereas sustainability consciousness and perceived planetary-health competency were not significantly associated in 300 Saudi nursing students, despite associations with previous sustainability education[12]. In Egypt, climate-related knowledge

and self-reported practice improved after a sustainability education program for 100 first-year nursing students, although the one-group pretest–posttest design cannot establish intervention effects[13]. Educational frameworks have also been proposed to translate planetary-health commitments into reflective teaching[14]. Together, these studies justify investigating correlates of sustainability awareness while avoiding claims that digital readiness has already been shown to produce sustainable clinical behavior.

Saudi Arabia and Egypt provide a pertinent context. Saudi nursing students have described general sustainability awareness alongside gaps in curricular integration and institutional support[15], and fear of COVID-19 was negatively associated with e-learning readiness ($r = -0.34$) among 110 Saudi male nursing students[16]. In Egypt, sustainability consciousness differed significantly across three public universities[17], and a study spanning both countries linked students' climate consciousness to environmentally oriented purchasing intentions[18]. However, these studies examined online-learning readiness, sustainability consciousness, climate-health knowledge, or self-reported practices separately. Multicenter evidence that simultaneously examines technical competency, self-directed learning, digital attitudes, and sustainability-awareness dimensions across both countries remains limited.

The conceptual framework integrates connectivism, self-directed learning theory, and planetary-health education. Connectivism positions learning within networks of digitally available expertise and resources[5]; self-directed learning emphasizes the learner's agency to identify information needs, select evidence, and monitor learning[6]; and the planetary-health perspective treats environmental change as integral to population health and clinical decision-making[14,19]. Together, these perspectives suggest that digital learning readiness may accompany, but not necessarily cause, greater awareness of environmental health and healthcare sustainability. We treat technical competency (TC), self-directed learning (SDL), and digital attitudes (DA) as distinct, correlated dimensions of digital learning readiness (DLR), and environmental health consciousness (EHC), resource stewardship (RS), and sustainable clinical practice (SCP) as the three self-reported domains of health sustainability awareness (HSA). Academic year and prior sustainability instruction are contextual factors rather than components of either scale (Fig. 1).

In addition to describing the levels and dimensional profiles of DLR and HSA, we tested four hypotheses. H1: overall DLR is positively associated with overall HSA. H2: students in later academic years report higher DLR and HSA than those in earlier years. H3: previous formal sustainability education is associated with higher DLR and HSA. H4: TC, SDL, and DA each

show a positive independent association with HSA after controlling for academic year, with SDL showing the largest standardized coefficient among the readiness dimensions. Because both constructs were measured contemporaneously by self-report, the model is associational; no mediation, temporality, or intervention effect was tested.

Methods

Study design and participants

Instrument preparation, expert panel review, and preliminary administrative procedures took place in September and October 2025. Following institutional bioethics approval in late October 2025 (Prince Sattam bin Abdulaziz University Protocol No. SCBB-592-2025, approved 23 October 2025), participant recruitment and electronic survey administration were conducted between 1 November 2025 and 20 January 2026 across four university nursing colleges: Prince Sattam bin Abdulaziz University (PSAU; lead and funding institution) and the University of Bisha in Saudi Arabia, and Beni-Suef University and Nahda University in Egypt. A stratified convenience sampling approach was used to recruit undergraduate nursing students through institutional communication channels and electronic survey invitations. Eligibility criteria were enrollment in a participating undergraduate nursing program, age 18 years or older, and provision of electronic informed consent; graduate students, students on academic leave or deferred enrollment, and internship-year students were not eligible.

Of 680 students invited, 512 initiated the survey and 30 submissions were excluded because of incomplete required responses, yielding 482 complete records: PSAU (Institution A, n = 132), Beni-Suef University (Institution B, n = 127), University of Bisha (Institution C, n = 122), and Nahda University (Institution D, n = 101). The Saudi sites contributed 254 students (52.7%) and the Egyptian sites 228 (47.3%); these descriptive country groupings were not used to estimate a country effect.

Measures

The Digital Learning Readiness Scale (DLRS; 15 items) comprises technical competency, self-directed learning, and digital attitudes, and the Health Sustainability Awareness Scale (HSAS; 15 items) comprises environmental health consciousness, resource stewardship, and sustainable clinical practice, each with five items. Items are rated on a five-point scale (1–5) with no reverse-keyed items. Each subscale score is the unweighted mean of its five items, and each total score is the mean of the corresponding 15 items; higher values indicate greater

self-reported readiness or awareness. Full item wording, the codebook, and scoring rules are provided in the Supplementary Information (Section 1).

