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Envisioning Scenarios. A Simulator to Develop Systemic Thinking in Higher Education Students

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Abstract– Systemic Thinking is a core competence for higher education students, as it enables them to address present and future development challenges. It involves cognitive abilities related to integrative thinking and the recognition of interconnections among elements of reality. This competence also influences the capacity to envision alternative scenarios and to anticipate the consequences of prioritizing certain actions over others in specific contexts. The Systemic Thinking Simulator was designed and developed to support undergraduate students in decision-making processes, helping them understand the impact of their choices within a fictional scenario. The design process was initially supported by ChatGPT (Open AI) and was subsequently developed as an open educational resource. The Systemic Thinking Simulator was tested with a group of undergraduate students to gather their perceptions regarding its suitability as a learning tool. The findings of this study highlight the benefits of using GenAI tools in the design of educational resources, particularly in terms of reduced development time and cost, as well as their potential to expand the diversity of learning media for fostering relevant competencies in higher education.

Keywords—Systemic Thinking, Digital Simulator, Development Scenarios, Higher Education, Educational Innovation.

I. INTRODUCTION

Systemic Thinking (ST) is a key competence to addressed contemporary challenges in the frame of Education 5.0, as it allows the integration of dimensions of reality. As a competence, it involves analyzing complex systems across different domains to understand the impact that cross interactions have in each context [1]. The Systemic Thinking Simulator (ST-Sim) was created to be integrated in the ComplexHub platform (https://complexhub.net/), an educational digital hub developed to host Open Education Resources (OER) on complex and computational thinking for Spanish speakers [2]. The ST-Sim objective is to foster the development of systemic thinking competence among higher education (HE) students by presenting scenarios that emerge as consequences of decision-making processes. Rather than guiding learners toward a single correct solution, the simulator's interactions are designed to support an understanding of complex systems, encouraging reflection on competing priorities, and enabling informed decision-making within real-world sustainability contexts. This resource addresses a gap in the solutions for OER in Spanish and contextualized in developing environments.

As systemic thinking becomes a relevant competence related to sustainable development [3], diverse approaches to promoting it among students are emerging. In this sense, focusing on the relation it keeps with the Sustainable Development Goals (SDG) requires visualizing complex scenarios with multiple constraints [4]. This visualization underpins the interconnection between elements of reality that have an impact on reaching the SDG. However, HiEd institutions face the growing need to support their communities in developing the skills and competencies required to informed decision-making processes aligned with sustainable development [5].

In recent years, simulators have become popular to facilitate learning experiences based on environments that bring training situations relatively close to reality [6]. Across disciplinary fields, different technologies are gaining attention according to specific educational needs. For instance, in medical education, Virtual Reality (VR) has proven effective in providing simulated, immersive experiences that enable students to engage with human physiology. [7]. Other fields, like architectural design, might prefer other solutions that allow high complexity in the integration of structural, aesthetical, and other systems in a large-scale project [8]. The growing attention given to simulators as effective educational experiences stems from their ability to encapsulate context-relevant situations within accessible digital artifacts, enabling self-paced learning while providing structured opportunities for reflection.

From this perspective, the ST-Sim was designed to offer an educational experience that foster the development of ST competence by allowing students to follow a decision-making process based on visualizing scenarios caused by the impact of allocating a budget towards developing a fictional city. The simulator combines the multidimensional approach of a range of indicators of sustainable development with logic and realistic economic constraints. It is conceived under the premise that systemic thinking is not acquired solely through conceptual exposure, but through active interaction with dynamic systems that force students to anticipate effects, recognize trade-offs, and reflect on the short- and medium-term impacts of their decisions. In this sense, the simulator fosters processes of analysis, comparison, and reflection typical of real decision-making contexts.

