Work-In-Progress: What Goes into an Engineering Decision: An Infrastructure Decision-Making Game for Exploratory Equity Learning - Phase 4 Comparing Learning Formats

Prof. Eun Jeong Cha, University of Illinois at Urbana - Champaign

Eun Jeong Cha is an associate professor in the Department of Civil and Environmental Engineering at the University of Illinois at Urbana–Champaign. Dr. Cha holds a Ph.D. (2012) and a M.S. (2009) in Civil and Environmental Engineering from the Georgia Institute of Technology, and a B.S. (2006) in Architectural Engineering from Seoul National University, South Korea. Her awards and honors include the NSF Next Generation of Hazards and Disasters Researchers Fellowship in 2015 and the UIUC Office of Risk Management and Insurance Research Faculty Scholar in 2021. Her research interests are in the general areas of risk-based decision-making for civil infrastructures subjected to natural hazards, including climate adaptation, community resilience, life-cycle analysis, probabilistic hazard impact simulations for buildings and other infrastructure exposed to extreme events including earthquakes, hurricanes, and floods, and structural safety target optimization.

Abigail Louise Beck, University of Houston

Abigail Beck is a Ph.D. Candidate in Civil Engineering at the University of Illinois Urbana-Champaign. She received her M.S. in Civil Engineering from the University of Illinois Urbana-Champaign and her B.S. in Civil Engineering from the University of Texas at Austin. Her research surrounds equity-based infrastructure decision support by integrating her fundamental specialization in structural reliability, risk assessment, systems modeling, and probabilistic methods with social science approaches. She is a recipient of the NSF Graduate Research Fellowship and a 2023-2024 Mavis Future Faculty Fellow. She is a member of the NIST Center of Excellence for Community Resilience and collaborates with engineers, economists, social scientists, and planners on the development of tools to support community resilience decision-making. She has been recognized for her research at multiple international conferences with a Student Best Paper Award at ICOSSAR 2021/2022 and CERRA Student Recognition Award at ICASP 2023.

Luc Paquette, University of Illinois at Urbana - Champaign
Eric G Shaffer

Eric Shaffer is a Teaching Assistant Professor in the Department of Computer Science. He teaches a revolving set of courses including Virtual Reality, Computer Graphics, and Scientific Visualization. In addition to teaching, he has done research in the

Work-In-Progress: What Goes into an Engineering Decision: An Infrastructure Decision-Making Game for Exploratory Equity Learning - Phase 4 Comparing Learning Formats

Abstract

This paper presents the next phase of an ongoing effort to integrate consequence-based thinking into structural engineering education through game-based learning. Earlier phases of the project introduced an infrastructure decision-making game designed to engage students with tradeoffs among risk reduction, community impact, system performance, and equity during post-disaster recovery. Two versions, a board game and a computer-based version, were developed to support learning about decision-making under uncertainty and resource constraints with multiple competing objectives.

Phase 4 extends this effort by comparing learning outcomes across board and computer game implementations to date and evaluating two instructional enhancements introduced in the most recent computer game testing: (1) a short instructional module introducing fundamental concepts of resilience and equity in infrastructure systems and (2) in-game feedback messages designed to prompt student reflection on decision outcomes. We analyzed post-game self-assessments aligned with the six learning objectives, and targeted survey questions on the lecture module, in-game messages, and open-ended student feedback.

Across all implementations, post-game self-assessment scores were consistently high for both the board game and computer game formats, suggesting that both formats can support the intended learning objectives. In the most recent computer game testing, students rated the lecture module and in-game messages as moderately helpful overall, and qualitative feedback indicated that the messages supported real-time decision-making by helping teams anticipate hazard impacts, identify neighborhoods falling behind, and adjust repair and retrofit strategies. These results highlight the potential of both board and computer-based formats for consequence-oriented and equity-aware learning and motivate continued refinement of instructional supports to strengthen student learning experiences.

Introduction

The field of civil and structural engineering is facing an evolving set of challenges, including aging infrastructure, increasing hazard exposure, climate change, and growing concerns about social equity in infrastructure performance and recovery. Addressing these challenges requires engineers to move beyond purely technical optimization and engage in consequence-based decision-making, where uncertainty, community impacts, and equity are treated as central design considerations rather than afterthoughts [1], [2].