Content validity and psychometric evaluation

Before the main survey, the preliminary 30-item questionnaire was pilot tested with 45 nursing students at two sites to assess clarity, face validity, and survey administration; these students were excluded from the main sample. All 482 participants in the main sample had complete and valid responses to the 30 items and demographic variables.

Content validity was assessed by eight experts (five nurse educators, two planetary-health specialists, and one biostatistician). The experts were informed about the study and provided informed consent before undertaking the instrument evaluation. They independently rated the relevance of each item on a four-point scale (1 = not relevant, 2 = somewhat relevant, 3 = quite relevant, 4 = highly relevant), with ratings of 3 or 4 indicating relevance. The overall scale-level content validity index based on average agreement (S-CVI/Ave) was 0.988 and the universal agreement index (S-CVI/UA) was 0.900 (DLRS, 0.983 and 0.867; HSAS, 0.992 and 0.933). Twenty-seven items had an item-level index (I-CVI) of 1.000 and three had 0.875; restricting the panel to the seven subject-matter experts yielded an overall S-CVI/Ave of 0.990. Because relevance ratings were overwhelmingly positive (237 of 240 judgments), chance-corrected agreement was low (Fleiss' $\kappa = -0.013$), reflecting the prevalence paradox[20]; tie-corrected Kendall's W was 0.232 and the two-way random-effects, absolute-agreement, average-measures intraclass correlation [ICC(2,8)] was 0.558. Content validity indices were therefore prioritized when evaluating item relevance[21] (Supplementary Information, Section 2 and 11).

Structural validity was evaluated in the current sample by confirmatory factor analysis (CFA) fitted separately for each scale (three correlated factors, five items per factor, no cross-loadings; normal-theory maximum likelihood on Pearson correlations). Fit was poor for both the DLRS ($\chi^2(87) = 1163.49$, CFI = 0.849, TLI = 0.817, RMSEA = 0.160, SRMR = 0.097) and the HSAS ($\chi^2(87) = 1137.46$, CFI = 0.870, TLI = 0.843, RMSEA = 0.158, SRMR = 0.154), although all standardized loadings were positive (0.588–0.985); the proposed factor structures are therefore not confirmed (Supplementary Information, Section 3). Kaiser–Meyer–Olkin values were 0.901 (DLRS) and 0.903 (HSAS), and Bartlett's tests were significant for both scales (DLRS, $\chi^2(105) = 7123.4$; HSAS, $\chi^2(105) = 8067.0$; both $P < 0.001$). Corrected item–total correlations ranged from 0.638 to 0.891.

Statistical analysis

Analyses were conducted in IBM SPSS Statistics version 29.0 (IBM Corp., Armonk, NY, USA) and replicated in Python (pandas, SciPy, and statsmodels). Descriptive statistics are reported as means (SD) and counts (percentages). Two-group comparisons used Welch's *t* tests with Cohen's *d*, and comparisons of three or more groups used one-way ANOVA with Tukey HSD contrasts for academic year. Associations between continuous scores were assessed with Pearson correlations. In the prespecified primary model, hierarchical ordinary least-squares regression entered academic year (modelled as a linear term) in Step 1 and TC, SDL, and DA in Step 2; final-model coefficients were evaluated with heteroskedasticity-consistent (HC3) standard errors and 95% confidence intervals, and the nested-model *F* change used the conventional OLS comparison. An exploratory sensitivity model additionally entered prior formal sustainability training (0 = no; 1 = yes) in Step 1. All tests were two-sided with $\alpha = 0.05$. These exploratory comparisons were not adjusted for multiple testing, and because students were clustered in only four institutions, cluster-robust standard errors could not be estimated reliably.

