Application to the Bauder Fund Endowment for the Support of Physics Teaching: The development, testing, and dissemination of a quantum mechanics board game

PI NAME (PI_EMAIL@INSTITUTION.edu)

The rules of quantum mechanics are non-intuitive and many students struggle the first time they encounter them. In the summer of 2019, I worked with a student to prototype a board game that incorporates some of the "rules" of quantum mechanics by referencing classic experiments in the history of quantum mechanics. The goal being that players will learn or reinforce the concepts of quantum mechanics by interacting with mock versions of the experiments in the gameplay. The board game focuses on a handful of experiments that demonstrate specific concepts: the "rules" of the randomness inherent in quantum mechanics, quantization of spin, quantization of photon energies, blackbody radiation, and others. The audience for the board game would be high-school students up to graduate students as well as members of the general public. We plan to have 1-3 students working on tweaking and finalizing the game, developing a set of pre- and post-assessment questions to determine the efficacy of the game, and holding testing workshops with students, local high school teachers, and the general public at a local board game cafe. The grant would fund both equipment needed for the prototyping stage and multiple copies of the game for the workshops and distributing to local high schools.

I am an associate professor in the Physics and Astronomy department at COLLEGE NAME and a member of the CMS particle physics experiment at the LHC. I have a strong interest in how to teach others, both formal students and the non-expert publics, about what we understand about the underlying nature of our Universe, specifically the counter-intuitive rules of quantum mechanics. The idea was to take advantage of the explosion of interest in board games and gamification of education, and to design a game that does not *explicitly* teach quantum mechanics but instead bakes the rules of quantum mechanics into the game itself. My research stduent has come up with a working prototype that we have tested with a handful of students so far. We anticipate they and/or additional students in our Physics Education program will continue to develop the game over the course of the 2018-2019 academic year. I am the recipient of two NSF grants (RUI: Research at Undergraduate Institutions) from the Elementary Particle Physics division that support my efforts on CMS and a past recipient of a CMS Minigrant for Outreach, which was used to develop Peltier-powered cloud chambers and run a workshop to teach high school teachers how to build their own. In all cases, I have been successful in engaging and mentoring students on these projects and seeing them through.

No one game is going to be able to teach an entire undergraduate quantum mechanics course and so we have decided to focus on a handful of concepts and historical developments. The current version of the game is modeled after Monopoly (see Fig. 1), where players go around the edges of the board and acquire objects and/or money. The goal is to collect enough funds to purchase *six* lasers, which you use to create a Bose-Einstein condensate. The first person to do this is the winner. Along the way, the players have to answer trivia questions about quantum mechanics and can collect cards which help their cause or hurt the cause of the other players. For example, you might draw a card which allows you to send Wolfgang Pauli to the lab of one of the other players, causing their experiment to fail and for them to lose a turn[1].

Players advance by first drawing a card which determines which experimental apparatus determines how far they move. The experiments are as follows.

- **Blackbody radiation**. Players roll a weighted die to determine what photon they sample from the oven. The higher energy photon, the more squares they advance. A player might also possess a card that allows them to raise the temperature of the oven.

