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Collaboration, Creativity and Compassion in a Digital Society

Which design features of a digital simulation predict sustainability competency gains? Evidence from a large first-year business cohort

Mary Jesselyn Co, Bruce Mitchell, Lisa Powell

Monash University

Digital simulations offer experiential learning environments where students make consequential decisions under constraints. Yet little empirical evidence identifies which specific design features of these environments are associated with learning outcomes. This study examines a hotel carbon reduction simulation embedded in a first-year management unit (n=1,079 students, 190 teams) and investigates which of the 10 simulation design features predict self-reported gains in sustainability competencies. Students completed pre- and post-simulation surveys measuring 25 competency items aligned to an eight-domain sustainability competency framework (n=212 matched pairs), alongside a 10-item simulation evaluation scale (α=0.92). All self-reported 25 competency items improved significantly (composite d=0.62, p<.001). Overall simulation design quality strongly predicted competency gains (B=1.03, p<.001, R^2=.49), with active learning engagement (r=.40) and feedback quality (r=.39) showing the strongest individual associations. Full-cohort performance data showed 97.4% of teams maintained profitability while reducing emissions, with 45.8% clustering in a "productive struggle zone" just below the target. These findings suggest that simulation designers should prioritise active engagement mechanisms and timely feedback over surface-level realism. Implications for the design of technology-enhanced experiential learning environments are discussed.

Keywords: simulation-based learning, sustainability competencies, learning design, experiential learning, technology-enhanced learning

Introduction

Sustainability education in higher education faces a persistent challenge: students can learn about sustainability concepts without developing the competencies to act on them (Redman & Wiek, 2021). Digital simulations offer a promising response by placing students in consequential decision-making environments where trade-offs are experienced rather than merely described (Hallinger & Wang, 2020). However, most evaluation studies treat simulations as black-box interventions, measuring whether they work without examining which design features are associated with the learning outcomes observed (Chernikova et al., 2020; Cook et al., 2013). Duchatelet and Donche (2022) argue that the assessment perspective mainly focuses on the product of simulation-based learning, that is, the learning outcomes.

This gap matters for learning designers. A simulation's effectiveness depends on specific design choices: how feedback is structured, whether decisions feel consequential, how collaboration is scaffolded, and whether cognitive challenge is calibrated appropriately. Without empirical evidence linking these features to outcomes, designers rely on intuition rather than evidence when building or commissioning digital learning tools.

This study addresses this gap by examining a hotel carbon reduction simulation embedded in a large first-year management unit. Rather than asking only whether the simulation developed sustainability competencies, we ask which features of the digital environment predicted competency gains. Our research questions are: (a) Which simulation design features predict self-reported sustainability competency gains? (b) Does the simulation improve self-reported sustainability competencies across all eight domains? (c) Does the simulation influence students' behavioural intentions regarding sustainability?

The simulation environment

The Net Zero simulation (Rogmans, 2022) is a web-based digital learning environment published by Harvard Business School Publishing. Students manage a 500-room hotel over seven simulated years, selecting from 29 available sustainability initiatives across three decision categories: Energy (e.g., solar rooftop installation, LED

lighting, HVAC upgrades), Purchasing (e.g., water-efficient appliances, organic food sourcing, low-carbon furniture), and Management (e.g., staff training expenditure, guest awareness communication, recruiting a Sustainability Officer). A maximum of three initiatives may be selected per round, forcing prioritisation under constraint. This constraint manages cognitive load; choices refresh with new options after each round, requiring students to evaluate a changing decision landscape rather than optimise from a static menu.

The simulation's digital architecture includes several key design features relevant to this study. A real-time dashboard displays electricity consumption, CO_2e emissions by source and scope (Scope 1 direct options, Scope 2 energy use, Scope 3 value-chain emissions including suppliers), and an income statement showing revenue, operating expenditure, and net profit after each round, creating an immediate feedback loop between decisions and consequences. Written feedback explains the impact of each selected initiative. A carbon budget tracker shows cumulative emissions against a seven-year budget, requiring students to consider timing and trajectory rather than year-by-year targets alone. Progressive difficulty is embedded: high-impact Energy initiatives (solar, LED, HVAC) are typically exhausted by round three or four, after which further reductions require increasingly sophisticated combinations of Purchasing and Management decisions. Recruiting a Sustainability Officer unlocks additional initiatives and increases the effectiveness of training and communication spending, introducing a strategic timing dimension that rewards sequencing decisions rather than treating each round independently.