Yet, despite the importance of these topics, undergraduate structural engineering curricula often provide limited opportunities for students to learn how to evaluate disaster consequences and equity-informed tradeoffs in a practical and intuitive way. Many of the foundational ideas behind resilience- and equity-based decision-making rely on advanced concepts such as multi-criteria decision-making, systems thinking, and risk analysis, which are rarely introduced early in the curriculum. To bridge this gap, this project adopts a game-based learning approach that allows students to actively experience the complexity of infrastructure decision-making through an interactive and collaborative simulation of post-disaster recovery [3-13].

Over the past three years, this effort has advanced through a sequence of development phases that progressively expanded the game's educational scope and classroom readiness. Phase 1 (ASEE 2023) introduced the initial Resilient Community board game as a hands-on instructional module that immerses students in infrastructure retrofit and recovery decisions under uncertainty and limited resources [14]. Phase 2 (ASEE 2024) expanded the board game by introducing multiple stakeholder roles, encouraging students to negotiate competing priorities and recognize how engineering decisions can affect different groups in a community in unequal ways [15]. Phase 3 (ASEE 2025) transitioned the game into a computer-based format, improving scalability for large classes, streamlining gameplay and scoring, and enabling detailed logging of student decisions for assessment and future instructional enhancements [16].

Building on this foundation, Phase 4 advances the module by comparing the board and computer-based formats and evaluating two instructional enhancements designed to strengthen learning: (1) a short pre-game module introducing core resilience and equity concepts, and (2) in-game reflective messages that prompt students to interpret outcomes and connect their decisions to broader consequences. This paper presents a work-in-progress study answering our research questions on how these formats and instructional enhancements influence student learning outcomes related to consequence-oriented, equity-aware decision-making, and how learning outcomes differ across implementations.

Instruction Module for Resilience and Equity in Structural Engineering Decision-Making

Overview

The instructional module was developed to promote community resilience-based and equity-based multi-criteria decision-making in structural engineering education. The module combines a short lecture with a game-based learning activity, allowing students to first build foundational concepts and then apply them through an interactive decision-making experience. The gameplay is designed as a cooperative activity that encourages students to explore tradeoffs among risk reduction, system performance, resource constraints, and equity, while engaging in team discussion and reflection. The learning objectives (LOs) guiding the module are consistent with those established in earlier phases of the project and include:

LO1: Understanding factors that influence community resilience
LO2: Applying multi-criteria decision-making to infrastructure systems
LO3: Incorporating equity considerations into engineering decisions
LO4: Assessing differential impacts of decisions on community stakeholders, including marginalized groups

LO5: Collaborating with peers to make informed and equitable decisions
LO6: Reflecting on the challenges of balancing multiple, competing objectives

These learning objectives informed the design of the lecture content, game mechanics, reflective supports (e.g., in-game messages), and assessment approach used in Phase 4. In practice, the instructional module typically includes a short slide-based lecture, a game overview, gameplay, and a brief discussion or reflection activity, with the allotted time for each segment varying based on course context and available class time.

Game module

The Resilient Community game simulates post-disaster recovery and improvement of an electric distribution system subject to recurring hurricane hazards. Teams make decisions about repairing and upgrading system components (electric power substations and distribution poles) under limited budgets and uncertainty. Gameplay proceeds in repeated cycles of hazard impact, decision-making, and feedback, allowing students to observe the consequences of their choices over time. Team performance is evaluated using multiple criteria, including system functionality, network strength, restoration equity, improvement equity, and overall community functionality. These metrics capture complementary aspects of system performance, including the extent of service availability (functionality), structural robustness (network strength), and the distribution of recovery and upgrade actions across neighborhoods. In this context, equity is operationalized as the relative balance in restoration and improvement outcomes across different areas of the community, allowing students to observe how uneven allocation of resources can lead to disparities in system performance. Two of the metrics are formulated to directly benchmark these differences. These criteria emphasize the tradeoffs inherent in real-world infrastructure decision-making. Equity considerations are further reinforced through varying hazard exposure. Different regions are exposed to hazard events with different probabilities of occurrence and challenge players to recognize these systemic differences in exposure.

<u>Board Game Version</u>
The board game version is a face-to-face, multi-player experience that emphasizes teamwork, discussion, and negotiation. Physical game components, including the game board and role cards, support collaborative decision-making and peer-to-peer learning. The board game environment naturally encourages verbal justification of decisions and collective reflection during gameplay.

