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Board 44: Work-In-Progress: What Goes into an Engineering Decision: An Infrastructure Decision-Making Game for Exploratory Equity Learning

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Abstract

In structural engineering education, social considerations, beyond life-safety, have not been incorporated or highlighted within the curriculum. With ABET's EAC Criterion 5 expansion, we see calls for increased embracement of diversity, equity, and inclusion as a profession. It is the duty of educators to convey to students that engineering decisions have broad reaching impacts on the community beyond their pure technicalities. As engineering decisions are made, elements concerning equity should be weighed along with classic performance benchmarks. This paper introduces an infrastructure decision-making game that highlights many different aspects of risk mitigation decision-making: equity, community impact, system performance, uncertainty, and resource constraint. 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. While making decisions, the teams must weigh many different metrics and be conscious of the sociodemographics across the community. The construction of this game proves an apt complement within classic educational structure, such as in a basic structural engineering course, where students can connect design retrofit strength levels with broader community impact. This game is applicable to students in high school, college-level, and also professionals as an introductory course module for complex multi-faceted risk mitigation engineering decision-making and the role of equity considerations in it. The game design is flexible and can include other impending issues such as climate adaptation. It also has potential to be expanded to include other social considerations such as diversity and inclusion. The paper presents the game development, along with results from a post-game survey demonstrating the effectiveness of the initial version of the game and direction for further game development.

Introduction

Civil engineers are expected to play the role of risk managers who consider and balance potential societal, environmental, and economic impacts, along with opportunities for improvements [1], [2]. With the shift of the risk management paradigm in recent years, holistic views of risk considering the socio-economic impact of physical failures, i.e., community resilience, have been driving studies for innovative risk management solutions in civil engineering. With such a paradigm shift, structural engineers are also increasingly called to consider the broader implications of the design levels they adopt for structures and infrastructure. No longer is a design level simply selected for its technical implications but a design level should be selected in light of the impacts on the broader community and resilience. By extending the view of risk management to be more holistic, the concept of diversity, equity, and inclusion (DEI) has gained attention in risk management as well, since overall community resilience can only be achieved by the well-functioning of all community components. The national emphasis on the increased embracement of DEI is also noted by ABET's EAC Criterion 5 expansion. Additionally, emphasis of social impact and the curricular inclusion of DEI have been noted by current undergraduate students as critical factors to attract new students [3].

However, the current structural engineering curriculum at our institution, University of Illinois Urbana-Champaign, offers students only minimal opportunities for learning the topics of disaster social impacts and DEI in their education. As they practice structural engineering in their career, this lack of understanding may serve as an obstacle for them to play the required role as a risk manager. This highlights a significant gap between the role needed by society and the educational preparation for structural engineers.

Despite the importance of incorporating community resilience and DEI 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 socio-economic disaster impact analysis. It is one of the reasons why these concepts are often taught in a more advanced graduate level course, 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 career after their undergraduate program. While the civil and environmental engineering field has been cited as having the most observed curriculum expansions to include resilience [4], to our knowledge this has less frequently translated to the subspecialty of structural engineering. In this paper, we introduce a novel game-based education module to efficiently teach complex concepts of community resilience and DEI-based decision-making. The module is developed at the level of the high school, college-level, and also professionals. In the following sections, the studies on the effectiveness of game-based learning (GBL) are summarized first and review on its implementation potential to engineering education is provided as well. Then, the developed game is explained briefly with the learning goal and topics. We implemented this learning module in two different settings, first for 25 high schoolers at a civil and environmental engineering departmental summer camp and second for a little under 30 community resilience researchers at the National Institute of Standards and Technology (NIST)'s Center of Excellence for Community Resilience semi-annual meeting. Feedback was collected after the second implementation which is presented as well to discuss the module's future development directions.