[1] https://en.wikipedia.org/wiki/Pauli_effect

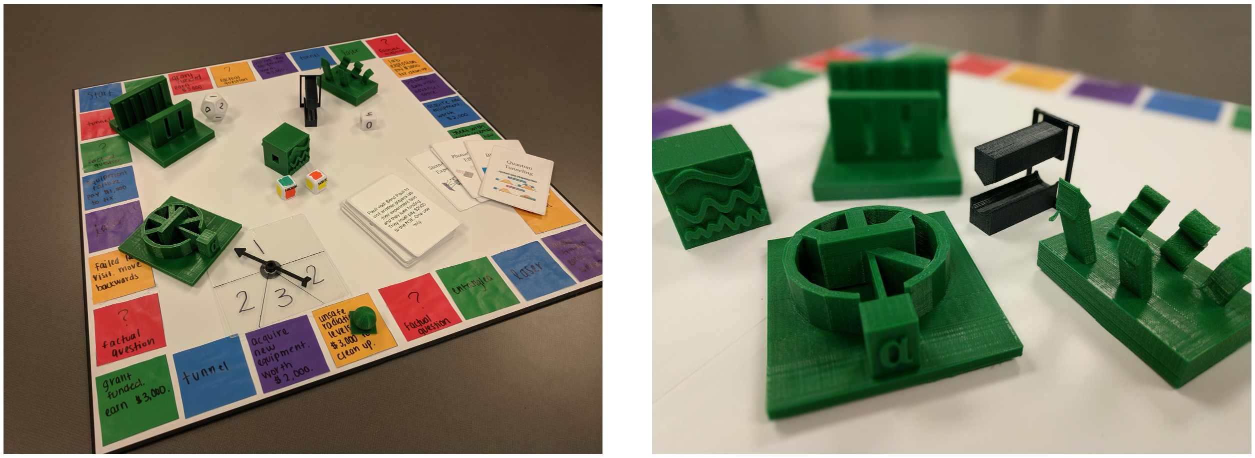

Figure 1: (left) Overview of the board, cards, and totems and (right) a closer view of the totems.

- **Double-slit experiment**. Players roll a weighted die to determine which maxima or minimal they fall into and the number of squares they advance.
- **Stern-Gerlach experiment**. Players predict whether or not their ion passes through and is spin-up or spin-down. A die is then rolled to see if the player can advance.
- **Photoelectric effect**. Players roll a die to see what wavelength of light they get, which determines the kinetic energy of the ejected electron and how many squares they advance. Players lose a turn if they draw a light with a photon energy below the work function.
- **Rutherford's alpha scattering experiment**. Player have a spinner with unequal areas representing the probability of the alpha particle scattering in the forward direction (likely, advance few squares) or backward (unlikely, advance many squares).

In addition to the game itself, a set of mini-lectures and links to additional resources will be provided in case teachers or players want to go further than just the game itself. It is hoped that the pieces, like the Stern-Gerlach models, will act as *totems* (see Fig. 1) for students to help with their retention of the material by providing a physical object to build their intuition around.

We would like to test the efficacy of the game in introducing these concepts to people and also with retention of those concepts. We will select questions from the assessments that are on PhysPort[2], a website that hosts resources for based on physics-education research (PER) and/or develop our own. We hope to administer the quesions not just before and after playing but weeks or months after, to test long-term retention. We will also select questions that test concepts *not incorporated* in the game play to try to account for players who already might know the rules of quantum mechanics before playing the game. We plan on testing it out at our institution with three types of students (all undergraduate): physics majors, non-physics science majors, and non-science majors. In addition, our institution has a good relationship with multiple high school science teachers and we will work with them to try it out in their classrooms. One more very interesting population to assess will be the general public. Very close to our institution is *Bard and Baker*[3], a board game cafe. Once a prototype game is developed, we will reach out to the proprietors about running a series of game nights built around the game such that we can solicit feedback from non-students and the general public.

The game design and all 3D printing files will be released with an open source license so that anyone can play the game, modify it, or come up with their own design.

[2] https://www.physport.org/
[3] https://www.bardandbaker.com/

Budget

This summer, we spent about \$100 on the equipment for prototyping, not including the cost of filament for the 3D printers. The money went toward blank boards, blank spinners, blank dice, labels, markers, and related craft tools.

We anticipate spending an additional \$100 on additional prototyping equipment, as well as another \$50 on filament for the school's Makerbot 3D printer and resin for the school's SLA 3D printer.

After that, we plan to make multiple versions of the game to distribute at testing workshops and to local high schools. We are looking to keep the cost-per-game to \$20 or less and would like to produce about 20 games, which comes out to \$400.

We will seek out internal funds at our school for any additional costs associated with the workshops or travel for myself or students to AAPT or APS conferences to disseminate the results.

Table 1: Estimated budget.

	Cost
Prototyping materials	\$150
(3D printing filament, board materials, printing costs)	
Costs of finalized versions of game (20 x \$20)	\$400
Total	\$550

Timeline

- *Fall 2019.* Work with students to finalize a playable version of the game and test on students. Develop pre- post-playing assessment questions.
- *Winter break 2019-2020.* Run workshop for local high school teachers where we play the game and teach them the rules.
- *Spring 2020.* Modify game based on feedback. Distribute to high schools. Run a game night at local board game cafe to gather feedback from general public and advertise the game.
- *Beyond.* Present at AAPT local or national meetings and/or prepare a publication for one of the AAPT-related journals.