<u>Computer-Based Game Version</u>
The computer-based game version builds upon the same core mechanics as the board game, leveraging a digital format to enhance scalability and data collection while still supporting team-based discussion and collaborative decision-making during gameplay. The digital interface automates hazard generation, scoring, and feedback, reducing instructional overhead and enabling efficient deployment in larger classes. The computer-based game also logs teams’ actions and game states, providing detailed interaction data that can be used for assessment and future game refinement. This format supports individualized reflection and enables more complex scenario configurations than are feasible in a physical board game format.

Instructional Enhancements

Pre-Game Lecturing

To provide a conceptual foundation, short pre-game lecture slides were developed to introduce key concepts related to resilience, equity, and consequence-based decision-making in infrastructure systems. Three sets of slides were developed to reach diverse student groups, including (1) 15-minutes lecture for 50-minutes class time, typically introductory undergraduate level course, (2) 30-minutes lecture for extended introductory class time and (3) 80-minutes lecture for a topic-specific graduate level course.

In-Game Feedback Messages

The computer game format incorporates in-game messages designed to prompt players' reflection on decision outcomes. These messages were developed to support learning across the six learning goals and associated key concepts by drawing attention to varying risk levels, system-wide effects, stakeholder impacts, equity considerations, long-term consequences, and collaboration. Messages are triggered using predefined conditions based on the current game state and the team's actions, providing timely, context-specific prompts for reflection. The messages are delivered in a news reporter style to enhance immersion. An example message is shown in Figure 1.

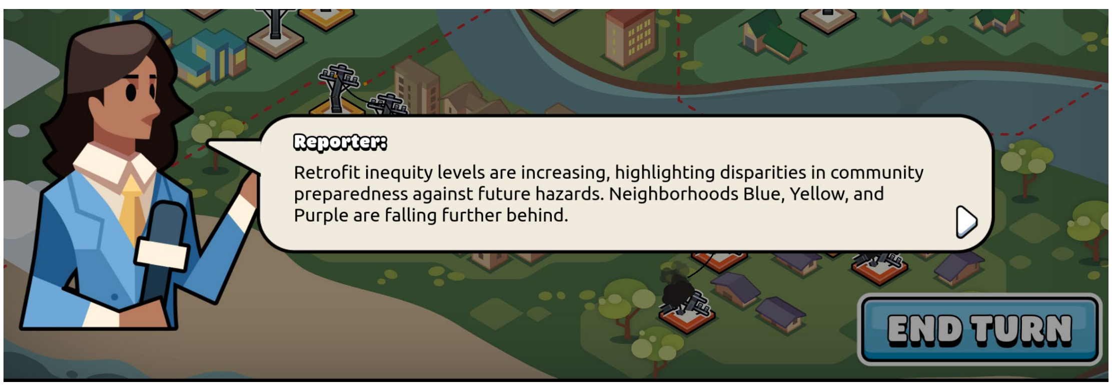

Figure 1. An example in-game feedback message

Classroom Implementation and Evaluation

This section summarizes results across board and computer game implementations to date and reports the detailed evaluation results from the most recent computer game testing. The board game was first tested during a Civil and Environmental Engineering Departmental game night, and the computer-based game was subsequently implemented in multiple offerings of an undergraduate introductory structural engineering course. Although the cohorts differed in context (voluntary extracurricular participation versus course-based implementation), participants were broadly comparable in terms of academic level and disciplinary background (primarily undergraduate civil engineering students), supporting qualified assessment across implementations. A post-game self-assessment aligned with the six learning objectives (LO1–LO6) was collected using a Likert scale from 1 (strongly disagree) to 5 (strongly agree). The results from the board game and three computer game implementations are summarized and compared in Table 1. For the computer game implementations, both pre- and post-game surveys were administered, and all learning objectives showed meaningful increases from pre to post. These improvements were further quantified using normalized gain, defined as the ratio of the observed improvement to the maximum possible improvement on the Likert scale, indicating moderate to substantial learning gains across most learning objectives. For the board game testing, only post-game self-assessments were collected. Overall, post-game self-assessment scores were consistently high across both formats, and the computer game results further suggest improvement in students' perceived understanding and abilities aligned with the learning objectives.

