The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
ASEE
Paper ID #42436

Development of an Interactive, Game-Based Nuclear Science Museum Exhibit on Probabilistic Risk Assessment

Camille S. Levine, University of Maryland

Camille Levine is a graduate student in the SyRRA Lab pursuing her Ph.D. in Reliability Engineering. She graduated from the University of Maryland in 2021 with a bachelor's in Mechanical Engineering with a minor in Project Management. Her research focuses on enhancing the causal basis behind current human reliability analysis methods. She has also worked on human reliability analysis for external hazard probabilistic risk assessment, particularly in nuclear power plant applications.

Samantha Ellen Wismer, University of Maryland
Ryan Painter
Katrina Groth, University of Maryland

Development of an Interactive, Game-based Nuclear Science Museum Exhibit on Probabilistic Risk Assessment

Camille S. Levine [a*], Samantha E. Wismer [a], Ryan Painter [b], Katrina M. Groth [a]

[a] Systems Risk and Reliability Analysis (SyRRA) Lab, Center for Risk and Reliability, University of Maryland, College Park, MD
[b] National Museum of Nuclear Science and History, Albuquerque, NM

*Corresponding author: clevine1@umd.edu

Abstract

Science and engineering museums must leverage a variety of pedagogical strategies to facilitate STEM learning for a public audience. Complex, abstract concepts such as reliability engineering and risk analysis are difficult to convey in a technical manner to non-technical visitors without losing fidelity. Techniques such as exhibit interactivity, open-ended tinkering, and competitive games are frequently used to hold visitors' attention and draw analogies to more familiar concepts.

Reliability engineering principles are vital to the growth and continued safety of the nuclear energy industry. General knowledge of risk as it applies to nuclear energy can be expanded by disseminating this information to the public via engaging educational content. In this paper, we present the design of an interactive, game-based museum exhibit developed through iterative collaboration between exhibit designers and reliability engineering researchers at the University of Maryland, curators at the National Museum of Nuclear Science and History (Nuclear Museum), and media design students and faculty at the New Mexico Highlands University (NMHU). Museum visitors have frequently asked how the risks of nuclear power compare to other energy sources, and to date, no museum exhibit at the Nuclear Museum has answered this question. This work presents examples of museum exhibit content, artifacts, and graphics to convey concepts in probabilistic risk assessment at a level accessible to the general public. In addition to the physical exhibit installation, the game will also be available on the public-facing museum website to increase the breadth of outreach. Finally, a proposed questionnaire method for evaluating exhibit efficacy and public engagement is presented. Feedback obtained will allow for periodic revisions of exhibit content.

Introduction

Science museums, such as the National Museum of Nuclear Science and History (Nuclear Museum), are a valuable national and community resource enabling the dissemination of STEM concepts to the general public. To be successful, a museum exhibit must both attract public interest and convey its technical information concisely and accurately. This requires close interdisciplinary collaboration between subject matter experts, museum curators, and exhibit designers during its developmental stages. Exhibits that are relatable and interactive can provide engaging and effective learning opportunities to a broad range of visitors.

Interactive science museum exhibits tend to promote open-ended exploration of concepts, but this open-endedness also means that meaningful interactions are dependent on an individual's attention and motivation levels [1]. If a particular exhibit takes too much effort to understand, especially toward the end of a museum experience, the visitor will turn to another exhibit [2]. Many museums seek to foster active prolonged engagement (APE) with their educational content. APE comprises several types of museum visitor behavior: questioning that drives exploration, active and passive observation, investigation along branching paths, and reflecting upon causal phenomena [3]. The Exploratorium Museum in San Francisco has sought to implement exhibits that facilitate APE, and has measured visitor engagement levels through detailed observation of their interactions, both with the content and with each other [2]. Activities involving tinkering also tend to better convey engineering concepts in a museum setting. By playfully exploring and iterating upon previous actions, learners can refine their concept of the problem as well as the solution they generate [4]. Interactive components can be implemented through a digital medium which may afford a wider range of inputs and outputs than the physical world.