Introduction to the *Resilient Community*: A Board Game for Learning How to Manage Community Resilience

Game-Based Learning

Games are known to provide effective learning environments by enhancing motivation and engagement and offering adaptivity and graceful failure opportunities [5]. The entertaining nature of games motivates learners to stay engaged over long periods. Games also allow for a wide range of ways to engage learners: cognitively (i.e., mental processing and metacognition), affectively (i.e., emotion processing and regulation), behaviorally (i.e., gestures, embodied actions, and movement), and socioculturally (i.e., social interactions embedded within a cultural context) [5], [6]. Its adaptivity facilitates learner engagement as well [7]–[10]. Lastly, the lowered consequences of failure in games encourage risk taking, trying new things, exploration [11], and provide opportunities for self-regulated learning during play, where the player executes strategies of goal setting, monitoring of goal achievement, and assessment of the effectiveness of the strategies used to achieve the intended goal [12]. A serious game, a game used with a purpose other than entertainment: learning and training [13], is known to have many benefits compared to traditional lecture style teaching regarding problem-solving skills, knowledge acquisition, higher cognitive gains, and improved attitudes towards learning [14], [15]. The potential of GBL approach for engineering education has been investigated in several studies, for earthquake preparedness [16]–[18], disaster impact mitigation [19], [20], flooding policies [21], territorial risk management [22], and construction projects [23].

Learning Goal and Topics

The goal of the proposed game is to familiarize players with the community resilience-based multi-criteria decision-making process and its fundamental concepts including equity. The game is designed as a cooperative board game to emphasize the feature of multi-criteria decision-making by facilitating discussion among players who would have different weights on the considered criteria. The multi-criteria nature can demonstrate all the different facets a structural engineer will need to consider as they design infrastructure for communities and work to mitigate their community risk. For the game development, we identified key fundamental concepts for community resilience-based decision making, which includes 1) Multi-criteria decision-making (competing criteria, weighting, resource constraints), 2) Equity (equity-based criteria, varying infrastructure quality), 3) Community resilience (community resilience metrics, physical strength, infrastructure functionality, community functionality, socio-economic disaster impact), 4) Cyclic decision phase (pre-disaster retrofit and post-disaster recovery decision-making), 5) System analysis (connectivity, dependence, component criticality), and 6) Risk analysis (uncertainty in hazard occurrence (i.e., location, intensity, climate change) and structural vulnerability). These concepts are embedded in the game through the game components, actions, and scoring system. The game design is briefly introduced in the following sections. Of highlight is the embedment of equity considerations that are apparent in inherent game structure and also criteria teams need to consider.

Game Overview

The *Resilient Community* is a cooperative board game for group-play where each group makes a series of retrofit and recovery decisions for power distribution system structures for managing the community hurricane risks. As a team, players work together to recover and improve *Resilient Community*'s electric infrastructure as hurricanes impact the community. Five objectives are considered while making infrastructure decisions throughout the game, including 1) Network Strength (measured by number of improvements), 2) Inequity of Improvements (measured by the maximum difference in improvements for different neighborhoods), 3) Inequity of Restoration (measured by the maximum difference in the number of non-operational components for neighborhoods), 4) System Functionality (measured by the total number of operational components), and 5) Community Resilience (measured by the area under recovery curve). Teams consider all five of these objectives as they make infrastructure decisions which are considered in final game scoring. At the end of the game each team community's performance is compared among the other teams based on the scoring system reflecting the five objectives. The exact scoring is defined later in the game description.

This game follows a simple game model of a basic structure which consists of three key elements: a challenge, a response, and feedback. During game play, hazards will continue to strike the community and lead to newly damaged components, which is a challenge. Throughout the game, each team responds to the challenges by making decisions regarding repairing and retrofitting electric system components all while keeping the previously outlined objectives in mind. With two objectives formulated specifically for equity, teams are forced to maintain equity-minded objectives (i.e., Objs. 2 and 3) along with system performance objectives (i.e., Objs. 1, 4, and 5) to simulate realistic decision constraints engineers are likely to face in practice. The feedback is given as the next challenge of a hurricane strikes as their community's impact caused by the hurricane varies by the actions taken in the previous steps. Areas with lower income have a higher likelihood of being impacted by a hazard, and in conjecture with the equity-based objectives, players are forced to confront the equity implications of their decisions.