The main contribution of this study lies in the GenAI-assisted design of a simulator contextualized for Spanish speakers in a setting that naturally integrates issues of sustainability, urban growth, and environmental vulnerability to address present and future challenges. A fictional developing coastal city allows complex systems to be represented in a way that is accessible to undergraduate students, maintaining a balance between realism and cognitive manageability. Unlike generic or highly technical simulators, the ST-Sim prioritizes conceptual clarity, visualization of the state of the system, and understanding of interdependencies over algorithmic optimization. The study also contributes to the field of educational innovation by articulating principles of systems thinking with a design-based research approach, documenting an iterative development process that integrates pedagogical decisions, systems modeling, and visual feedback. In this way, the ST-Sim is presented not only as a learning tool, but also as a replicable model for the design of educational simulators aimed at training in complexity and sustainability in higher education.

II. Theoretical Framework

A. Systemic Thinking for Sustainable Development

Systemic Thinking (ST) has been defined as a practice-grounded concept closely linked to innovation [9], as it enables the integration of diverse elements of reality across sectors and their interactions during the idea-generation process. It has also been framed as a competence connected to systemic ethics [10], with the potential to raise awareness by fostering an understanding of the roles that both living and non-living components of the planet play within interconnected systems. This perspective entails the intentional consideration of the systemic effects of policies and projects, aiming to transform knowledge into practice by aligning community goals with stakeholders' interests and supporting informed decision-making in pursuit of SDG [11].

In the context of Industry and Education 5.0, the need for effective educational experiences addressing sustainable development, with novel pedagogical methods, has gained relevance and attention in recent years [12]. From this perspective, new approaches for ST development among HiEd students is critical for them to face contemporary global challenges, such as climate change, social inequality, and digital divide [10,13]. Educational experiences aimed at fostering the development of systemic thinking should integrate essential components that reflect the complexity of reality and its interconnections.

One relevant aspect that has gained traction is creating significant learning experiences combining the human dimension (affective domain) to the foundational disciplinary knowledge (cognitive domain) [14]. As these dimensions intertwin in many nodes, it is most important to set boundaries in the learning experiences to reach, so creating concrete scenarios with logical rules and real-life constraints increases the certainty of tasks to complete [15].

As systemic thinking contrasts with reductionist approaches [16], students may find it challenging to identify and navigate the multiple dimensions and levels of impact involved in complex systems. Therefore, offering visualization tools, opportunities for iterative exploration [17], structured and timely feedback [18], and space for reflecting in the impact of decisions, are key features for the ST-Sim. In this sense, some studies have underpinned the demands that the academic community is focusing on regarding the curricula updating.

Our proposal for building the ST-Sim includes key features to allow students relating the educational experience with real-life challenges with a logical level of constraints and the possibility to iterate the interactions in the search of a specific objective. Table I summarizes the components included as features and their impact on students' learning.

TABLE I
Components included on the ST-Sim

Component	Feature	Learning effect
Authentic context-rich problems.	A fictional coastal city from a developing country.	Significant learning [14].
Logical constraints according to the context.	A limited budget set in percentages.	Framing the problem [15].
A clear objective and problem framing.	A set of indicators across social, environmental, economic, and technological dimensions.	Analyzing complex systems across different domains [1].
Emphasis in interconnections and effects of decisions.	A visualization panel with images of modifying scenarios.	Scenarios visualization for strategic decision-making [16].
Opportunities for iterative decision-making.	Unlimited opportunities to edit the budget allocation.	Gamified iterations [17].
Structured feedback.	Messages to highlight the effect of decisions made.	Adaptive feedback supporting reflections [18].
Highlight the impact of decisions.	A space to write personal reflections.	Significant learning [14].
Possibility of analyzing the results and reflections.	A download button to save in PDF format for the final iteration.	Research and evaluation.