Motivation & Background

Developing a museum exhibit on probabilistic risk assessment (PRA) presents unique challenges in promoting engagement due to the abstract and advanced nature of the subject matter. PRA, at its core, is concerned with the probability and consequences of risks to the safe operation of complex engineering systems. It is important for the general public to understand why PRA is needed and how it is used, because it systematically catalogs potential system risks and justifies which mitigation or avoidance measures are appropriate. These risks are often low-probability and high-consequence, which are inherently difficult to conceptualize (e.g., a probability of occurrence of 2E-6 per year, corresponding to one event expected every 500,000 years). The theoretical nature of PRA means that there is a lack of observable physical phenomena or artifacts that can be used to convey its concepts to a museum audience.

Furthermore, PRA is typically offered as a graduate-level university course and tends to build upon years of experience working with complex engineering systems and probabilistic modeling. To incorporate PRA concepts into a public-facing museum exhibit targeting a middle-school level of understanding, the content must be pared down and significantly simplified. The goal of this exhibit is to encourage visitors of all ages to stay and engage in learning despite the advanced nature of the content, rather than moving on to other exhibits that may require less effort to understand.

To promote user engagement, we have developed an interactive game that allows players to tinker with the effects of their decisions. In particular, the game allows users to investigate branching decision paths, a key component of APE [3]. The basic premise of the game is that the user must make driving-related decisions that modify the probability and consequences of an accident. They may play the game any number of times to see how their decisions change the chances of each outcome as well as the outcome itself. In this paper, we have included an example of typical gameplay progression, as well as our plan for evaluating learning outcomes.

The development of this museum exhibit was motivated by a larger initiative to increase the public knowledge of engineering risk assessment and broaden the participation of underrepresented groups in reliability engineering. The Nuclear Museum is a Smithsonian-affiliated institution in Albuquerque, New Mexico that hosts approximately 65,000 visitors annually, and presents educational programs to approximately 10,000 students annually. According to the museum's previous director, there has been intense visitor interest in nuclear safety and associated risks. This exhibit will be the first to address these topics and directly provide factual information to help the public understand the tools used in ensuring nuclear safety. To reach an even wider audience, the digital portions of the exhibit will be made available online at the Nuclear Museum's website so that it can be experienced from anywhere.

Methods

Conveying the principles of reliability engineering and risk as they apply to the nuclear energy industry, to a broad audience mandated an interdisciplinary approach. Proper dissemination of scientific knowledge requires clear and accessible communication of information to a range of audiences. In the planning and creation of the exhibit, researchers at the University of Maryland (UMD) provided expertise in the content area of PRA. The Nuclear Museum provided a platform to display the information to a range of audiences in terms of both age and background and facilitated translating the PRA content into a 7^{th} grade level of understanding. Design students and faculty from New Mexico Highlands University (NMHU) created visuals and framework for a video game to engage museum patrons in the exhibit. The Nuclear Museum is currently working with a professional exhibit designer to arrange additional exhibit content and to transform the framework from NMHU into an interactive game within the exhibit to guide the player through the risk-informed decision making.

In collaborative meetings held by UMD researchers and Nuclear Museum staff, exhibit content was developed according to the Nuclear Museum's principles of showcasing 3 to 5 main ideas. The UMD team deemed the main topics of the reliability engineering "risk triplet" suitable to build the exhibit narrative. Formal risk analysis uses the risk triplet to define risk by answering the following questions [5]:

- What can go wrong?
- How likely is it to happen?
- If it happens, what consequences are expected?

Risk analysts use tools such as event trees and fault trees to answer the above questions [6]. However, these methods are unfamiliar, and can be confusing, to new audiences. Additionally, unlike a classroom setting, there is a greater uncertainty in the background knowledge held by those seeing the exhibit. To combat these challenges, the risk triplet and these tools were introduced in the context of a more familiar topic: safety while driving a car. This creates a better environment for learning new topics in reliability engineering and forms a foundation of understanding that can later be related to risk around nuclear energy.

