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Work-In-Progress: What Goes into an Engineering Decision: An Infrastructure Decision-Making Game for Exploratory Equity Learning - Phase 3 Video Game Version Development

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Abstract

Community resilience focuses on the socioeconomic impact of structural failures post-disaster, emphasizing the need for equitable risk management. Achieving resilience requires well-functioning community components, bringing equity to the forefront of resilience education. Despite its importance, undergraduate structural engineering programs often provide minimal exposure to disaster social impact and equity topics.

Integrating these concepts into undergraduate curricula is challenging due to their complexity, relying on advanced subjects like multi-criteria decision-making, systems analysis, and risk analysis. As most structural engineers enter the workforce with undergraduate degrees, introducing these topics early is essential. To address this gap, an active learning approach was adopted through an infrastructure decision-making game that highlights key aspects of risk mitigation: equity, community impact, system performance, uncertainty, and resource constraints.

In the game, teams decide which elements (e.g., poles and substations) of an electric network to repair or retrofit under constraints while managing random hazards. Two board game versions were developed: one with a voting feature and one without. This paper introduces a computer-based version derived from the board game version without the voting feature. The digital format simplifies integration into large classes, automates scoring, and allows broader dissemination at lower cost and time. The computer version also enables more efficient data collection for assessment purposes.

Tested in an undergraduate structural engineering course, the computer game's effectiveness was evaluated through pre- and post-game assessments, observation, assignment, and log data analysis. The game demonstrated its ability to achieve key learning objectives related to resilience and equity-based decision-making.

Introduction

The field of civil engineering faces an evolving set of grand challenges, including aging infrastructure, increasing user demand due to urban growth, and the rising prevalence and magnitude of natural hazards driven by climate change. To address these challenges, civil engineers must embrace a more holistic risk management paradigm that extends beyond technical considerations to include socioeconomic impacts, community resilience, and equity. Future civil engineers will need to act as risk managers who can navigate complex, multi-faceted disaster impacts on society [1], [2]. Preparing them for this role requires integrating new pedagogical approaches within the civil engineering curriculum, particularly those that foster critical skills in risk-informed decision-making and balancing competing priorities in disaster risk management.

To support this goal, game-based learning has emerged as a promising educational tool [3]-[13]. Previous phases of this research introduced a board game as an interactive instructional module for undergraduate structural engineering students [14], [15]. This module was designed to

introduce students to multi-criteria disaster risk management concepts by placing them in decision-making roles where they must weigh competing objectives. The game proved effective in enhancing students' understanding of these concepts and fostering the entrepreneurial mindset promoted by the Kern Entrepreneurial Engineering Network (KEEN), which emphasizes creating value, building connections, and cultivating curiosity, by emphasizing the impacts of engineering decisions, encouraging broader systems thinking, and provoking student's curiosity of how to best prepare their community for hazards under uncertain conditions [16].

Building upon the board game, this paper presents the next phase of development, focusing on creating a computer-based version of the initial board game. The transition to a digital platform aims to increase accessibility, scalability, and engagement, facilitating classroom implementation and further enhancing its educational impact. By incorporating a computer-based format, the game can also facilitate more complex decision-making scenarios, provide instant feedback, and track players' decisions and progress over time, offering valuable data for both students and instructors.

The game addresses the pilot version (2023-2025) of ABET EAC Criterion 5, which highlights the importance of incorporating diversity, equity, and inclusion (DEI) into engineering curricula. By simulating real-world disaster scenarios and highlighting the varied impacts of engineering decisions on different community groups, the computer-based game fosters a more inclusive approach to engineering problem-solving.

In this paper, we outline the development and implementation of the computer-based game. We begin by revisiting the learning goals and objectives that guided the game development. Next, we describe the design and functionality of the digital game, including its interface, decision-making mechanics, and feedback systems. We then discuss the testing of the computer-based game, including the effectiveness of the game and other insights from student feedback.

Resilient Community: A Video Game for Learning Resilience and Equity in Decision-Making

Learning goal and objectives

The game-based module was developed with the goal of promoting community resilience-based and equity-based multi-criteria decision-making and its fundamental concepts. Structured as a cooperative game, it encourages players to explore diverse perspectives through both their personal viewpoints and specialized roles within the game. This format mirrors the complexity of real-world engineering challenges, helping students build essential skills for making informed, community-conscious decisions that balance competing priorities.