Ethics declarations

The study was conducted in accordance with the Declaration of Helsinki and its subsequent amendments[22]. The study protocol was approved by the Standing Committee of Bioethics Research at Prince Sattam bin Abdulaziz University, Saudi Arabia (Protocol No. SCBB-592-2025; Project No. PSAU/2025/01/38828; approval date: 23 October 2025), and the Nursing Research Ethics Board, Faculty of Nursing, Beni-Suef University, Egypt (Approval No. FNBSUREC/012025). Administrative permissions were obtained from Nahda University and the University of Bisha. All methods were carried out in accordance with relevant institutional guidelines and regulatory frameworks. Electronic informed consent was obtained from all participating undergraduate students before survey administration. Documented informed consent was also obtained from all eight expert validators before the content-validity assessment. All student responses and expert relevance ratings were analyzed as de-identified records.

Use of large language models

ChatGPT (OpenAI; GPT-6, accessed November 2026) and Claude (Anthropic; claude-opus-5-5) were used to assist with English-language refinement, clarity, organization, and formatting. These tools were not used to generate data or analyses and are not authors. The

authors reviewed and approved the final wording, figures, citations, and interpretations and take full responsibility for the content.

Results

Sample characteristics

The sample comprised 482 nursing students with a mean age of 19.86 years (SD 1.53; range 18–25); 326 (67.6%) were female and 156 (32.4%) male. All four academic years and institutions were represented, and 170 students (35.3%) reported prior formal sustainability training (Table 1).

Scale distributions and internal consistency

Mean DLR was 3.85 (SD 0.42) and mean HSA was 3.90 (SD 0.42) on the 1–5 scale. Among the readiness dimensions, SDL had the highest mean (4.03) and DA the lowest (3.69). Among the sustainability dimensions, EHC had the highest mean (4.07), followed by SCP (3.86) and RS (3.75). The within-person difference between EHC and SCP was 0.21 points (paired $t(481) = 12.72$, $P < 0.001$). Cronbach's α was 0.949 for the DLRS and 0.952 for the HSAS, and ranged from 0.911 to 0.926 across the six five-item domains (Table 2; Supplementary Fig. S1). These are self-reported scores, not observed clinical actions.

Group differences

DLR ($F(3, 478) = 11.31$, $P < 0.001$) and HSA ($F(3, 478) = 26.29$, $P < 0.001$) differed across academic years (Fig. 2; Supplementary Tables S1 and S2). Tukey HSD contrasts showed that Year 1 students reported lower DLR than Year 3 and Year 4 students, and Year 2 students lower DLR than Year 4 students (all $P \leq 0.003$); HSA differed between every pair of academic years except Years 1 and 2 ($P = 0.055$). Students with prior sustainability training reported higher HSA than those without training (4.235 [SD 0.314] versus 3.712 [SD 0.351]; Welch $t = 16.70$, $P < 0.001$; Cohen's $d = 1.54$) and slightly higher DLR (3.916 [SD 0.405] versus 3.812 [SD 0.418]; Welch $t = 2.65$, $P = 0.008$; $d = 0.25$). Neither composite differed by institution, primary learning device, or gender (all $P \geq 0.275$; Supplementary Table S1). These contrasts are observational and could reflect prior interests or selection into training.

Correlations

Total DLR correlated positively with total HSA ($r = 0.568$, $P < 0.001$; Fig. 3), and each readiness dimension correlated positively with total HSA (TC, $r = 0.469$; SDL, $r = 0.523$; DA, $r = 0.503$; all $P < 0.001$). All subscale and total-score correlations are reported in Table 3. These estimates describe co-variation and are not evidence that digital readiness preceded changes in HSA.

Hierarchical regression

Academic year alone explained 14.2% of the variance in HSA ($R^2 = 0.142$). Adding the three readiness dimensions increased R^2 by 0.241 to 0.383 (adjusted $R^2 = 0.377$; F change (3, 477) = 62.09, $P < 0.001$). In the final model, SDL ($B = 0.222$, 95% HC3 CI [0.126, 0.318], β = 0.242, $P < 0.001$), DA ($B = 0.186$, 95% CI [0.100, 0.272], β = 0.213, $P < 0.001$), and TC ($B = 0.106$, 95% CI [0.020, 0.191], β = 0.122, $P = 0.015$) were each positively associated with HSA, as was academic year (β = 0.244, $P < 0.001$; Table 4; Supplementary Fig. S2).