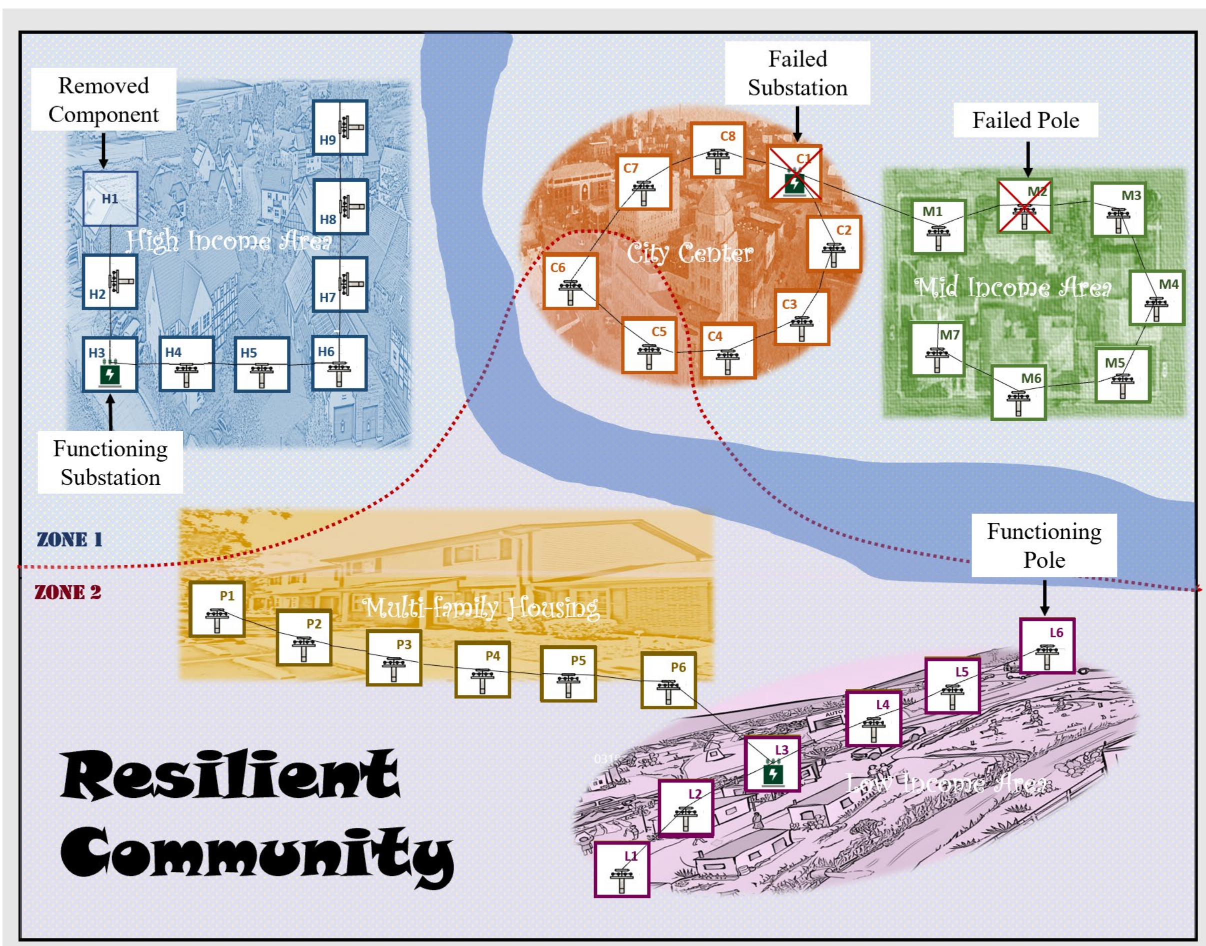

Figure 1: Resilient Community board game layout

Order of Game Play

In the game play, each team practices multi-criteria decision-making by making actions against future hurricane events under resource constraints, while considering the community resilience-based objectives defined by the game scoring system. For instance, players need to weigh the fact that lower-income areas have a greater likelihood of failure compared to the higher-income areas due to the intrinsic probability of occurrence built into the hazard deck. They need to then consider these performance disparities as they make repair and retrofit decisions to maintain performance across the entire community which highlights the importance of equity. This inequity in impact occurrence impacts all objectives considered. The order of gameplay is summarized below. The board layout is shown in Figure 1 with component tile examples highlighted.