The learning objectives (LOs) guiding the game design focus on key concepts for community resilience-based and equity-based multi-criteria decision-making. Students gain an understanding of factors influencing community resilience (LO1) and learn to apply multi-criteria decision-making to infrastructure systems (LO2) and integrate equity considerations into their decisions (LO3). They also learn to evaluate the impact of various choices on different community stakeholders, particularly marginalized groups (LO4), collaborate with peers to reach equitable decisions (LO5), and reflect on their learning experiences to apply these insights in real-world scenarios (LO6).

These objectives shaped the game's structure, components, actions, special roles, and scoring system to ensure a comprehensive learning experience. The current paper focuses on transitioning the initial board game to a computer-based platform, aiming to enhance accessibility, engagement, and scalability. The following sections provide a brief overview of the original game design [14], [15], followed by a detailed description of computer game development and its potential to improve learning outcomes through interactive digital tools.

Brief game overview

The Resilient Community game was originally developed as a cooperative board game where teams make decisions to retrofit and recover an electric distribution system affected by hurricane hazards. Players work together to repair and improve network components across neighborhoods as they face repeated hazard events. Two board game versions were developed: one with a voting feature and one without. In this paper, we build upon the board game version without the voting feature.

The game follows three phases: 1) A hazard event impacts the community. 2) Teams make repair and retrofit decisions. 3) The hazard recurs, providing feedback on past choices. Each turn, players take actions within a set budget to retrofit, repair, or recover components. Hazards are applied based on a drawn card and a die roll for intensity, with components surviving if their strength meets or exceeds the hazard level. Budget cards then determine actions available for the next turn.

Teams must manage five key objectives: System Functionality, Network Strength, Restoration Equity, Improvement Equity, and Community Functionality. Team performance across all five objectives is compared and the final score is based on their comparative performance. To enhance gameplay, teams choose one of five special roles, i.e., engineer, regulatory official, emergency official, community official, or community member, that offer advantages in repair, retrofit, or recovery tasks, reflecting real-world decision-makers involved in disaster preparation and response.

Video game development

Building upon the original board game, the Resilient Community game has been further developed into a computer-based format to enhance accessibility, engagement, and scalability while maintaining its core educational goals. The digital platform can facilitate more complex decision-making scenarios, provide instant feedback, and track players' decisions and progress over time, providing an immersive experience for players and valuable data for both students and instructors.

The computer-based game retains the original game structure described in the previous section. The digital format streamlines gameplay, allowing players to interact with a virtual board, select actions through an intuitive interface, and receive instant feedback on decisions. Figure 1 shows the game board, including the electric network, component tiles, and neighborhoods.

The digital version can provide several enhancements over the board game, including a more advanced hazard simulation engine, customizable scenarios, and role-specific special abilities that can be strategically deployed. The game interface can display key performance metrics, visual indicators of system status, and progress toward objectives. Developed on a web-based platform, the game is optimized for seamless implementation and scalable dissemination.

The Godot game engine is used as the development platform. A game engine is a software development environment that includes libraries of low-level code for basic video game tasks such as rendering computer graphics, generating audio, and handling user input. Game engines support the rapid development of video games, and virtually every modern video game is developed using a game engine. The Godot game engine is free and open source under the MIT license. As such it is an excellent target for research development. It also does not require royalties, should the game ever be commercialized. Godot supports multi-platform development. Using it, one can create a game that will run on Windows, MacOS, mobile devices, or web browsers supporting HTML5 and WebAssembly. The Godot development environment itself can run on a relatively modest desktop or laptop computer.

The pilot version of the game includes the capability to log player behavior and game events. This data set provides a source of research opportunities, allowing us to analyze player behaviors and choices in gameplay for further game enhancement to meet the learning objectives.

Figure 1: Game board with electric network component tiles

Classroom Implementation and Evaluation

The developed video game was tested with 56 undergraduate students enrolled in an introductory structural engineering course. Teams were formed by student choice, encouraging collaborative decision-making in a familiar setting. To assess the game's effectiveness in achieving the LOs, anonymous pre- and post-game surveys were administered. A total of 47 responses were collected for the pre-game survey and 40 responses for the post-game survey.