Utilizing the idea of safety when driving a car also lends itself well to making the exhibit interactive through a game. Players can participate in active learning through making choices regarding driving safety and reading content along the way describing the risk analysis process. Additionally, with different possible outcomes, multiple playthroughs are incentivized, and thus multiple exposures to the material. This implementation of different learning pedagogies through gameplay encourages museum patrons to give the complex material the time and attention it requires to best be understood. To play, only a seat, steering wheel for choice selection, and a screen to display the game are needed, which also fits well into the limited space available (150 square feet) to implement the exhibit. The physical construction of the exhibit is being conducted by staff at the Nuclear Museum. Programming for the game was initiated with students and faculty at NMHU, who created 3D models using the graphics software Blender. UMD developed the storyline and gave general direction to NMHU regarding the desired layout and graphics. A series of monthly meetings were required to iterate through design options and ensure that the message of risk and reliability was accurate in the materials. This also allowed the students at NMHU to gain experience in project management and interfacing with clients.

Content of Museum Exhibit: "Buckle Up!"

The exhibit will be displayed as part of the "Energy Encounter" exhibition at the Nuclear Museum. As mentioned above, the available floor space was limited to only around 150 square feet, and the nature of the research topic necessitated a more interactive, hands-on approach. It was decided to display most of the content digitally and incorporate a game component involving driving a car, which stemmed from some research content about seatbelts and associated safety risks in choosing to use them or not.

Figure 1: 3D rendering of physical game setup. A car seat and steering wheel are mounted in front of the exhibit's digital screen where visuals will be displayed.

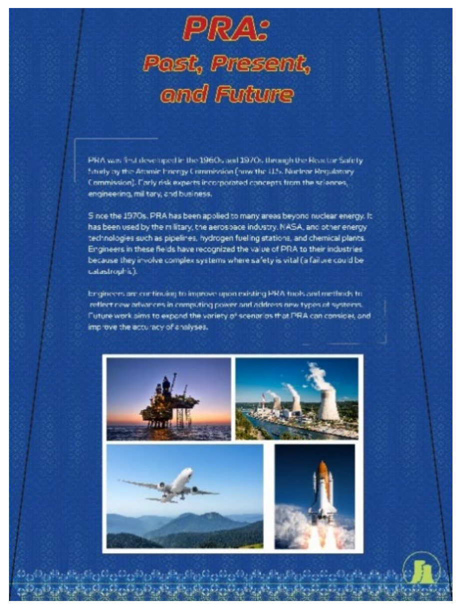

Figure 2: Example content panel describing past, current, and future applications of PRA.

When complete, the user will be able to read the exhibit panels digitally on a large 75"-85" screen with enabled audio. A steering wheel will be used to control the interactive components, allowing users to select options or game scenarios. A car seat will be placed behind the steering wheel, in the style of arcade racing games, as shown in Figure 1. The team is currently working to design alternative ways to interact with the exhibit screen to enhance accessibility. Physical panels with educational content, like the panel shown in Figure 2, will be placed around the game setup so that users may engage with the exhibit without playing the game.

The five main concepts of the exhibit are shown in Table 1. Main idea 1 begins by introducing the idea of risk and its assessment. Main ideas 2, 3, and 4 correspond roughly to the three aspects of the risk triplet: potential areas for risk analysis to be applied, risk quantification methods, and PRA's contribution to managing consequences. Finally, main idea 5 draws a connection from relatable, everyday risks to nuclear energy risks, which is the final abstraction needed to fully understand PRA as a tool in the nuclear context.

Table 1: Five main ideas employed in exhibit, with detailed description of each.

Main Idea	Description of Theme
1. What is Risk?	PRA at its core is figuring out what could go wrong, how likely it is, and what the consequences would be: the risk triplet.
2. Where is PRA applied?	PRA methods have been applied to a variety of large and complex systems that help society to function, with a rich history across many industries.
3. What are the methods that PRA uses?	Methods and tools such as Failure Modes and Effects Analysis, logic trees, Boolean logic, probabilities, and expert knowledge from all aspects of the system, help experts identify the components of the risk triplet and what to do about system risks.
4. Why is PRA important and how does it make systems safer?	PRA makes these systems safer by identifying the main risk contributors so that they can be addressed, and consequences can be avoided or managed. PRA is necessary for complex systems like nuclear power plants because the consequences of failure are high, but the good news is that the probability of something going wrong is extremely low.
5. Should we be scared of nuclear risk?	Nuclear risk, compared to other risks that we take in day-to-day life, is comparatively small.