Table 1. Post-game Self-Assessment Results from Board and Computer Game Implementations

Learning Objectives	**Board Game (N=15)**	**Computer Game 1* (N=33)**			**Computer Game 2* (N=60)**			**Computer Game 3* (N=17)**		
		Pre	**Post**	**Normalized Change**	**Pre**	**Post**	**Normalized Change**	**Pre**	**Post**	**Normalized Change**
LO1	3.93	3.28	3.95	0.39	3.48	4.2	0.47	2.79	4.06	0.57
LO2	4	3.09	3.93	0.44	3.35	4.18	0.50	2.54	3.89	0.55
LO3	3.87	3.12	4	0.47	3.41	4.18	0.48	2.75	4.11	0.60
LO4	3.6	3.09	4.03	0.49	3.47	4.13	0.43	3	4.06	0.53
LO5	4.33	3.47	4.03	0.37	3.73	4.3	0.45	3.46	4.33	0.56
LO6	4.2	3.28	4.1	0.48	3.68	4.28	0.45	3.39	3.89	0.31
Average	**3.99**	3.22	4.01	**0.44**	3.52	4.21	**0.47**	2.99	4.06	**0.53**

*Computer Game 1: Phase 3 implementation; Computer Game 2: additional implementation; Computer Game 3: Phase 4 implementation with lecture + in-game messages.

Further, to evaluate the effectiveness of the in-game reflective messages, students in the most recent computer game implementation (Computer Game 3) rated how helpful the messages were in highlighting key concepts during gameplay. The results are summarized in Table 2. Overall, the messages were rated as moderately effective. Messages about hazard occurrence rates, the importance of substations, and collaboration received the highest scores, while messages related to nonfunctional neighborhoods and equity disparities were rated lower, suggesting areas for refinement. We hypothesize that these lower ratings may be due to these messages being less direct and requiring greater interpretation than those related to hazard impacts and system components. This may limit their immediate usefulness during decision-making. These findings suggest that additional support may be needed to more clearly connect equity-related messages to observable game outcomes and player decisions. Additionally, in open-ended responses, students described using the messages to guide decision-making in real time. Common themes included identifying which neighborhoods were falling behind and needed additional support, anticipating which areas were most likely to be impacted by hazards, and adjusting repair/retrofit strategies in subsequent turns based on observed outcomes. Several students also noted that the messages helped their teams coordinate roles and plan actions more effectively.

Lastly, the effectiveness of the short lecture module was evaluated. Students rated how helpful the lecture was in supporting the six learning objectives (LO1–LO6). As summarized in Table 3, the lecture module was rated as moderately helpful overall, suggesting opportunities to further strengthen the lecture content and examples to better support student learning.

Table 2. Student Ratings of In-Game Message Effectiveness

In-game Message Effectiveness	Score
Climate change	3.39
Different hazard occurrence rates by zone	4.06
Importance of substations	3.81
Nonfunctional neighborhoods	3.31
Retrofit disparity	3.29
Restoration disparity	3.27
Collaboration	3.80
Average	**3.56**

Table 3. Student Ratings of Lecture Module Effectiveness Across Learning Objectives

Learning Objectives	Score
Understand different factors that influence community resilience. (LO1)	3.67
Apply multi-criteria decision-making for infrastructure systems. (LO2)	3.41
Understand how equity can be considered in infrastructure decision-making. (LO3)	3.56
Assess the potential impact of different decisions on various stakeholders in the community, including marginalized groups. (LO4)	3.67
Collaborate with others to make informed and equitable decisions based on multiple criteria and perspectives. (LO5)	3.61
Understand the challenges of considering multiple criteria in infrastructure decisions. (LO6)	3.61
Average	**3.59**

Conclusions and Future Work

This work-in-progress paper compared learning outcomes across board and computer-based implementations of an infrastructure decision-making game and evaluated two Phase 4 pedagogical enhancements: a short lecture module and in-game reflective messages. Across all implementations to date, students reported consistently high post-game self-assessment scores aligned with the learning objectives, suggesting that both the board game and computer game formats can effectively support consequence-oriented and equity-aware decision-making learning. In the most recent computer game testing, students rated the in-game messages and short lecture module as moderately helpful, and open-ended feedback indicated that the messages influenced real-time decisions by helping teams anticipate hazard impacts, identify underserved neighborhoods, and adjust repair and retrofit strategies. These findings highlight the value of game-based learning for introducing complex resilience and equity concepts in undergraduate structural engineering and point to opportunities to further refine instructional supports to strengthen learning outcomes.

Acknowledgements

This material is based upon work supported by the Kern Family Foundation. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Kern Family Foundation.