The simulation was embedded in MGC1010 (Introduction to Management) at a large Australian university with 1,079 enrolled students across 18 tutorial groups. The simulation was directly connected to unit learning outcomes on stakeholder management and responsible business practice, and completion contributed to an assessed reflection task. While Net Zero is designed as a single-player simulation, we structured it as a team-based activity with mandatory consensus: all five to six team members discussed options and agreed on a collective strategy before one designated member entered the team's decisions. This structure aimed to create social interdependence, though we acknowledge that the dynamics of consensus, including potential dominance by individuals with prior expertise or persuasive tendencies, may have influenced the collaborative process in ways not captured by this study. Sessions ran for two hours with scaffolded timing (15 minutes for Round 1 orientation, then 10-minute rounds). The first round functioned primarily as orientation, during which students familiarised themselves with the interface and decision categories. A structured debrief with comparative team analysis followed in which the facilitator displayed team outcomes side by side, prompting discussion of differing strategies and results. Students then completed a 500-word individual reflection mapping their experience to Redman and Wiek's (2021) sustainability competency framework.

Method

Ethics approval was granted by the University's Human Research Ethics Committee (Project ID: 47334). Survey responses were collected anonymously through voluntary participation with informed consent obtained at commencement. The reflection task was a standard assessed component; only de-identified reflections were used for research purposes.

A pre- and post-simulation survey design was used. The instrument comprised 25 sustainability competency items measured on a four-point agreement scale, aligned to eight domains: systems thinking, futures thinking, values thinking, strategies thinking, implementation, interpersonal, intrapersonal, and integration (Ploum et al., 2018; Redman & Wiek, 2021; Savage et al., 2015). The items were adapted from these validated frameworks for the simulated context; several domains, particularly intrapersonal competence, are relatively recent constructs not yet widely tested in implementation settings. A 10-item simulation evaluation scale assessed design features including realistic scenarios, active learning engagement, cognitive challenge, feedback quality, personal investment, multiple perspectives, logical reasoning, collaboration, theory-practice connection, and real-world complexity (α=0.92). Four behavioural intention items captured post-simulation attitudes. Survey completion was voluntary.

Of the 1,079 enrolled students, 1,063 completed the simulation in 190 teams, over 940 completed the pre-survey, and 212 completed both surveys, forming the matched sample for paired analysis. The attrition from 940+ to 212 matched pairs likely reflects voluntary completion and may over-represent more engaged students. No imputation was applied; only complete matched pairs were included. Paired t-tests with Cohen's

d were used for competency gains; no adjustment for multiple comparisons was applied across the 25 items, which should be considered when interpreting item-level results. Multiple regression examined which simulation features predicted gains, controlling for demographic variables.

Results

Simulation design features predicting competency gains

Given the high internal consistency of the 10-item simulation design-feature scale (α=0.92), the 10 features were treated as a single composite predictor in the primary regression model, with competency gain (the difference between composite post- and pre-simulation scores) as the dependent variable and demographic controls (gender, domestic/international status) as covariates. Overall simulation design quality strongly predicted competency gains (B=1.03, p<.001, R^2=.49), confirming that students who rated the design highly also reported greater learning. Bivariate correlations were then examined to characterise which aspects of the design were most strongly associated with gains. Active learning engagement (r=.40) and feedback quality (r=.39) showed the strongest associations, followed by theory-practice connection (r=.37), logical reasoning (r=.35), and realistic scenarios (r=.36). Collaboration (r=.23) and cognitive challenge (r=.27) showed the weakest associations, suggesting that while students found the simulation collaborative and challenging, these features were less strongly linked to reported competency growth than the quality of feedback and the sense of active engagement.