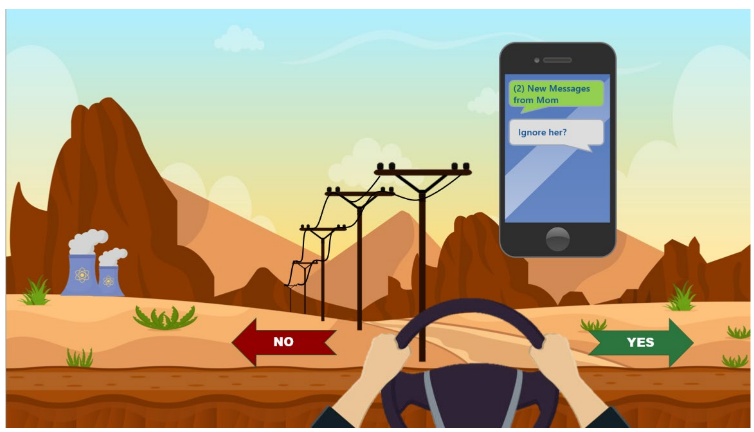

Figure 3: User is driving and must decide whether to ignore an important text.

In the beginning of the interaction, the user is asked which is safer: nuclear power plants or cars. The answer is withheld until the game is completed. To play the game, the user first must allocate a limited budget toward purchasing a vehicle and conducting necessary maintenance. Next, they are asked if they choose to put on a seatbelt. They may then choose from four different game scenarios to play. In this example, the "texting" scenario is demonstrated. The user is asked if they choose to ignore or respond to an important text message (Figure 3) - then suddenly, a work area pops up and they must swerve (Figure 4).

The probability that they can successfully swerve depends on their choice to ignore the message and their initial choices of maintenance. Bad driving decisions and deciding not to get certain car repairs increase the probability of an accident across all scenarios. The consequences of a crash (which may or may not happen) depend on their choice to respond or ignore and their choice to wear or not wear a seatbelt. Just as the user's decisions affect the probability of an adverse outcome, the consequences increase when the user makes bad driving decisions or chooses not to wear a seatbelt (Figure 5). The text at the end of the scenario is meant to encourage the user's counterfactual reasoning (e.g., if I had gotten the steering replaced instead of the headlights, would my result be a successful stop instead of a crash? what if I had not texted?), leaving open potential for replaying the game to get a different risk level.

Figure 4: Immediately after receiving the text, a work area pops up that the user must swerve around.

At the end of the game, the exhibit circles back around to the question from the beginning- and the user is surprised to see that the answer is that nuclear power plants are approximately 1,200 times safer than cars.

In addition to the game, the user may use the steering wheel to select from several digital exhibit content panels. These resources answer the questions of 1) what risk is; 2) where PRA is typically applied; 3) what methods are typically used in PRA; and 4) how PRA makes systems safer. The UMD research team drew upon textbooks and formative PRA texts such as WASH-1400 ([6], [7]) to develop factually accurate content at a middle-school level of understanding.