In an exploratory sensitivity model that entered academic year and prior sustainability training in Step 1 ($R^2 = 0.385$), adding the readiness dimensions increased R^2 to 0.609 (adjusted $R^2 = 0.604$; $\Delta R^2 = 0.224$; F change (3, 476) = 90.78, $P < 0.001$). Prior training was associated with higher HSA ($B = 0.448$, SE = 0.026, 95% CI [0.397, 0.500], β = 0.510, $P < 0.001$), and all three readiness dimensions remained positively associated with HSA: SDL ($B = 0.201$, SE = 0.041, β = 0.219, $P < 0.001$), DA ($B = 0.150$, SE = 0.038, β = 0.171, $P < 0.001$), and TC ($B = 0.146$, SE = 0.037, β = 0.169, $P < 0.001$). Academic year also remained associated with HSA ($B = 0.026$, SE = 0.012, β = 0.070, $P = 0.023$). The readiness associations therefore persisted after adjustment for training, although training had the largest standardized coefficient in this model (Fig. 4).

Discussion

In this four-site study of undergraduate nursing students in Saudi Arabia and Egypt, digital learning readiness was moderately and positively associated with health sustainability awareness, and all three readiness dimensions retained independent associations with awareness after adjustment for academic year and, in a sensitivity model, for prior sustainability training. Self-directed learning showed the largest standardized coefficient among the readiness dimensions, and resource stewardship was the lowest-rated sustainability domain.

Self-reported readiness and awareness were moderately high, but their profiles were not uniform. Self-directed learning was the highest-rated readiness dimension and digital attitudes the lowest, while environmental health consciousness was the highest-rated sustainability domain and resource stewardship the lowest (Table 2; Supplementary Fig. S1). These descriptive differences indicate uneven perceived preparedness rather than objectively demonstrated differences in clinical competence, consistent with work distinguishing knowledge, attitudes, and practical engagement in sustainable nursing education[1,7,8].

The positive association between overall readiness and awareness supported H1, and each readiness dimension correlated with total awareness (Table 3; Fig. 3). These results are compatible with connectivism and self-directed learning theory, under which access to networked resources and autonomous information seeking may accompany greater engagement with planetary-health topics[4–6]. These mechanisms were not measured directly, however, and a contemporaneous correlation cannot establish that digital readiness preceded or produced sustainability awareness.

Consistent with H2, students in later academic years reported higher readiness and awareness, with Year 1 to Year 4 means rising from 3.70 to 3.99 for DLR and from 3.69 to 4.11 for HSA (Fig. 2; Supplementary Table S2). These cross-sectional differences may reflect curricular exposure, clinical experience, cohort composition, or selection rather than individual developmental change. Institution, primary device, and gender were not associated with either composite (Supplementary Table S1), which weakens any broad expectation that these characteristics differentiate readiness or awareness in this population.

H3 was supported at the level of observed group differences: students reporting previous sustainability training had substantially higher awareness and slightly higher readiness (Supplementary Table S1). This pattern accords with reports linking educational exposure to climate-health awareness[9,13], although the constructs and designs differ. In particular, the Egyptian program evaluation examined pre–post change after instruction[13], whereas the present study measured neither baseline equivalence nor subsequent change and cannot attribute the training contrast to the instruction itself.

H4 was supported insofar as all three readiness dimensions had positive independent associations with awareness, which together explained an additional 24.1% of its variance beyond academic year (Table 4; Supplementary Fig. S2). Self-directed learning ranked first among the readiness dimensions, but its standardized coefficient was slightly smaller than that of academic year, and prior training had the largest coefficient in the sensitivity model (Fig.

4). Educational exposure is therefore an important correlate rather than a negligible covariate, and the unique contribution of self-directed learning should not be overstated.

The comparatively low resource-stewardship mean complicates any simple awareness-to-action interpretation. Although environmental health consciousness exceeded sustainable clinical practice by about 0.21 points, the lowest domain was resource stewardship rather than clinical practice. Because all domains were self-reported, a behavioral knowledge–practice gap cannot be confirmed without observed clinical activities, objective waste-segregation tasks, or longitudinal evidence. Related studies likewise show that environmental knowledge and positive attitudes need not align with perceived competence[12] and that eco-anxiety can modify associations involving sustainability attitudes[11], supporting a multidimensional, context-dependent account (Fig. 1) rather than a universal digital-to-sustainability pathway.

