Work-In-Progress: What Goes into an Engineering Decision: An Infrastructure Decision-Making Game for Exploratory Equity Learning (Phase 2 Multiple Stakeholders)

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Abstract

Community resilience emphasizes the socioeconomic impact of structural failures post-disaster. This holistic view of structural risk has been driving studies for structural risk management. Since overall community resilience is achieved by the well-functioning of all community components, the concept of equity has gained attention in community resilience research. Key to community resilience and equity education is the emphasis on multi-faceted impacts of engineering decisions and systems thinking. However, the current structural engineering curriculum at the authors' university offers students only minimal opportunities for learning about the topics of disaster social impact and equity in their education.

Despite the importance of incorporating community resilience and equity concepts into the curriculum, it is not a trivial task due to the concepts' complexity. These concepts are defined based on other complex subjects, such as multi-criteria decision-making, systems analysis, risk analysis, and socioeconomic disaster impact analysis. It is one of the reasons why these concepts are often taught in more advanced graduate-level courses, if at all, instead of undergraduate courses. However, introducing these concepts early on is crucial, since the vast majority of practicing structural engineers start their careers after their undergraduate program. To address these issues, we adopt an active learning approach and introduce an infrastructure decision-making game that highlights many different aspects to be considered in risk mitigation decision-making: equity, community impact, system performance, uncertainty, and resource constraints. In this game, teams make decisions about which elements of an electric network to repair and retrofit given constraints as hazards randomly impact the community.

This paper introduces a new version of an infrastructure decision-making game which extends the original game to emphasize the role of multiple criteria in decision making by introducing multiple stakeholder roles. Each student plays a stakeholder role and champions their metric while the team collaboratively tries to achieve overall community resilience. This game is developed as part of an instructional module that aims to be implemented into undergraduate structural engineering courses, where students can connect retrofit strength levels with broader community impact. The paper presents the game development, along with results from a post-game survey, collected during a pilot implementation. This feedback demonstrates the effectiveness and improvement of the new version of the game in achieving intended learning objectives.

Introduction

The field of civil engineering faces a tripartite of grand challenges as our infrastructure continues to age, user demand increases with urban growth, and hazards increase in prevalence and magnitude with climate change. To properly address these challenges, the risk paradigm is

expanding to a more holistic view that also considers the socioeconomic impact of physical failures (i.e., community resilience). Given multi-faceted disaster impacts on society, it is also becoming more critical to consider and balance varying impacts among multiple stakeholders. To prepare future civil engineers to fulfill a risk manager role, the civil engineering curriculum should expand to also address these elements. These skill sets are also directly related to fostering the 3C's of the KEEN Network's Entrepreneurial Mindset for creating value, connections, and curiosity to promote entrepreneurial mindset learning [1]. This development is further supported by the ABET engineering education criteria expansion, specifically for EAC Criterion 5, stipulating expanded incorporation of DEI (diversity, equity, and inclusion) into curricula. While these topics have begun to enter the broader civil and environmental engineering curriculum and have made monumental gains in coverage [1], they have less often been integrated into structural engineering. The current undergraduate structural engineering curriculum at our institution lacks the incorporation and facilitation of the necessary skills to support the entrepreneurial mindset development needed for multi-faceted disaster risk management. As many structural engineers begin their practice after undergraduate education, it is critical to begin to integrate and build these skills before they enter practice [2], [3]. Therefore, we develop an instruction module to provide a proper introduction of multi-criteria disaster risk management to undergraduate structural engineering students. We adopt a game-based learning approach. Game-based instructional modules have been shown to be an effective tool for learning [4], [5], [6], [7], [8], [9] by facilitating a more engaging environment [10], [11], [12], [13], [14]. This type of learning environment can be structured to mirror many of the real life environments and challenges students will face in their careers. Further, a decision-making game facilitates development of KEEN's entrepreneurial mindset 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.