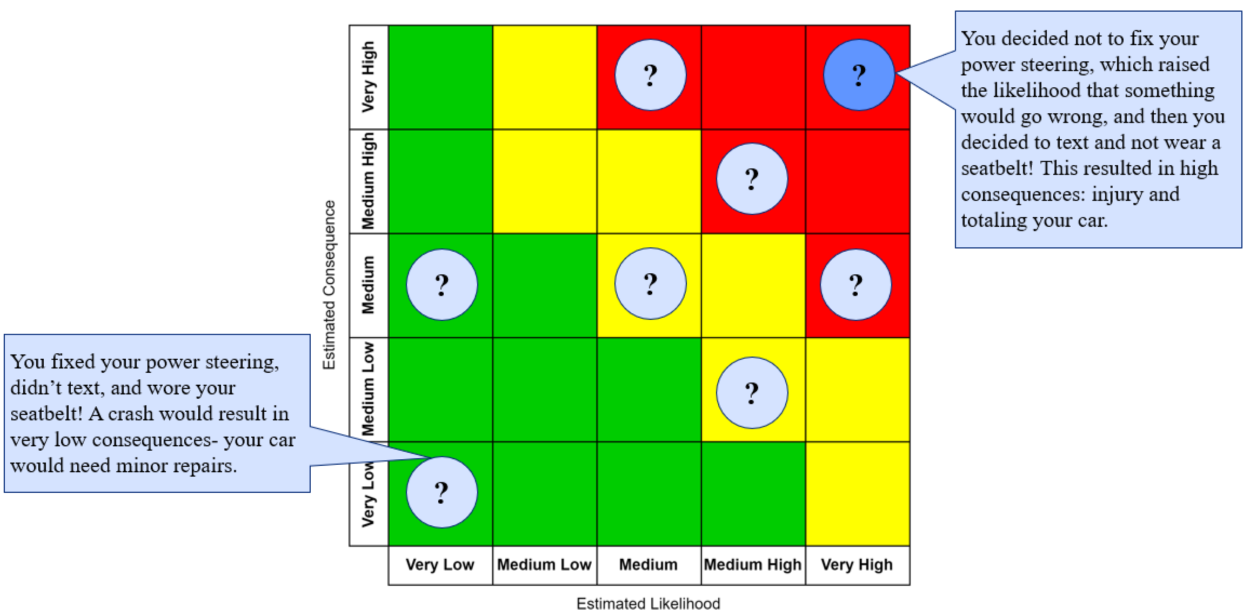

Figure 5: At the end, the user is shown a risk matrix, which explains how their actions affected the likelihood and consequences of a crash. They can explore each game ending, represented by a blue circle. The red area indicates high risk scenarios, yellow indicates moderate risk, and green indicates low risk.

Exhibit Evaluation and Future Work

After the implementation of this exhibit, it will be important to measure the resulting impact on the public's understanding of PRA and their view of nuclear energy. Many techniques exist for measuring engagement and learning in museums, such as timing and tracking studies, interaction logs, questionnaires, interviews, and direct/video observations [8]. However, many of these techniques do not align with the proposed allocation of the museum's limited resources. To effectively evaluate the exhibit without placing an undue burden on the museum staff or visitors, we plan to analyze the game's interaction logs and develop a short, anonymous questionnaire to assess learning outcomes.

The visitors are asked at the beginning of their interaction to guess whether nuclear power plants or cars are safer, which will allow the museum to log how many users the PRA exhibit sees over the course of its operation. This will also enable the museum to track the percentage of total visitors that choose to engage with the exhibit, the average length of time they spend from the beginning to the end of the interaction, and visitor knowledge before the encounter. However, logs alone cannot provide a full picture of the user's actions, thoughts, and reactions. Direct qualitative input from the visitors will be solicited to gain these insights.

Toward this end, a short, anonymous questionnaire will be developed. This questionnaire will be made available in pen-and-paper format at the location of the physical exhibit in the Nuclear Museum. At the end of the online game, an identical questionnaire will also be made available in digital format. Because there is a known concern of questionnaires that respondents with strong opinions will self-select [8], the questionnaire should be kept as short as possible to avoid discouraging any visitors who are willing to participate. Questions will also be open-ended, centering around whether the respondents feel that their knowledge about PRA has improved. The questionnaire will contain a disclaimer that users' responses are anonymous but will be used to improve the quality of the exhibit.

Any quantitative results obtained from the questionnaire (e.g., Likert scale answers to questions such as "How would you rate your knowledge of PRA [prior to/after] experiencing the exhibit?") will be statistically analyzed to unearth any statistically significant relationships affecting learning. For qualitative results from any open-ended responses, we will use keyword coding to interpret themes in accordance with the method described in [9]. First, emergent ideas will be identified from initial readings through the data. Then, a concise list of tentative codes can be constructed from these ideas and textual examples. Lastly, results can be interpreted and represented in tabular or graphical form [9]. Crucially, conducting this analysis does not require the input of subject matter experts. Results can then be used to improve the exhibit.