The findings favor examining blended digital and environmental-health learning as testable educational strategies rather than as interventions already validated by this correlational analysis. Self-directed digital inquiry, critical appraisal of climate-health evidence, simulation-based waste-management and resource-management exercises, and supervised sustainability audits could be evaluated in prospective designs with objective behavioral outcomes[14,23], giving particular attention to resource stewardship without compromising patient safety, infection prevention, or established clinical standards. Such studies should account for prior training, cohort differences, site context, and shared-method bias.

Several limitations warrant consideration. First, the cross-sectional design precludes causal inference. Second, self-reported measures introduce potential common-method and social-desirability biases, and no clinical behaviors were observed. Third, although both scales were internally consistent, the proposed three-factor structures did not achieve acceptable fit in confirmatory factor analyses of the current sample, so subscale scores should be interpreted as theoretically defined composites rather than confirmed latent factors. Fourth, climate-related emotions such as eco-anxiety, which may shape how students connect environmental knowledge with sustainability attitudes[11,24], were not measured. Fifth, the analyses involved multiple exploratory tests, students were clustered in only four institutions, and unmeasured covariates may have influenced the associations, limiting generalizability. Strengths include complete item-level data for all 30 items from four sites in two countries (Table 1), a prespecified primary model with heteroskedasticity-robust inference, and a sensitivity analysis adjusting for prior training.

In conclusion, digital learning readiness, particularly self-directed learning, was positively associated with health sustainability awareness among nursing students in Saudi Arabia and Egypt, and resource stewardship emerged as a potential priority for curricular attention. Longitudinal, multisite, and controlled intervention studies that pair digital-learning competencies with independently assessed sustainability knowledge, environmental decision-making, and observed clinical behaviors are needed to determine whether integrated digital and planetary-health education can translate this association into more environmentally responsible nursing practice.

Data availability

The de-identified item-level dataset analyzed in this study is included in the Supplementary Information (Section 12). Further information is available from the corresponding author on reasonable request.

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Author contributions

A.A.: conceptualization, methodology, investigation, writing—review and editing. M.N.A.A.-D.: formal analysis, investigation, data curation, writing—original draft. M.S.A.: resources, software, validation, writing—review and editing. M.M.M.E.: conceptualization, supervision, project administration, funding acquisition. R.N.A.A.: visualization, formal analysis, writing—original draft. M.M.: formal analysis, visualization, validation, writing—original draft. All authors reviewed and approved the final manuscript.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary Information accompanies this paper. Correspondence and requests for materials should be addressed to M.S.A.

Figure legends

Figure 1. Conceptual model of the hypothesized cross-sectional associations. The three dimensions of digital learning readiness are hypothesized to be positively associated with health sustainability awareness (solid arrows; H1 and H4). Academic year and prior sustainability education are contextual characteristics (dashed arrows; H2 and H3); only academic year was entered as a covariate in the primary hierarchical regression, whereas prior training was examined in unadjusted comparisons and an exploratory sensitivity regression. Arrows are analytical, not causal.

Figure 2. Digital learning readiness and health sustainability awareness by academic year. Points show group means (circles, digital learning readiness; squares, health sustainability awareness) and error bars show 95% confidence intervals for the means. Year 1, $n = 122$; Year 2, $n = 113$; Year 3, $n = 123$; Year 4, $n = 124$.

Figure 3. Cross-sectional association between digital learning readiness and health sustainability awareness. Each point represents one student ($N = 482$), with slight jitter to reduce overplotting; the line is the unadjusted least-squares fit ($r = 0.568$, $P < 0.001$). The association does not establish causation.

Figure 4. Standardized regression coefficients for health sustainability awareness. Points show standardized coefficients (β) and horizontal bars show 95% HC3 confidence intervals from the primary model (circles; academic year and the three readiness dimensions) and the exploratory sensitivity model additionally adjusting for prior sustainability training (squares). $N = 482$.

Tables

Table 1. Participant characteristics ($N = 482$).

Characteristic	Category	*n*	%
Gender	Female	326	67.6
	Male	156	32.4
Academic year	1	122	25.3
	2	113	23.4
	3	123	25.5
	4	124	25.7
Institution	A (Prince Sattam bin Abdulaziz University)	132	27.4
	B (Beni-Suef University)	127	26.3
	C (University of Bisha)	122	25.3
	D (Nahda University)	101	21.0
Primary device	Laptop/computer	277	57.5
	Smartphone	73	15.1
	Tablet/iPad	132	27.4
Prior sustainability training	No	312	64.7
	Yes	170	35.3
Country	Saudi Arabia (A + C)	254	52.7
	Egypt (B + D)	228	47.3

Country groupings are descriptive; Institutions A and C are in Saudi Arabia and Institutions B and D in Egypt.