B. Simulators for Learning

Educational simulators and simulation games are widely used to support learning in complex domains because they allow students to test decisions, observe system responses, and iterate in a safe, time-compressed environment. In this context, a simulator can be defined as an interactive digital environment for key features modeling of a real or plausible system, enabling users to manipulate inputs (i.e., make decisions) and observe resulting changes in system states and outcomes. In higher education, meta-analytic evidence indicates that simulation-based learning can yield meaningful gains for complex skills, with outcomes shaped by design features and the supports embedded in the learning environment [19]. Beyond increasing engagement, simulation-based learning can improve knowledge and skill outcomes relative to traditional approaches, particularly when learners can iterate, receive feedback, and reflect on outcomes [20].

At the same time, simulation environments can impose substantial cognitive demands. Classic work on learning with computer simulations shows that, without appropriate guidance, learners may engage in unproductive exploration or struggle to interpret outcomes and connect actions to underlying mechanisms [21]. Consistent with this, simulation-based learning appears more effective when it incorporates instructional supports—such as representational scaffolding, prompts, and feedback—that help learners interpret outcomes and build coherent causal explanations of system behavior [22]. In addition, evidence suggests that personalization strategies, implemented through adaptivity (system-driven support) and/or adaptability (learner-driven choices), can further strengthen learning when aligned with learners' needs and task progression [23].

GenAI simulators have been explored as an emerging possibility for modeling dynamic, interactive, and open-ended systems in a vast field of applications [24], [25]. Although, the use of GenAI tools such as ChatGPT for the design process is still an emerging field open for exploration and systematization in suitable methodologies and protocols. Concerns at this point among researchers lie in the realm of avoiding the replacement of critical thinking inherent to research and using these tools to enhance ideas' refinement and expediting processes [26]. From this perspective the methodology applied for the ST-Sim creation, responds to cycles of defining design requirements and human dialogue between a group pf experts in Educational Technology, Education, Phycology, and UX Design to validate the critical role that this artifact´s features might have in HiEd students learning experience.

C. Generative AI as a design tool for simulators

A relevant aspect to highlight in this study is the design-based research (DBR) [27] approach using Generative AI (GenAI) through ChatGPT 4o model to conceptualize and iterate the simulator structure. The DBR approach is applicable for iterative design processes that lead to knowledge development addressing interventions with the potential of impacting the contexts with a research objective [28]. In this study, the context is given by the ComplexHub platform, a Learning Hub (LH) designed to contain and offer OER on complex and computational thinking for Spanish speakers under the Complex Thinking Education for All project (CTE4A). The project's objective is to provide high quality resources for Life-Long Learners (LLL) and HiEd students. It focuses on complex [29] and computational thinking [30] as these are two of the most relevant competencies to develop in future professionals [31].

Systemic Thinking has been allocated as a sub competence of Complex thinking [32], and this study aligns with this conception. Therefore, the inclusion of a simulator to assist in the development of systemic thinking was ideal to be included as an OER in the ComplexHub, although it should be suitable for HiEd students and LLL from different regions of the planet. The case to be observed should be generalizable enough to make sense to anyone willing to interact with it, and it should set real-life scenarios without stigmatizing developing regions. Hence, the systematic search of this type of scenario was prompted in an initial brainstorming [33] with the GenAI tool using a fictional developing coastal city as a scenario to promote the reflection on how to reach the SDG 11 sustainable cities and Communities.

From the first idea, many iterations occurred as they do in every design process. Indicators such as environmental services or education were included to embrace the different dimensions of reality impacted by a set of decisions. The limits and actions allowed to frame the problem [15] were structured to make sense and reflect real-life constraints for cognitive plausibility [24]. Visual clues and the pre-set feedback sentences allowed to add pieces of information for the user, inviting them to keep looking for diverse combinations. The process consisted in improving and testing through HTLM files that serve as prototypes to test the features and the logical structure. An important note here is that frequently the process was interrupted by misunderstandings, error files, and limitations of the ChatGPT 4o model to comply with the design requirements. This was a constant reminder that this is still not the moment in which all the production processes can be carried out within this tool. Nevertheless, the design process was fluent enough to have a complete idea of what was required and how this artifact would make sense for the target user.