Herein, we present an expanded multi-role version of a previously developed novel game-based instructional module, Resilient Community. The expansion is for improved learning efficiency of community resilience and equity-based multi-criteria decision-making skill development. We describe the game-based module in the next section: first, we describe the learning goal and derived learning objectives (LOs), secondly, we describe the original game format, and lastly, we describe the multi-role expansion. We have pilot tested the multi-role expansion in a civil and environmental engineering departmental game night with 15 students. Feedback was collected after gameplay for improved game design, and we present this feedback with a brief discussion on further multi-role expansion development. We conclude with a brief discussion on further development.

Resilient Community multi-role expansion: An improved board game for learning how to manage community resilience in multi-criteria 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. The game is structured in a cooperative format. This format was selected to facilitate discussion among players who likely possess different views (both personally and with adopted special roles) on the multiple criteria and decisions to be made throughout the game. This design was selected to simulate the complex nature of multi-criteria decision-making students will face throughout their engineering careers. This design also fosters the development of knowledge and application skills to conduct community conscious multi-criteria decision-making.

To achieve our overall learning goal, six LOs were identified related to key fundamental concepts for community resilience-based and equity-based multi-criteria decision-making: 1) Students will be able to understand the different factors that influence community resilience and the challenges of multiple criteria application in community resilience-based decision-making. 2) Students will be able to apply multi-criteria decision-making for infrastructure systems. 3) Students will be able to understand how equity can be considered in community resilience-based infrastructure decision-making. 4) Students will be able to assess the potential impact of different decisions on various stakeholders in the community, including marginalized groups. 5) Students will be able to collaborate effectively with their peers to make informed and equitable decisions based on multiple criteria and perspectives. 6) Students will be able to reflect on their learning experience and apply the knowledge and skills gained from the game to real-world situations. The concepts stemming from these objectives drive the entire game design and motivate choice for game structure, components, actions, special roles, and scoring system. Additionally, the multi-role modifications presented in this paper are derived to better facilitate the LOs. The original game design as presented in [15] is briefly introduced followed by details on the multi-role expansion in the following sections.

Brief game overview

The Resilient Community game was initially designed as a cooperative board game for group-play where teams make decisions for electric distribution system retrofit and recovery under hurricane hazards. All of a team's players cooperate to select electric distribution system components for recovery and improvement across the entire community's electric distribution network as it is impacted by hurricane events. Figure 1 displays the game board and Resilient Community's electric network, component tiles that indicate a component's functionality, and community neighborhoods. Three elements constitute the game's structure: 1) A hazard impacts the community. 2) Teams respond by making decisions on repairs and retrofits. 3) The hazard repeats allowing for players to gain feedback on their previous decisions. Throughout the gameplay, teams repeatedly execute multi-criteria decision-making as they enact improvements on the distribution system to perform against hurricane hazards. In each turn, gameplay is structured as follows: 1) Teams implement a certain number of actions under the community budget in a turn for a combination of retrofit (i.e., strengthening) of undamaged components, repair of damaged components, or recovery of destroyed components. Both retrofit and repair utilize one action to enact while recovery utilizes three actions to enact. 2) A hazard card that

specifies the impacted area is drawn and a die is rolled to dictate the intensity of the hazard (i.e., 1, 2, 3). The hazard is applied to the community by an evaluation of component strength levels relative to the applied intensity. A component survives if its strength is at or greater than the hazard intensity. Otherwise, it is damaged or, if already damaged, the component is destroyed. 3) A community budget card that influences the community budget (i.e., number of actions available to a team in the next turn) is drawn.