Table 2. Descriptive statistics and internal consistency of the digital learning readiness and health sustainability awareness scales ($N = 482$).

Scale	Items	Mean	SD	Range	α
Technical competency	5	3.820	0.486	2.00–5.00	0.921
Self-directed learning	5	4.034	0.458	2.60–4.80	0.923
Digital attitudes	5	3.692	0.481	2.00–5.00	0.921
DLRS total	15	3.849	0.416	2.33–4.87	0.949
Environmental health consciousness	5	4.075	0.475	2.80–5.00	0.926
Resource stewardship	5	3.752	0.463	2.60–5.00	0.911
Sustainable clinical practice	5	3.863	0.476	2.40–4.80	0.916
HSAS total	15	3.897	0.421	2.67–4.87	0.952

Scores are item means on a 1–5 scale. SD, standard deviation; range, observed minimum–maximum; α, Cronbach's alpha; DLRS, Digital Learning Readiness Scale; HSAS, Health Sustainability Awareness Scale.

Table 3. Pearson correlations among digital learning readiness and health sustainability awareness scores ($N = 482$).

Measure	TC	SDL	DA	DLR	EHC	RS	SCP	HSA
TC	1.000							
SDL	0.657	1.000						
DA	0.635	0.660	1.000					
DLR	0.875	0.877	0.875	1.000				
EHC	0.423	0.484	0.472	0.524	1.000			
RS	0.373	0.453	0.428	0.477	0.672	1.000		
SCP	0.457	0.461	0.446	0.519	0.704	0.705	1.000	
HSA	0.469	0.523	0.503	0.568	0.889	0.886	0.901	1.000

All off-diagonal correlations are significant at $P < 0.001$ (two-sided). TC, technical competency; SDL, self-directed learning; DA, digital attitudes; DLR, digital learning readiness total; EHC, environmental health consciousness; RS, resource stewardship; SCP, sustainable clinical practice; HSA, health sustainability awareness total.

Table 4. Hierarchical regression predicting health sustainability awareness ($N = 482$).

Predictor	*B*	SE	*P*	β	R^2 (Step 1) / 95% CI (Step 2)
Step 1: Academic year	0.140	0.016	<0.001	—	0.142
Step 2: Academic year	0.091	0.014	<0.001	0.244	[0.064, 0.118]
Step 2: Self-directed learning	0.222	0.049	<0.001	0.242	[0.126, 0.318]
Step 2: Digital attitudes	0.186	0.044	<0.001	0.213	[0.100, 0.272]
Step 2: Technical competency	0.106	0.044	0.015	0.122	[0.020, 0.191]

Step 1 uses conventional OLS standard errors; Step 2 coefficients use HC3 heteroskedasticity-robust standard errors and 95% confidence intervals. Final model $R^2 = 0.383$, adjusted $R^2 = 0.377$, $\Delta R^2 = 0.241$, F change (3, 477) = 62.09, $P < 0.001$. *B*, unstandardized coefficient; SE, standard error; β, standardized coefficient; CI, confidence interval.