III. METHOD

A. Development of the Simulators

The ST-Sim was developed using a DBR approach, characterized by iterative cycles of design, implementation, analysis, and refinement within real educational contexts. This approach allowed for the integrated articulation of pedagogical objectives, the integrative design of the simulator, and the progressive validation of its didactic functioning. In total, the process to build the first prototype for the proof of concept took approximately 6 months, during which 25 to 35 substantive design interactions were carried out with ChatGPT, equivalent to more than 80 detailed exchanges, considering technical and pedagogical micro-adjustments.

The design began with the definition of the educational purpose, focused on the development of systemic thinking as a key competency in undergraduate students. The foundational prompt used was the following:

"*Design an educational simulator based on the systems thinking approach for undergraduate students, using a developing coastal city as the setting. The simulator should allow students to make decisions under a limited budget,* *allocating resources to different variables (environmental, social, and economic), and visually and immediately show how these decisions affect the balance of the urban-coastal system. The system should represent interdependencies, side effects, and nonlinear consequences, avoiding simple cause-and-effect relationships. The state of the system should be visualized using aggregate indicators and graphical feedback that allows for the identification of states of equilibrium or imbalance*".

A fictional developing coastal city was selected as the base scenario due to its ability to naturally integrate environmental, social, and economic dimensions, as well as real tensions associated with urban growth, sustainability, and climate vulnerability. This context served as the narrative and systemic framework for the simulator's design.

In this phase, the following features were identified:

- systemic indicators (environmental, social, economic, and welfare),
- user-controllable intervention variables,
- and nonlinear relationships between variables and indicators, avoiding simple cause-and-effect schemes,
- inclusion of missions, levels of difficulty and visual indicators of success and feedback.

Based on the conceptual model, a decision panel was included to allow students to allocate resources to different variables under a limited budget, introducing real constraints to the decision-making process. The user's decisions simultaneously impact multiple indicators, reinforcing the understanding of systemic interdependence.

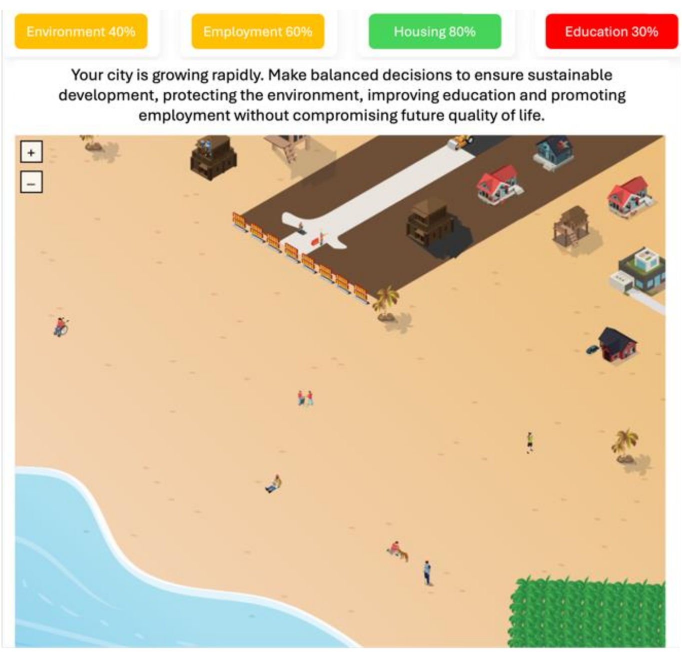

Fig. 1. A screenshot of the ST-Sim scenarios generated by the decision-making in budget allocation.

A system visualizer (Fig. 1) was incorporated, through which the overall state of the city is represented graphically, using color codes to indicate states of equilibrium or imbalance. This visual component plays a key role in making visible consequences that, in real systems, are often abstract or deferred in time. The colored indicators were defined in an algorithmic scheme, setting limits of what was acceptable in terms of the combinations: green for acceptable, amber for middle level and red for non-acceptable. The number of indicators and the budget allocated cause that there is no possibility of having all of them in green, so users must prioritize their decisions. Those selections are guided by missions that range in three levels: simple, medium, and difficult. The levels are given according to the number of indicators that must been set at "acceptable" or green. For instance, a "simple mission" would challenge one indicator in green, a medium one would search for two indicators in green, and a difficult one would set a combination of all indicators in no less than 50% of development.