1. *<u>Actions:</u>* In each turn, each team takes a given number of actions determined by considering the community budget. The actions can be of the same or different classes. There are 3 classes of actions: 1) Repair a damaged component, 2) Retrofit an undamaged component, and 3) Recover a removed component.
2. *<u>Draw from Hazard Card Deck and Apply Hazard to Resilient Community:</u>* Draw a hazard card and roll dice to determine hazard intensity (1, 2, 3). Likelihood is ½, ⅓, and ⅙ for intensity 1, 2, and 3, respectively. Each hazard card specifies the affected area. The likelihood of a hazard impacting an area varies by hazard zone. If the hurricane hazard hits a component, compare the strength of the component with the given hazard intensity to determine the damage. The component is damaged if strength is less than hazard intensity. An example hazard card is shown in Figure 2(i).
3. *<u>Draw a Community Budget Card:</u>* Draw from the community budget card deck to determine community budget for next actions. Example community budget cards are shown in Figure 2(ii) and 2(iii).

(i) Hazard Card | (ii) Community Budget Card Type 1 | (iii) Community Budget Card Type 2

Figure 2. Examples of gameplay cards

The game can end at any point and the end condition can be pre-defined based on play time or number of turns. Since pre-disaster risk mitigation and disaster recovery are continuous processes, these serve as apt benchmarks to see the progress community decision-makers have made. At the game's end, final scores are tallied and compared among teams. Scores can be calculated for each game objective and/or aggregated using predetermined weights. An example scoring aggregation is depicted in the following equation and the objectives defined as follows:

$$\begin{aligned} Overall\ Score \\ &= Network\ Strength + System\ Functionality - Inequity\ Metrics \\ &+ Community\ Resilience \end{aligned}$$

Evaluation

While no targeted evaluation was conducted after the module's implementation in the summer camp, general camp programming feedback revealed the game was well received and enjoyed by campers. In the module's second implementation with community resilience researchers, gameplay was followed with a survey to benchmark the module's educational outcomes and to garner feedback for game improvement. While this game is initially developed for engineers, it is meant to simulate the real-world difficult interdisciplinary nature of decision-making and as such input from other professionals, e.g., social scientists, economists, and urban planners, is warranted. This feedback will be used for game modification to better represent the infrastructure decision-making process and better support educational outcomes.

Ten participants completed the post-game anonymous survey and consisted of seven engineers, one social scientist, and two urban and regional planners. This sample size represents approximately one-third of participants. Participants were asked to rate the improvement of their ability or understanding on a Likert scale from 1 (strongly disagree) to 5 (strongly agree) for the ability to apply multi-criteria decision-making, for their understanding of the challenges of multiple criteria application, and for their understanding of how equity can be considered in infrastructure decision-making. These questions and the responses are tabulated in Table 1. Most respondents viewed the activity as constructive towards their decision-making development. This qualitative assessment of the activity indicates that it is a well-structured and well-suited activity for these respective components of infrastructure decision-making and educational exposure to the complex topic at a basic level.