Teams must weigh the following five objectives as they implement their actions to manage community risk: 1) *System Functionality* - number of functioning components, 2) *Network Strength* - number of improvements, 3) *Inequity of Restoration* – maximum difference of non-functioning (i.e., damaged and destroyed) components between neighborhoods, 4) *Inequity of Improvements* – maximum difference of improvements between neighborhoods, and 5) *Community Functionality* – number of non-deserted neighborhoods (i.e., the substation and more than half of the components are not destroyed in a neighborhood). Team performance across all five objectives is compared and the final score is based on their comparative performance. Additionally, in the original version, teams select one of three special roles to adopt for the whole team providing a benefit to aid their ability to repair, retrofit, or recover the electric distribution system. These roles relate to relevant decision-makers in the pre-event preparation and post-event response.

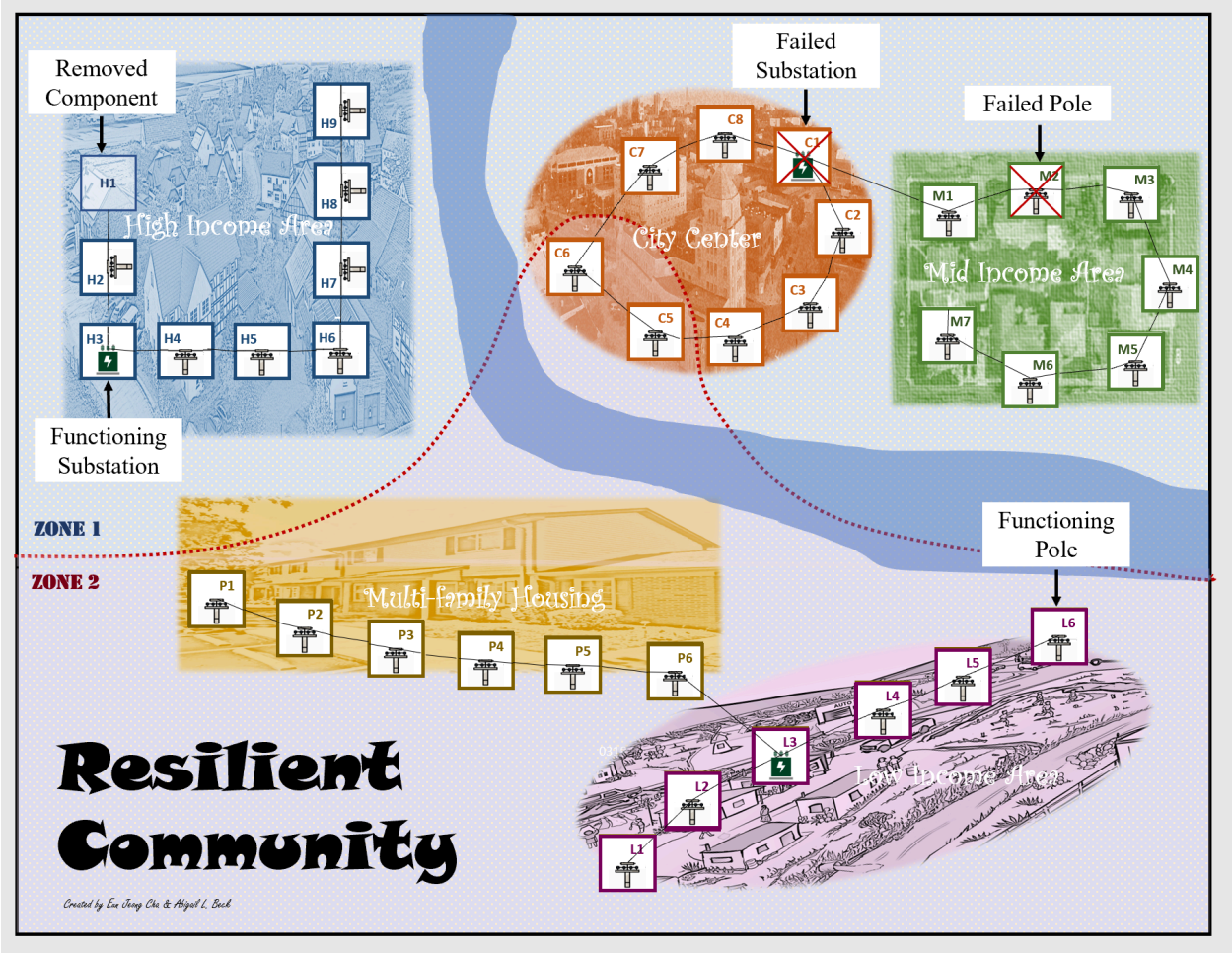

Figure 1: Game board with electric network component tiles [15]