Figures

Figure 1

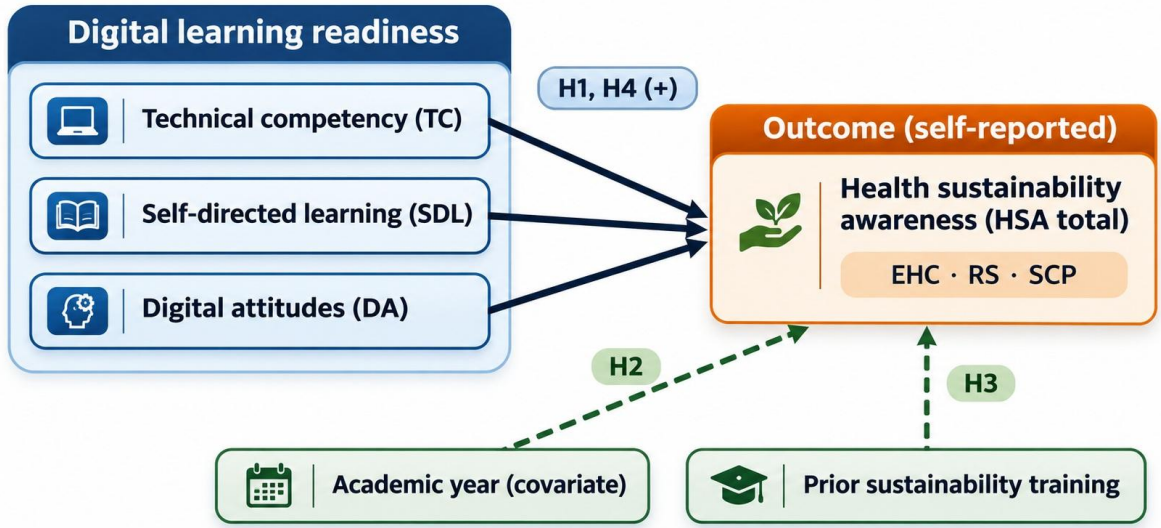


Figure 2

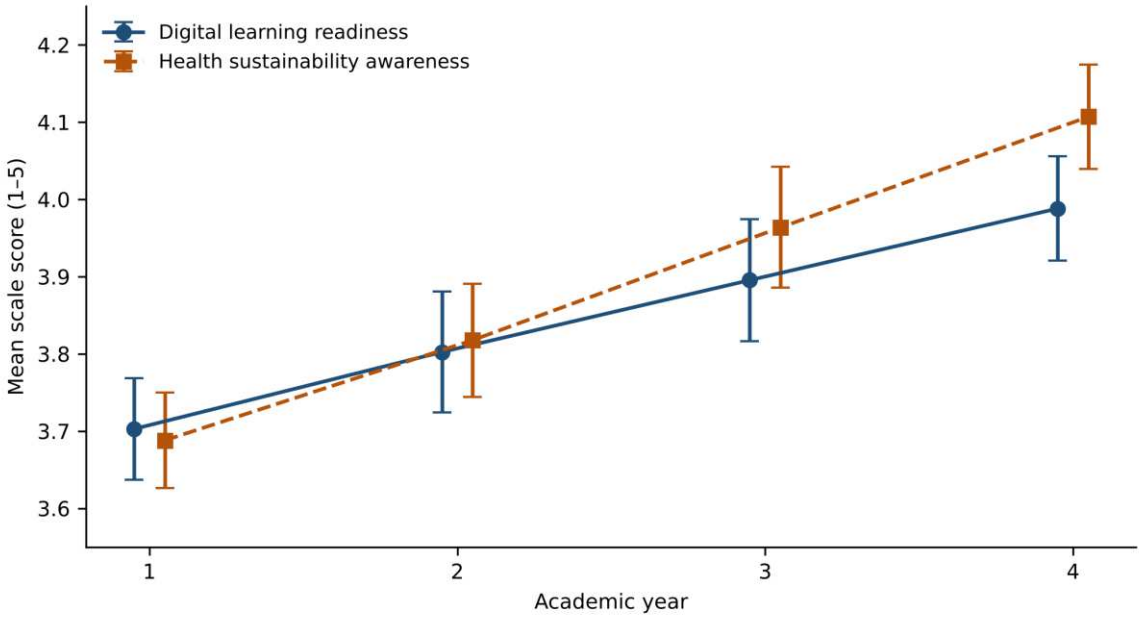


Figure 3