Once the overall structure of the ST-Sim was defined, an HTML visualization of the product was delivered to a programming team.

B. Participants and Piloting Procedure

The sample included 75 undergraduate students from a Mexican university, aged 18–25 years (M = 19.81, SD = 1.04). Participants were enrolled across multiple campuses nationwide and were in their 3rd to 7th semester. By broad disciplinary area, 46 students were enrolled in engineering programs and 29 in social sciences. The sample included 58 men and 17 women, corresponding to a male majority of 77.3%. This distribution is consistent with the sampling frame, which included a larger proportion of students from engineering-oriented programs. All participants were scholarship recipients who completed the simulator voluntarily after receiving a study briefing and being informed of their right to withdraw at any time. The eligible pool consisted of 117 scholarship-program undergraduates; because students selected activities from a menu to fulfill required scholarship hours, 75 opted into this assessment activity, yielding a participation rate of 64.1%. An opinion questionnaire regarding their engagement with the simulator was administered via Google Form™, completed independently and without supervision. Responses were anonymized, securely stored, and accessible only to the research team. Written informed consent was obtained from all participants prior to data collection. The study received approval from the Institutional Research Ethics Committee (CIEI) of the Tecnologico de Monterrey, P-IFE-202506-002.

The opinion questionnaire was administered immediately after the simulator experience and consisted of eight items: four 5-point Likert-type questions (1 = Strongly disagree to 5 = Strongly agree) and four open-ended questions. The Likert items were designed to capture (a) perceived impact on systemic thinking competency (Items 1–2) and (b) perceived usability and overall experience with the simulator (Items 3–4). Specifically, the Likert items were:

1. The experience allowed me to reflect on the consequences of my decisions.
2. I believe this simulator strengthened my ability to address complex problems.
3. Navigating the simulator was clear and intuitive.
4. I would recommend this experience to others.

The open-ended items elicited more detailed feedback on learning value, usability, and implementation issues:

1. Which aspect of the simulator did you find most interesting or valuable for your learning?
2. Was anything confusing, unclear, or difficult to follow during the experience?
3. What suggestions do you have to improve the simulator?
4. Did you experience any technical problems or difficulties while interacting with the simulator?

To promote response quality and reduce evaluation apprehension, participants were instructed to answer honestly and were reminded that responses would be anonymized and analyzed only in aggregate. Given that students' scholarship activities included testing educational platforms and assessments, the instructions explicitly emphasized that critical feedback was especially valuable for improving the simulator and that negative comments were preferred over overly positive or socially agreeable responses. This procedure was intended to encourage candid reporting and mitigate demand characteristics; however, as with self-report measures, responses may still be subject to residual response biases (e.g., acquiescence and social desirability), which should be considered when interpreting the findings.

IV. Results

A. Perceived Impact and User Experience

Overall, responses to the four Likert items were predominantly positive, indicating favorable perceptions of both the simulator's perceived learning value and its usability (Fig. 2). Descriptively, the highest mean score was observed for reflection on the consequences of decisions (Q1: M = 4.46, SD = 0.69), followed by perceived strengthening of complex-problem engagement (Q2: M = 4.13, SD = 0.88), clarity and intuitiveness of navigation (Q3: M = 4.13, SD = 1.01), and willingness to recommend the experience (Q4: M = 4.07, SD = 0.85). Likert response distributions were also compared between engineering and social sciences students. No significant difference was observed, $\chi^2 = 0.92$, $p = .633$, suggesting that the overall response pattern was not clearly concentrated in one disciplinary area. For the reflection-oriented systemic thinking item ("The experience allowed me to reflect on the consequences of my decisions"), most participants endorsed the highest agreement categories, with 54.7% selecting Strongly agree and 38.0% selecting Agree, and only a small residual share selecting neutral or negative options. A similarly positive pattern was observed for perceived complex-problem engagement ("I believe this simulator strengthened my ability to address complex problems"), where agreement was high but slightly more distributed: 40.2% selected Agree and *39.7% Strongly agree, while 14.5% selected the neutral option, suggesting that a meaningful minority did not clearly attribute competence strengthening to a single experience.