Multi-role expansion

The game is expanded to accommodate a multi-role structure to better facilitate learning in alignment with the LOs. In all real infrastructure decisions, there will be multiple stakeholders for which competing views will need to be negotiated. Engineers often play a critical role in facilitating risk management and communication among all parties. For students to become prepared to fulfill this role and manage multi-criteria decision-making, they must understand and be able to identify stakeholders in a decision problem, understand conflicting assessment criteria, and identify impacts on a community due to adopted alternatives. Additionally, in a realistic setting stakeholders will interact and cooperation in the game will further develop students skills and ability to cooperatively navigate multi-criteria decision-making. The multi-role revision is structured so that each player takes on their own unique special role.

Each special role stems from a common stakeholder involved in pre- and post-event disaster decisions. Table 1 lists the special roles and describes their defining characteristics. Each special role has a primary objective, one of the five outlined objectives (i.e., *System Functionality*,

Network Strength, *Inequity of Restoration*, *Inequity of Improvements*, and *Community Functionality*). During gameplay, a player is tasked with working towards their primary objective while cooperatively working with other players to best serve the community. At the end of the game, players are scored by a comparative assessment against other players with the same special role in other teams of their performance on their objective. A team's aggregate score is then determined based on all roles ranked performance. This formulation and scoring simulates how stakeholders will often be vying for their own objective while also working to mitigate overall community risk and serve the greater community. Additionally, each special role has its own unique special ability tailored to their role and related to their objective. During the game in each turn, players in each team must discuss and select one of the special roles who will then enact their special ability in that turn. These special roles promote discussions between players, better simulate realistic decision-process, and ultimately aid students in developing cooperative decision-making skills.

Table 1: Special role description

Special Role	**Objective of Concern**	**Special Ability**
Engineer	System Functionality (Obj. 1)	Able to place an additional level of retrofit protection to intensity level of 4.
Regulatory Official	Network Strength (Obj. 2)	Additional retrofit or repair action when a budget or grant card is drawn.
Emergency Preparedness Official	Inequity of Restoration (Obj. 3)	Additional repair action for a component adjacent to a damaged component.
Community/Public	Inequity of Improvements (Obj. 4)	Additional action if all neighborhoods are functional (i.e., substation and more than half components in neighborhood functioning)
Community Official	Community Functionality (Obj. 5)	Recovery of removed component with 1 action for budget and grant cards (rather than 3)

Evaluation

The game expansion was tested in a civil and environmental engineering departmental game night. There were 15 game players including 4 undergraduate students and 11 graduate students. They constituted 4 teams, and the teams were formed by choice with groups consisting of mixes of undergraduate and graduate students. An anonymous post-game survey was implemented to capture feedback on: 1) alignment of the game with LOs, 2) general game structure, and 3) open-ended suggestions. This feedback guides further multi-role game expansion development. Overall, the game was well-received by the game players and many cited a desire to play the game again.