References

[1] College Factual, "2023 Structural Engineering Degree Guide." Accessed: Feb. 04, 2024. [Online]. Available: https://www.collegefactual.com/majors/engineering/civil-engineering/structural-engineering/
[2] Zippia, "Civil/Structural Engineer Demographics and Statistics [2024]: Number Of Civil/Structural Engineers In The US." Accessed: Feb. 04, 2024. [Online]. Available: https://www.zippia.com/civil-structural-engineer-jobs/demographics/
[3] J. L. Plass, B. D. Homer, and C. K. Kinzer, "Foundations of Game-Based Learning," *Educational Psychologist*, vol. 50, no. 4, pp. 258–283, Oct. 2015, doi: 10.1080/00461520.2015.1122533.
[4] P. Martín-Hernández, M. Gil-Lacruz, A. I. Gil-Lacruz, J. L. Azkue-Beteta, E. M. Lira, and L. Cantarero, "Fostering University Students' Engagement in Teamwork and Innovation Behaviors through Game-Based Learning (GBL)," *Sustainability*, vol. 13, no. 24, Art. no. 24, Jan. 2021, doi: 10.3390/su132413573.
[5] J. Krath, L. Schürmann, and H. F. O. von Korflesch, "Revealing the theoretical basis of gamification: A systematic review and analysis of theory in research on gamification, serious games and game-based learning," *Computers in Human Behavior*, vol. 125, p. 106963, Dec. 2021, doi: 10.1016/j.chb.2021.106963.
[6] W. Mao, Y. Cui, M. M. Chiu, and H. Lei, "Effects of Game-Based Learning on Students' Critical Thinking: A Meta-Analysis," *Journal of Educational Computing Research*, vol. 59, no. 8, pp. 1682–1708, Jan. 2022, doi: 10.1177/07356331211007098.
[7] P. Pando Cerra, H. Fernández Álvarez, B. Busto Parra, and P. Iglesias Cordera, "Effects of Using Game-Based Learning to Improve the Academic Performance and Motivation in Engineering Studies," *Journal of Educational Computing Research*, vol. 60, no. 7, pp. 1663–1687, Dec. 2022, doi: 10.1177/07356331221074022.
[8] K. Suzuki, T. Shibuya, and T. Kanagawa, "Effectiveness of a game-based class for interdisciplinary energy systems education in engineering courses," *Sustain Sci*, vol. 16, no. 2, pp. 523–539, Mar. 2021, doi: 10.1007/s11625-021-00912-3.
[9] M. Hartt, H. Hosseini, and M. Mostafapour, "Game On: Exploring the Effectiveness of Game-based Learning," *Planning Practice & Research*, vol. 35, no. 5, pp. 589–604, Oct. 2020, doi: 10.1080/02697459.2020.1778859.
[10] E. Andersen, "Optimizing adaptivity in educational games," in *Proceedings of the International Conference on the Foundations of Digital Games*, Raleigh North Carolina: ACM, May 2012, pp. 279–281. doi: 10.1145/2282338.2282398.
[11] D. Leutner, "Guided discovery learning with computer-based simulation games: Effects of adaptive and non-adaptive instructional support," *Learning and Instruction*, vol. 3, no. 2, pp. 113–132, Jan. 1993, doi: 10.1016/0959-4752(93)90011-N.
[12] J. L. Plass, D. M. Chun, R. E. Mayer, and D. Leutner, "Supporting visual and verbal learning preferences in a second-language multimedia learning environment," *Journal of Educational*

Psychology, vol. 90, pp. 25–36, 1998, doi: 10.1037/0022-0663.90.1.25.
[13]S. Turkay, C. Kinzer, and S. Adinolf, "The effects of customization on game experiences of a massively multiplayer online game's players," *Proceedings of GLS*, vol. 9, pp. 330–337, 2013**.**
[14]A. L. Beck and E. J. Cha, "Board 44: Work-In-Progress: What Goes into an Engineering Decision: An Infrastructure Decision-Making Game for Exploratory Equity Learning," Paper presented at 2023 ASEE Annual Conf. & Expo Baltimore, MD., USA, June 2023.
[15]A. L. Beck, E.J. Cha, E. Shaffer and L. Paquette, Work-In-Progress: What Goes into an Engineering Decision: An Infrastructure Decision-Making Game for Exploratory Equity Learning - Phase 2 Multiple Stakeholders. The ASEE 2024 Annual Conference and Exposition. Portland, OR, June, 2024.
[16]E.J. Cha, A. L. Beck, E. Shaffer and L. Paquette, Work-In-Progress: What Goes into an Engineering Decision: An Infrastructure Decision-Making Game for Exploratory Equity Learning - Phase 3 Video Game Version Development. The ASEE 2025 Annual Conference and Exposition. Montreal, CA, June, 2025.