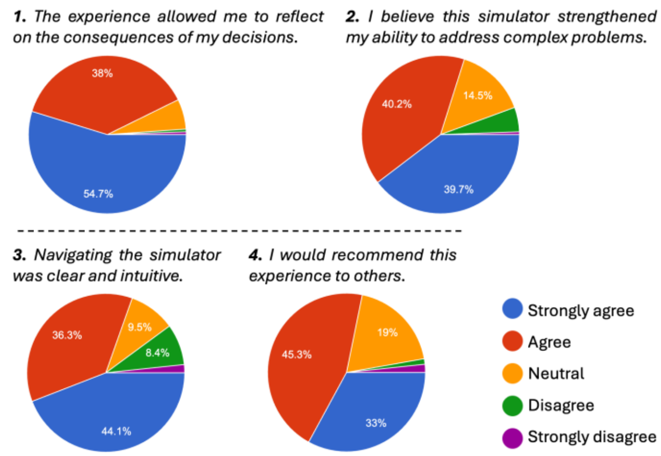

Fig. 2. Participant ratings of perceived learning impact and simulator experience (Likert 1–5). The figure presents response distributions (pie charts) for four 5-point Likert items (1 = Strongly disagree to 5 = Strongly agree). Upper panel: Queries regarding perceived systemic-thinking–related learning impact. Lower panel: Queries about usability and acceptability of the Simulator. Percent values within each pie chart indicate the proportion of respondents selecting each response option.

Usability and overall acceptability were also rated favorably. For clarity and intuitiveness of navigation ("Navigating the simulator was clear and intuitive"), the majority selected Strongly agree (44.1%) or Agree (36.3%); however, compared with the systemic-thinking items, responses showed greater dispersion, with 9.5% selecting Neither agree nor disagree and 8.4% selecting Disagree (and only a very small Strongly disagree segment). This distribution suggests that while the interface and flow were generally perceived as usable, a non-trivial subset experienced some friction, supporting the need for iterative refinements in instructions and navigation. Finally, willingness to recommend ("I would recommend this experience to others") was high, with 45.3% selecting Agree and 33.0% selecting Strongly agree; 19.0% chose the neutral option and negative responses were rare, indicating broad acceptability while also suggesting that recommendation may depend on individual fit, expectations, or perceived relevance for peers.

B. Perceived Learning Value, Clarity Challenges, Improvement Priorities, and Technical Issues

A narrative review of the four open-ended questions suggests participants engaged with the simulator as a visual, decision-oriented learning experience, while also identifying areas where clearer guidance and richer feedback could improve usability and learning value. Given the brief, self-report nature of the comments (and that some responses were very short), the patterns below should be interpreted as descriptive themes rather than prevalence estimates. Accordingly, frequency terms are used only to convey the relative salience of recurring comments in this exploratory reading, not as evidence of systematically coded qualitative categories or quantified response patterns.

Item 1. "Which aspect of the simulator did you find most interesting or valuable for your learning?"

Most responses emphasized the visual representation of the evolving city and the immediate, observable changes after reallocating resources. Roughly half explicitly referenced the graphic component (e.g., the city/map), describing it as making consequences more tangible. Many also highlighted the cause–consequence linkage—seeing how reallocations produced different outcomes across domains—suggesting support for reflection on trade-offs. A substantial subset valued by the budget constraint and percentage allocation as a realistic prompt for prioritization under scarcity. Fewer framed the experience in systemic terms (e.g., interconnections among education, health, environment, and community), indicating that some articulated the intended systems perspective in their own words.