The post-game survey asked players to rate their understanding and or ability related to each of the six LOs on a Likert scale from 1 (strongly disagree) - 5 (strongly agree). Table 2 displays the LO questions, players' answers, and average score for each question. This qualitative LO self-assessment and the high averages confirm the game's alignment to facilitate development in each LO around resilience-based decision-making. The survey also asked players if they agreed or disagreed with statements about the game's structure, such as game goal, rule learning time, gameplay time, and visual elements. The questions and answers are displayed in Table 3. These responses to the game's structure confirm the game is well developed. The feedback in regards to time (i.e., for rule learning and game play) are lower; however, researchers note that many players came in late to the board game night impacting rule discussion and game start. This may have impacted the answers for game timing. Yet, the successive open-ended questions reveal that many players felt oppositely and that the game could have been played with a faster pace to make the pressure of successive decisions greater. Lastly, the survey asked for any feedback or suggestions in an open-ended format. Table 4 summarizes the feedback for further game refinement.

Table 2: Learning objective facilitation

Question (n = 15)	1	2	3	4	5	Avg
I understand different factors that influence community resilience. (LO1)	1	1	-	9	4	3.93
I can apply multi-criteria decision-making for infrastructure systems. (LO2)	-	1	1	10	3	4
I understand how equity can be considered in infrastructure decision-making. (LO3)	-	1	2	10	2	3.87
I can assess the potential impact of different decisions on various stakeholders in the community, including marginalized groups. (LO4)	-	2	3	9	1	3.6
I can collaborate with others to make informed and equitable decisions based on multiple criteria and perspectives. (LO5)	-	1	3	1	10	4.33
I understand the challenges of considering multiple criteria in infrastructure decisions. (LO6)	-	1	1	7	6	4.2

Table 3: Game structure feedback

Statement	Percentage Agree (%)
The goal of the game was well-defined.	93.3

The game rules were learned quickly.	60
The game took too long to play.	73.3
The visual elements of the game were easy to understand.	93.3

Table 4: Categorization of game feedback

Feedback Classification	Occurrence
Visual	1
Game Structure	7
Final Scoring	2
Special Role Clarity	3
Game Rule Explanation	2
High Income/Equity Considerations	3

The open-ended feedback provided many suggestions for future game modifications. Our discussion herein will primarily highlight multi-role feedback for brevity as it is the primary focus of this paper. Two players responded that they were not sure why each player was assigned a special role, and one player suggested removing the special roles in favor of just voting on a 'powerup ability'. On the other end of the spectrum, another player suggested making the roles more complex and reported that it became 'simple after a while'. No other players explicitly commented on the multi-role formulation, but generally affirmed their favor of the game structure and ability to learn about decision-making. This feedback in combination with our observations of gameplay in the multi-role format, we plan to further solidify the implementation of the multi-roles. We plan to adopt additional rules that can further encourage players to assume their special role. One suggestion from a game player was for teams to not be able to select to enact the same special role twice in a row. We plan to continue to investigate the multi-role implementation.

Conclusion & Future Development

We presented the multi-role expansion of the game-based learning module for resilience- and equity-based infrastructure decision-making learning. The multi-role expansion more accurately simulates real-world decision-making with different stakeholders vying for their priority. This expansion helps facilitate engineering students to more broadly consider all facets of decision-making and practice cooperative decision-making. The expanded multi-role game was pilot tested in a civil and environmental engineering departmental game night for a mixed group of undergraduate and graduate students. A post-game survey was conducted to benchmark the

updated game's LOs and structure. This feedback will enable further refinement of the multi-role game and support the implementation into an undergraduate structural engineering course. This pilot implementation and collection of self-reported perception of learning was implemented to garner feedback quickly on game design. Further, we plan to utilize more robust data as more objective measures to investigate the validity of this game as an education tool. For this purpose, we plan to integrate this game module as a learning activity in an introductory structural analysis course. We also are developing a computer-based version that will support lower-cost widespread dissemination and implementation potential. The computer-based version will allow for refined multi-role implementation by automatically calculating each objective and displaying it on the computer interface. We anticipate developing the interface so that only the player with that special role will be able to see that objective's score. This mechanism is anticipated to solidify multiplayer adoption more easily than in board game version. The computer-based version will also allow for robust decision tracking and enable us to further assess the learning outcomes.

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