Table 1: Decision-making game improvement questions

Question	1	2	3	4	5
I improved my ability to apply multi-criteria decision-making for infrastructure systems.	-	1	4	2	3
I improved my understanding of the challenges of multiple criteria application in infrastructure decisions.	-	-	3	3	4
I improved my understanding of how equity can be considered in infrastructure decision-making	-	-	4	4	1

Participants were also asked to suggest target audiences. While the game was initially designed for students, the participants suggested other audiences, including community decision makers (e.g., stakeholders, city administrators, city officials, local planners), team building activity & team training participants, general community members, and scholars. Participants were also asked for other suggestions in an open-ended format for future game improvement. The suggestions included simplified final scoring method (e.g., "final scoring method can be simplified"), modifications to instruction and rules (e.g., "it would help to expand the instructions with examples of how multi-criteria and equity can be addressed in the game", "make some simplifications to the instructions/rules"), alternate game variations (e.g., "it would be interesting to develop variants for other hazards and infrastructure, including buildings"), more accurate network connectivity and dependency (e.g., add network connectivity elements; consider adding interdependency"), and inclusion of additional infrastructure systems (e.g., "add in other infrastructure impact for additional challenge").

In summary, these suggestions included simplified final scoring method, modifications to instruction and rules, alternate hazard variations, more accurate network connectivity and dependency, and inclusion of additional infrastructure systems. This feedback will help guide future development as the game is refined to be more user friendly and produce more accurate learning outcomes.

Summary & Future Development/Applications

In this paper, we presented a serious game to familiarize players with the community resilience and DEI-based multi-criteria decision-making process and its fundamental concepts. The game was developed for the high school, college, and professional levels, and pilot tested in two different settings, first for high schoolers at summer camp and second for community resilience researchers at a research meeting. Feedback was collected after the second pilot test about its educational and applicational potential. Suggestions on game modification were also collected. We plan to further develop the game as an introductory learning module in structural engineering education in collaboration with experts in game development and engineering education in the upcoming year. The future development effort includes revision of the game design based on the collected feedback and computer-based game development. Also, we plan to expand its implementation to enhance community resilience and decision-making communication in general. Our future implementation plan will be through 1) recurrent summer camp sessions, 2) undergraduate introductory risk management course, 3) community engagement events, and 4) workshop sessions for practicing engineers. As part of the implementation efforts, the game's effectiveness in achieving intended learning outcomes will be assessed as well.

References

[1] ASCE, "Achieving the Vision for Civil Engineering in 2025: A Roadmap for the Profession," in Proc. Summit on the Future of Civil Engineering, August 2009, doi: 10.1061/9780784478868.002.

[2] ASCE, *Code of Ethics*, 2020. Accessed: July 7th 2022. [Online]. Available: https://www.asce.org/career-growth/ethics/code-of-ethics

[3] D. E. Armanios *et al.*, "Diversity, Equity, and Inclusion in Civil and Environmental Engineering Education: Social Justice in a Changing Climate," presented at the 2021 ASEE Virtual Annual Conference. Jul. 2021. https://peer.asee.org/36988