*Item 2. "*Was anything confusing, unclear, or difficult to follow during the experience?"

Responses were mixed. Many reported no major confusion and described the experience as intuitive. Among those reporting difficulties, the most common issue involved instructions and constraints: several described the guidance as lengthy, repetitive, or inconsistent with available options (e.g., allowable percentage increments), and some were initially unsure how to allocate percentages without exceeding the total. Another recurring theme concerned interpreting outcomes—some noted results did not match expectations or that it was difficult to infer an "ideal" configuration—reflecting both the simulator's emphasis on trade-offs and a desire for clearer interpretive scaffolding. A smaller set noted early navigation/discoverability issues (e.g., locating where decisions were made).

*Item 3. "*What suggestions do you have to improve the simulator?"

Suggestions focused less on changing the core concept than on improving onboarding, feedback, and interface flow. Several recommended shorter, clearer instructions, often alongside requests for an example, tutorial, or guided step to demonstrate allocations. Many proposed more explicit feedback (e.g., brief explanations of outcome changes, clearer indications of what each allocation affects, or end-of-activity feedback supporting learning beyond trial-and-error). Another frequent recommendation was greater flexibility or granularity in allocations (e.g., smaller increments) to explore trade-offs more precisely. Fewer suggested layout changes (e.g., making the simulator visible sooner), minor visual enhancements, or expanded features (e.g., additional indicators/metrics to complement the city's visualization).

*Item 4. "*Did you experience any technical problems or difficulties while interacting with the simulator?"

Most participants reported no technical problems. Among the minority reporting issues (excluding blank/non-informative responses), comments mentioned intermittent glitches (e.g., the image/map disappearing or freezing), restarts, zoom/drag limitations, and occasional notification overload when allocations exceeded 100%. A few also noted loading delays (including in the survey form). Overall, technical performance appeared acceptable for most users, while indicating specific failure points for debugging and refinement.

V. Conclusions

This study presented the design and initial implementation of the Systemic Thinking Simulator (ST-Sim), a decision-based digital learning experience that supports undergraduate students in exploring sustainability trade-offs through a fictional developing coastal city scenario. The simulator was conceptualized through iterative design interactions supported by ChatGPT and subsequently implemented as an open educational resource, illustrating a feasible pathway for reducing development time and costs while expanding the repertoire of learning media available for competency development in higher education.

Across the opinion questionnaire, students' perceptions were largely favorable. Likert responses indicated high endorsement that the experience supported reflection on the consequences of decisions and, to a slightly lesser degree, perceived strengthening of their ability to address complex problems. Usability and acceptability were also rated positively, with most participants describing the simulator as clear and intuitive and indicating willingness to recommend the experience. The open-ended responses converged with these findings, frequently emphasizing the value of visualizing system states, and observing the consequences of reallocating scarce resources. At the same time, comments highlighted practical improvement opportunities, particularly the need for more concise onboarding, clearer constraints, and richer interpretive feedback to help users make sense of outcomes and trade-offs; a smaller subset noted minor technical issues that can be prioritized for refinement.

Taken together, these results provide preliminary support for the ST-Sim as an accessible tool for engaging learners with decision-making under constraints and prompting reflection on interdependencies central to systemic thinking.

Because this pilot relied on students' own perceptions from one university's context, the results should be read as evidence of initial acceptability rather than as evidence of learning gains. The instructions were designed to make critical feedback acceptable and reduce pressure to respond positively; however, they cannot fully eliminate acquiescent or socially desirable responding. In addition, the sample may reflect self-selection, since participants were scholarship students who chose this activity from a broader set of eligible options. Future studies should therefore include more direct evidence of learning, such as pre–post designs, behavioral trace data, or analysis of simulator logs, and should test the ST-Sim with broader and more diverse student samples.

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