Sustainability competency gains

All 25 competency items improved significantly (p<.001, except one item at p=.012) (see Figure 1). The composite score rose from 80.32 to 87.39 (d=0.62, p<.001), representing an 8.8% improvement. These are self-reported perceived competency gains; the single-group design means gains cannot be definitively attributed to the simulation alone. Domain-level effect sizes ranged from d=0.34 (interpersonal) to d=0.55 (systems thinking). The strongest gains appeared in systems thinking (d=0.55) and implementation (d=0.48), competencies directly exercised by the simulation's progressive difficulty and feedback mechanisms. Futures thinking (d=0.45) and strategies thinking (d=0.45) showed matching gains, consistent with the simulation's seven-year trajectory requiring students to anticipate consequences and sequence decisions strategically.

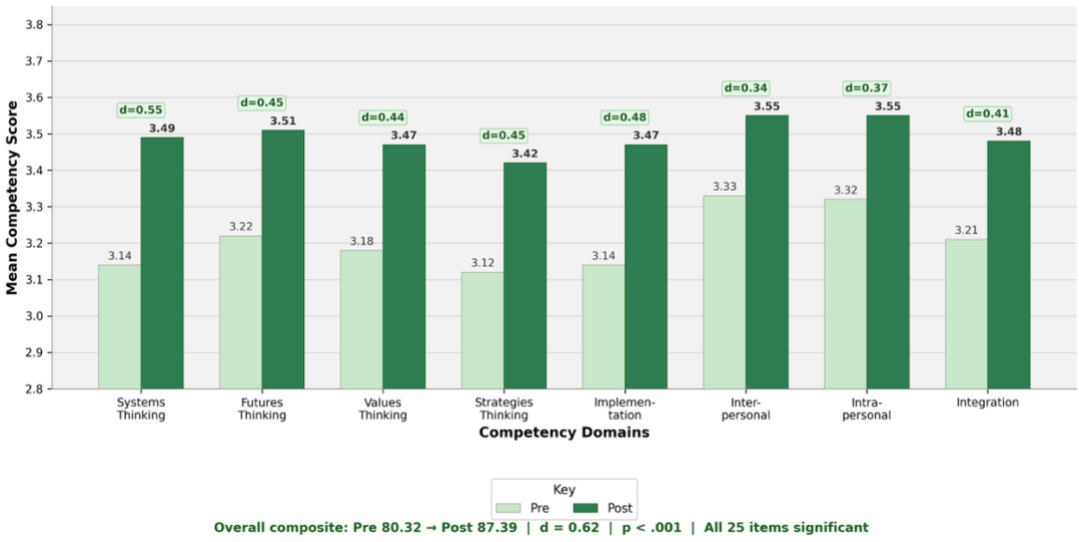


Figure 1. Pre- and post-simulation sustainability competency gains by domain

The close alignment across systems, futures, and strategies thinking may reflect the interdependence of these competencies within the simulation context, where they are exercised simultaneously rather than in isolation. The weakest gains were in interpersonal (d=0.34) and intrapersonal (d=0.37) competencies, consistent with these being skill-intensive domains requiring sustained practice beyond a single intervention. The intrapersonal gains are noteworthy given that this competency is sometimes characterised as dispositional;

the simulation and debrief may have created conditions for students to recognise these capacities, though this warrants further investigation. An unexpected finding was cohort convergence: despite different baseline scores across tutorial groups, post-intervention means converged to near-identical levels (M=87.4 and M=88.0), suggesting the simulation may tend toward a common performance range regardless of starting point.

Simulation performance and the productive struggle zone

Full-cohort data (190 teams) revealed a mean emissions reduction of 47.7% (SD=3.1%) against the 50% target, with 22.6% of teams meeting the target. Critically, 97.4% maintained profitability (mean profit growth 8.3%). The distribution of outcomes was left-skewed, with 87 teams (45.8%) clustering between 47% and 50% – what we term the productive struggle zone. We present this as a descriptive pattern rather than an established mechanism. Rogmans (2022) notes that 47-49% reductions represent strong performance, and productive learning may occur across the full performance range – not only within this cluster. Whether this pattern reflects a pedagogically distinct zone of desirable difficulty (Bjork & Bjork, 2011) or is an artefact of the simulation's difficulty curve requires further investigation with performance-linked learning outcome data. These teams had exhausted high-impact initiatives and were navigating the complex sequencing and trade-off decisions that characterise genuine sustainability problem-solving.