[4] A.-K. Winkens and C. Leicht-Scholten, “Does engineering education research address resilience and if so, how? – a systematic literature review,” *European Journal of Engineering Education*, vol. 0, no. 0, pp. 1–19, Feb. 2023, doi: 10.1080/03043797.2023.2171852.
[5] J. L. Plass, B. D. Hommer, and C. K. Kinzer, "Foundations of game-based learning," *Educational Psychologist*, vol. 50, no. 4, pp. 258-283, Feb 2015, doi: 10.1080/00461520.2015.1122533.
[6] S. Domagk, R. N. Schwartz, and J. L. Plass, “Interactivity in multimedia learning: An integrated model,” *Computers in Human Behavior*, vol. 26, no. 5, pp. 1024–1033, Sep. 2010, doi: 10.1016/j.chb.2010.03.003.
[7] 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.
[8] 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.
[9] 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.
[10] S. Turkay and C. Kinzer, “The Effects of Customization on Game Experiences of a Massively Multiplayer Online Game’s Players," in *Proc. of GLS 9.00: Games C Learning C Society Conf.*, C. Williams, A. Ochsner, J. Dietmeier, & C. Steinkuehler, Eds. Pittsburgh, PA. 2013, pp. 330-337.
[11] B. Hoffman and L. Nadelson, “Motivational engagement and video gaming: a mixed methods study,” *Education Tech Research Dev*, vol. 58, no. 3, pp. 245–270, Jun. 2010, doi: 10.1007/s11423-009-9134-9.
[12] S. Barab, S. Warren, and A. Ingram-Goble, “Conceptual play spaces,” in *Handbook of Research on Effective Electronic Gaming in Education*, R. E. Ferdig, Ed., Hershey, PA, USA: IGI Global, 2008, vol. 3, pp. 989-1009, doi: 10.4018/9781599048086.ch057.
[13] D. R. Michael and S. L. Chen, “Serious games: Games that educate, train, and inform," Muska & Lipman/Premier-Trade, 2005.
[14] J. Hamari, D. J. Shernoff, E. Rowe, B. Coller, J. Asbell-Clarke, and T. Edwards, “Challenging games help students learn: An empirical study on engagement, flow and immersion in game-based learning,” *Computers in Human Behavior*, vol. 54, pp. 170–179, Jan. 2016, doi: 10.1016/j.chb.2015.07.045.
[15] J. J. Vogel, D. S. Vogel, J. Cannon-Bowers, C. A. Bowers, K. Muse, and M. Wright, “Computer Gaming and Interactive Simulations for Learning: A Meta-Analysis,” *Journal of Educational Computing Research*, vol. 34, no. 3, pp. 229–243, Apr. 2006, doi: 10.2190/FLHV-K4WA-WPVQ-H0YM.
[16] J. Novak, J. C. Lozos, and S. E. Spear, “Development of an Interactive Escape Room Intervention to Educate College Students about Earthquake Preparedness,” *Natural Hazards Review*, vol. 20, no. 1, p. 06018001, Feb. 2019, doi: 10.1061/(ASCE)NH.1527-6996.0000322.
[17] Z. Tanes and H. Cho, “Goal setting outcomes: Examining the role of goal interaction in influencing the experience and learning outcomes of video game play for earthquake

preparedness," *Computers in Human Behavior*, vol. 29, no. 3, pp. 858–869, May 2013, doi: 10.1016/j.chb.2012.11.003.

[18] R. Lovreglio *et al.*, "Prototyping virtual reality serious games for building earthquake preparedness: The Auckland City Hospital case study," *Advanced Engineering Informatics*, vol. 38, pp. 670–682, Oct. 2018, doi: 10.1016/j.aei.2018.08.018.

[19] R. Kaneko, M. S. Al Farisi, S. Yamada, and K. Miwa, "Evaluation of the Disaster Mitigation Action Card Game for international students in Japan," *Tohoku Journal of Natural Disaster Science*, vol. 54, May 2018.

[20] G. Pereira, R. Prada, and A. Paiva, "Disaster Prevention Social Awareness: The Stop Disasters! Case Study," in *2014 6th International Conference on Games and Virtual Worlds for Serious Applications (VS-GAMES)*, Sep. 2014, pp. 1–8. doi: 10.1109/VS-Games.2014.7012155.

[21] G. Rebolledo-Mendez, K. Avramides, S. de Freitas, and K. Memarzia, "Societal impact of a serious game on raising public awareness: the case of FloodSim," in *Proceedings of the 2009 ACM SIGGRAPH Symposium on Video Games*, in Sandbox '09. New York, NY, USA: Association for Computing Machinery, Aug. 2009, pp. 15–22. doi: 10.1145/1581073.1581076.

[22] F. Taillandier and C. Adam, "Games Ready to Use: A Serious Game for Teaching Natural Risk Management," *Simulation & Gaming*, vol. 49, no. 4, pp. 441–470, Aug. 2018, doi: 10.1177/1046878118770217.

[23] F. Taillandier, A. Micolier, G. Sauce, and M. Chaplain, "DOMEGO: A Board Game for Learning How to Manage a Construction Project," *IJGBL*, vol. 11, no. 2, pp. 20–37, Apr. 2021, doi: 10.4018/IJGBL.2021040102.