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

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INTRODUCTION

The National Museum of Nuclear Science and History, is a valuable national and community resource enabling the dissemination of nuclear science and other 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.

In this work, we discuss the development of a new exhibit designed to teach the general public about nuclear probabilistic risk assessment (PRA). Our goal is to enhance public understanding of the science and engineering behind complex systems safety. There is both intense public interest and prevalent misunderstanding of the concept of nuclear safety and risk. Museum visitors often ask how risks from nuclear power compare to other energy sources, and to date no museum exhibit has addressed this question. The exhibit will be sited at the National Museum of Nuclear Science and History and will also have a digital element located on the museum website so it is accessible to audiences worldwide.

PRA understanding is especially important for nuclear audiences. It is an essential part of the NRC's risk-informed regulatory process, and is used to ensure the safe operation of nuclear power plants across the U.S. The primary value of a PRA is to highlight the system design and operational deficiencies, and support subsequent risk management efforts to identify and optimize resources that can be invested on system improvement [1]. Historically, the nuclear industry has been at the forefront of developing and implementing PRA methods and guidance to ensure the continued safe operation of nuclear power plants.

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, in order to give them an appreciation and understanding of the technical rigor in PRA.

Developing a museum exhibit on PRA presents unique challenges in promoting engagement due to the abstract and advanced nature of the subject matter. PRA often requires graduate-level engineering education to understand the systems, methods, and data involved. However, it is important for the general public to understand why PRA is needed and how it is used. PRA systematically catalogs potential system risks and justifies which mitigation or avoidance measures are appropriate and necessary to ensure nuclear safety. These risks are often low-probability and high-consequence, which are inherently difficult to conceptualize (e.g., a probability of occurrence of 2×10^{-6} per year, corresponding to one event expected every 500,000 plant-years). The theoretical nature of PRA also means that there is a lack of observable physical phenomena or artifacts that can be used to convey its concepts to a museum audience.

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 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 driving active prolonged engagement (APE) with the exhibit by visitors [2]. 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 [2]. 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 and the outcome itself.

The open-endedness of interactive exhibits means that meaningful interactions are dependent on an individual's attention and motivation levels [3]. 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 [4]. For complex subjects, it is important to employ strategies that promote APE. In addition, activities involving tinkering 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 [5]. Interactive components can be implemented through a digital medium which may afford a wider range of inputs and outputs than the physical world, and therefore a wider range of exploration.

RESULTS: "BUCKLE UP!"

This exhibit will be displayed as part of the "Energy Encounter" exhibition at the Nuclear Museum. The available floor space was limited to only around 150 square feet, so it was decided to display most of the content digitally. The focus of the exhibit is a game component involving driving a car, which stemmed from some research content about seatbelts and associated safety risks when motorists choose to use them or not.

The user can 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 is placed behind the steering wheel, in the style of arcade racing games. The team has designed alternative ways to interact with the exhibit screen to enhance accessibility. Physical panels with educational content are placed around the game setup so that users may engage with the exhibit without playing the game. The exhibit construction, with exterior panels and digital screen, is shown in Figure 1. The initial attract screen that the user sees before playing the game is shown in Figure 2.

Fig. 1. Physical panels have been constructed for the exhibit, and the digital display and seat have been installed.

Fig. 2. Attract screen for the exhibit, from which the user can select different informational text about PRA or can choose to play the game.

The exhibit seeks to convey five main concepts through the game and associated informational text. The first main idea 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 (scenarios, likelihood, consequences): 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.

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 then choose from four different game scenarios to play. In this example, the "speeding/deer" scenario is demonstrated. The user is asked if they choose to go the speed limit (Figure 3) - then suddenly, a deer jumps out and they must brake suddenly (Figure 4).

Fig. 3. The user is playing the game, when they are faced with a decision to speed or remain at the speed limit.

Fig. 4. Immediately after making their decision, a deer jumps into the roadway and they must stop.

The probability that they can successfully swerve depends on their choice to speed 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. This is then conveyed to the user through a risk matrix (Figure 5). The text displayed at the end of the scenario is meant to encourage the user's counterfactual reasoning (e.g., if I had gotten the brakes replaced instead of the headlights, would my result be a successful stop instead of a crash? what if I had not sped?), leaving open potential for replaying the game to get a different risk level.

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 exhibit development team drew upon textbooks and formative PRA texts such as WASH-1400 ([1], [6]) to develop factually accurate content at a middle-school level of understanding.

CONCLUSIONS

This museum exhibit is designed to inspire interest and foster thinking about PRA. Awareness and understanding of PRA is integral to an understanding of the risks and risk mitigation practices of the nuclear industry.

We encourage extended visitor engagement 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. Multiple playthroughs are incentivized, encouraging museum patrons to give the complex material the time and attention it requires to best be understood.

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

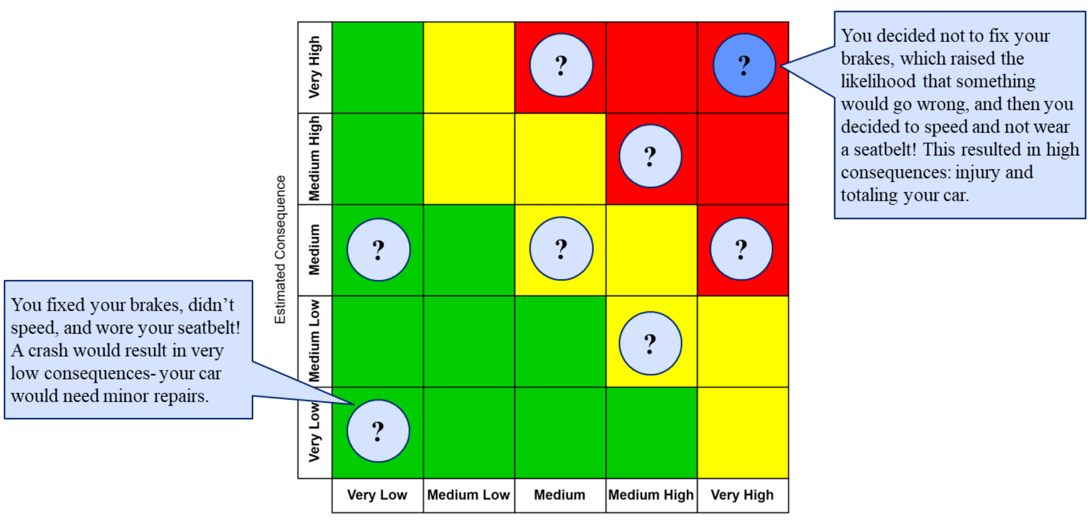

Fig. 5. A risk matrix showing the various risk levels that a user may obtain through their decisions, with explanatory text for each outcome.

energy systems. Unlike a classroom setting, there is a large uncertainty in the background knowledge held by those seeing the exhibit. 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. Reliability engineers and their work are integral to the continued growth and safety of the nuclear power industry, and it is our hope that this will inspire future generations to pursue careers related to the subject. A lack of accessible information about nuclear risk and reliability also contributes to public misconceptions about nuclear power generation. It is a worthwhile endeavor to educate the public about the risks associated with a necessary source of future clean energy. By the end of their interactions with the exhibit, museum visitors will understand more about nuclear safety, and may appreciate the usefulness of risk assessment in their daily lives in its applications to nuclear power and beyond.

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