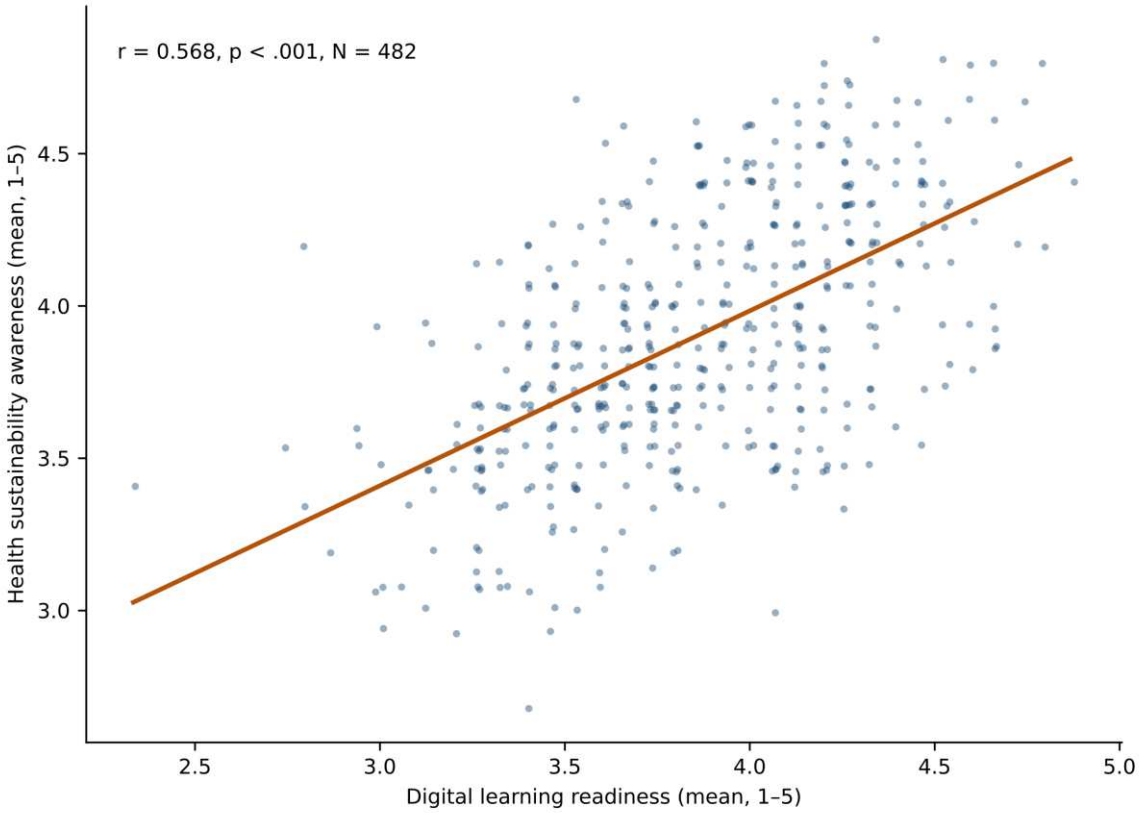
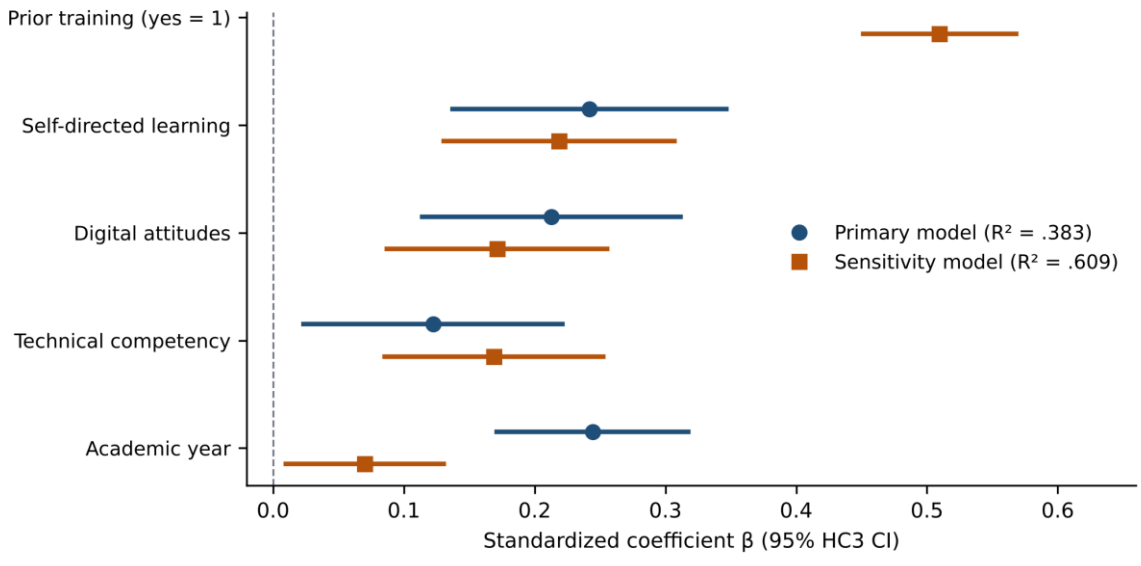


Figure 4



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