The surveys asked players to rate their understanding and abilities related to each of the six LOs using a Likert scale from 1 (strongly disagree) to 5 (strongly agree). Table 1 presents the LO questions and the average scores for each question. The average score improved from 3.22 in the pre-game survey to 4.01 in the post-game survey, indicating a substantial increase in students'

understanding and abilities across all six LOs. This improvement confirms that the game effectively supports the development of resilience-based decision-making skills.

Players were also asked to evaluate the game's visual elements. A large majority (97.5%) agreed that the visual elements were clear and easy to understand. Additionally, the survey included an open-ended section for feedback and suggestions. Players provided positive feedback on the game's design and functionality, with some recommending the inclusion of difficulty levels and increasing competitiveness. These suggestions will inform future improvements to the game.

Beyond surveys, additional evaluation methods were implemented, including observations, assignments, and log data analysis. We observed team interactions during gameplay, confirming active collaboration within each team. Before gameplay, teams were asked to agree or disagree with play data collection, and 11 teams consented to data collection. Detailed gameplay data, including team actions, hazard occurrences, budget levels, and scores at each turn, was recorded. This data will be used to develop in-game feedback mechanisms to enhance player experience and learning outcomes in future game development. An optional post-game assignment was made available, which was completed by 33 students. The assignment asked students to apply the LOs in consideration of another civil engineering problem of their choice with a clear assessment rubric provided. The assessment data of these assignments will be used to develop and best align the associated learning modules.

Overall, the evaluation confirmed that the video game was well-received by students and effectively facilitated learning. The combination of survey responses, observations, and data analysis provides a comprehensive understanding of the game's impact and highlights areas for future development.

Table 1 Computer Game Self-Assessment Results

Learning Objectives	**Pre**	**Post**	**Change**
I understand different factors that influence community resilience. (LO1)	3.28	3.95	+ 0.67
I can apply multi-criteria decision-making for infrastructure systems. (LO2)	3.09	3.93	+ 0.84
I understand how equity can be considered in infrastructure decision-making. (LO3)	3.12	4	+ 0.88
I can assess the potential impact of different decisions on various stakeholders in the community, including marginalized groups. (LO4)	3.09	4.03	+ 0.94
I can collaborate with others to make informed and equitable decisions based on multiple criteria and perspectives. (LO5)	3.47	4.03	+ 0.56
I understand the challenges of considering multiple criteria in infrastructure decisions. (LO6)	3.28	4.1	+ 0.82
Average	**3.22**	**4.01**	**+ 0.785**

Conclusion & Future Development

This paper presents the development and evaluation of a computer-based version of the Resilient Community game, aimed at enhancing learning in resilience- and equity-based infrastructure decision-making. The digital adaptation enhances the original board game by improving accessibility, engagement, and scalability through a web-based platform. By integrating automated feedback and real-time progress tracking, the digital game aims to create a more immersive and efficient learning environment for students. The game's automated system tracks player actions and simplifies the scoring process, making classroom implementation easier.

The computer-based game was tested with undergraduate students in an introductory structural engineering course. Student surveys were conducted to assess the game's effectiveness in achieving its learning objectives. In this version, we collected post-game surveys and, for the first time, pre-game surveys to measure changes in students' understanding of the learning objectives. Results indicated a substantial improvement in students' self-reported understanding of resilience-based decision-making. The majority of students found the game's visual elements easy to understand. Open-ended feedback suggested further enhancements, such as adding difficulty levels and increasing competitiveness between teams. We also confirmed active collaboration between team members by observing team interactions during gameplay. In addition, detailed gameplay data and an assignment were collected, which will be used to evaluate the game's impact and further refine the game and instruction module.

Overall, the computer-based version of the Resilient Community game demonstrates significant potential as an educational tool for introducing engineering students to multi-criteria decision-making in infrastructure resilience. By leveraging a digital platform, the game supports wider dissemination and implementation at a lower cost while providing robust mechanisms for assessing learning outcomes. Future work will focus on improving the user interface, incorporating automated in-game feedback through non-player characters, expanding the platform for the version with a voting feature as described in [15], and developing instructional modules with pre- and post-game activities. The ongoing development of this digital game underscores its capacity to foster critical thinking, cooperative decision-making, and stakeholder engagement, preparing students to navigate complex real-world infrastructure challenges in their professional careers.

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