Behavioural intentions

Eighty percent of students reported increased interest in sustainability. Sixty-two percent indicated they would change their behaviour as hotel guests, and 52% expressed willingness to pay more for sustainable accommodation. Among those unwilling to pay more, the primary barrier was financial constraints as students (60%) not rejection of sustainability values, suggesting the simulation developed awareness even where current circumstances limited capacity to act. Students who rated the simulation's design features more highly were significantly more likely to report behavioural change intentions, with active engagement (β=1.80, p<.001) and cognitive challenge (β=1.56, p<.001) as the strongest predictors.

Discussion and conclusions

This study moves beyond asking whether simulations work to identifying what about them is associated with reported learning gains. While previous reviews have documented the growth of simulation-based learning across disciplines (Hallinger & Wang, 2020), most evaluation studies treat simulations as undifferentiated interventions. Our design feature analysis provides empirically grounded guidance for learning designers by linking specific digital environment characteristics to self-reported competency outcomes. Three findings have direct implications for the design of technology-enhanced experiential learning.

First, active learning engagement and feedback quality showed the strongest associations with competency gains (r=.40 and r=.39 respectively), outperforming surface-level features like visual realism. This distinction between a simulation's visual design and its underlying engagement mechanics is important: a simulation could be visually unattractive yet effective if its decision structure and feedback loops demand genuine cognitive engagement. What mattered was not whether the hotel looked real, but whether students felt their decisions carried consequences. The team-based consensus structure aimed to create interdependence that passive group structures cannot replicate, though the extent to which this was experienced, versus influenced by dominance or social loafing, remains an open question. The real-time dashboard reinforced consequentiality by making the feedback loop between decision and outcome visible and immediate.

Several confounding factors should be acknowledged. The facilitator's approach to debriefing and scaffolding team discussions likely contributed to the learning experience alongside the simulation itself. The connection to course learning outcomes and an assessed reflection task may have introduced transactional motivators influencing engagement independently of the simulation's design features. This study does not isolate the simulation from these contextual factors.

Second, the productive struggle zone is a promising descriptive finding warranting further investigation as a design principle for digital simulations. With 45.8% of teams clustering between 47% and 50% emissions

reduction, the simulation created conditions where cognitively demanding decisions occurred at the point of highest engagement. This aligns with desirable difficulty theory (Bjork & Bjork, 2011), though without performance-linked outcome data, we cannot confirm that learning was greater for teams in this cluster than at other performance levels. The near-universal profitability (97.4%) alongside substantial emissions reductions suggests students learned to hold competing objectives in tension.

Third, the divergence between quantitative gains and student reflection choices offers a methodological insight. Students wrote most about interpersonal competence (20.9%), the domain with the weakest effect sizes (d=0.22–0.43), and least about systems thinking (16.9%), the domain with the strongest gains (d=0.49–0.59). The structure of the debrief and reflection rubric may have influenced which competencies students emphasised; interpersonal challenges may also reflect the social dynamics of team-based consensus rather than the simulation mechanics per se. This pattern suggests that self-reported learning may better capture experienced difficulty than perceived skill development. For designers this finding underscores the risk of relying on any single measure of learning effectiveness.

Several limitations should be noted. The voluntary survey design means the matched sample of 212 may over-represent more engaged students. The self-report competency measure captures perceived rather than objectively demonstrated skill development, and the single-group design cannot definitively attribute gains to the simulation. The simulation evaluation items were administered post-intervention only. Facilitator effects were not controlled; while consistency across 18 tutorial groups is encouraging, facilitator approach may have contributed to outcomes. The mandatory consensus structure introduced team dynamics, including potential dominance, social loafing, or role allocation, that were not measured and may confound the reported gains.

Future research should examine whether these design feature associations replicate across different simulation contexts, discipline areas, and student populations. Controlled studies comparing simulations with and without specific design features would strengthen causal claims. Longitudinal studies tracking competency persistence would address durability. Comparing individual and team-based play modes, now both available in the simulation platform (Rogmans, 2022, updated 2024), could help isolate the contribution of social interaction to competency development.

Despite these limitations, this study contributes empirical evidence on a question that matters to learning designers: not just whether digital simulations work, but which aspects of their design are associated with reported learning. The findings suggest that engagement structure, calibrated difficulty, and consequential feedback are promising active ingredients in simulation-based sustainability education.

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