This methodology for measuring museum visitors' engagement and learning is intended to determine the exhibit's overall efficacy. This work represents a novel technique for explaining the technical concepts of PRA to a non-technical audience, which has not been done before in a museum setting. The qualitative results will be used to iterate upon the exhibit's design and further cater content toward eliciting the desired educational outcomes.

Discussion & Conclusions

This museum exhibit is designed to inspire interest and foster APE through two main aspects: interactivity and tinkering. The nature of the game also encourages competition and contrasting goals among groups of museumgoers. Players may compete against each other to see who can get the highest or lowest risk levels. A user might initially play through the game using the "best" decisions, then run a second playthrough to see what happens when they make the "worst" decisions. Other visitors might do this in the opposite order, or they might aim to survive all of the scenarios without crashing at all.

To hold the attention of a non-technical audience and deliver information in an understandable manner, the game draws analogies to familiar situations involved with driving. Typical PRA scenarios for nuclear power plants involve events such as a failure to isolate a steam generator tube rupture or failure of backup diesel generators. Most users lack interest in these scenarios, or concrete knowledge of nuclear energy systems. Furthermore, additional engagement that goes beyond reading museum panels is needed to grasp the upper-level engineering concepts of PRA. The game is intended to both hold the users' attention and provide prolonged, relatable exposure to the topics at hand.

The museum exhibit presented in this paper aims to teach probabilistic risk concepts to a varied audience of visitors to the Nuclear Museum. Through the design of a relatable, visually interesting game, users are encouraged to linger at the exhibit and absorb PRA concepts. By the end of their interactions with the exhibit, museum visitors may appreciate the usefulness of risk assessment in their daily lives beyond its applications to nuclear power.

Acknowledgments

This material is based upon work supported in part by the National Science Foundation under Grant No. 2045519. 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 National Science Foundation.

The authors would like to thank Vincent Paglioni from the University of Maryland, James Stemm from the National Museum of Nuclear Science and History, and Lauren Addario, Rianne Trujillo, Jonathan Lee, Becca Sharp, and Dion Boyer from New Mexico Highlands University for their work toward this project.

References

[1] S. Allen, "Designs for learning: Studying science museum exhibits that do more than entertain," *Sci. Educ.*, vol. 88, no. S1, pp. S17–S33, 2004, doi: 10.1002/sce.20016.

[2] C. Tisdal, "Phase 2 Summative Evaluation of Active Prolonged Engagement at the Exploratorium," Sep. 2004.

[3] T. Humphrey and J. P. Gutwill, *Fostering Active Prolonged Engagement: The Art of Creating APE Exhibits*. Routledge, 2017.

[4] L. Lyons, M. Tissenbaum, M. Berland, R. Eydt, L. Wielgus, and A. Mechtley, “Designing visible engineering: supporting tinkering performances in museums,” in *Proceedings of the 14th International Conference on Interaction Design and Children*, in IDC ’15. New York, NY, USA: Association for Computing Machinery, Jun. 2015, pp. 49–58. doi: 10.1145/2771839.2771845.

[5] S. Kaplan and B. J. Garrick, “On The Quantitative Definition of Risk,” *Risk Anal.*, vol. 1, no. 1, pp. 11–27, 1981, doi: 10.1111/j.1539-6924.1981.tb01350.x.

[6] M. Modarres and K. Groth, *Reliability and Risk Analysis*, 2nd ed. Boca Raton: CRC Press, 2023. doi: 10.1201/9781003307495.

[7] N. Rasmussen, “Reactor safety study: An assessment of accident risks in U. S. commercial nuclear power plants,” U.S. Nuclear Regulatory Commission, Washington, D.C., WASH-1400, Oct. 1975.

[8] E. Hornecker and L. Ciolfi, *Human-Computer Interactions in Museums*. Morgan & Claypool Publishers, 2019.

[9] J. W. Creswell and C. N. Poth, *Qualitative Inquiry and Research Design: Choosing Among Five Approaches*. SAGE Publications, 2016.