

Collaborative learning of quantum measurement with on-line software and Google Docs



Dean Zollman, Adrian Madsen

*Kansas State University, Department of Physics, 116 Cardwell Hall,
Manhattan, KS, 66506-2601, USA.*

E-mail: dzollman@phys.ksu.edu

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Abstract

The probabilistic nature of quantum measurement through collapse of the wave function is demonstrated clearly in the "Quantum Tunneling and Wave Packets" program which is available at <http://phet.colorado.edu/en/simulation/quantum-tunneling>. By making repeated "Quantum Measurements" using a button in the program, students can see that the wave function collapses at different locations. A difficulty arises because repeating the measurement many times by an individual student is somewhat tedious. We have addressed this problem by having each student in a class enter their measurement in a Google spreadsheet. The data are then collected into histograms which show the collective results to the virtual experiment.

Keywords: On-line, quantum tunneling, collaborative learning.

Resumen

La naturaleza probabilística de la medida cuántica a través del colapso de la función de onda se demuestra claramente en el "efecto túnel cuántico, y los paquetes de onda", programa que está disponible en <http://phet.colorado.edu/en/simulation/quantum-tunneling>. Por lo que repite "las mediciones cuánticas" utilizando un botón en el programa, los estudiantes pueden ver que la función de onda colapsa en diferentes lugares. Una dificultad surge porque repetir los tiempos de medición por muchos un estudiante en particular es algo tedioso. Hemos abordado este problema haciendo que cada estudiante en una clase de entrar en su medición en una hoja de cálculo de Google. Los datos son entonces recolectados en histogramas que muestran los resultados colectivos de la experiencia virtual.

Palabras clave: On-line, efecto túnel cuántico, aprendizaje colaborativo.

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I. INTRODUCTION

We have been teaching quantum mechanics for many years to students who were not studying physics [1, 2, 3]. To teach students some level of understanding of this complex topic we have frequently used inactive computer visualizations which enable students to visualize wave functions in a variety of situations and to make changes that affect these wave functions by changing variables. This type of instruction in the basics of quantum physics has been effective for a variety of audiences.

While we have had some success in teaching the probabilistic nature of quantum physics, the probabilities involved in quantum measurement have always been somewhat difficult for students to master. When students learn about a wave function collapsing when we make a measurement, they seem to see why this collapse is a reasonable model for the measurement process. However, they seldom immediately grasp the idea that each measurement may result in a collapse to a different location.

II. THE STUDENTS

Each year our Department teaches a course in contemporary physics for students who are not studying physics. The course is open to all undergraduate students except physics students. The students must have completed at least one previous course in physics, but we have no other requirements on their background.

In a typical offering of *Contemporary Physics* the students will be studying a wide variety of disciplines. We usually have students from the humanities, social sciences, engineering, journalism and some students who plan to teach some science in secondary schools. With the spectrum of students we need to provide interactive and concrete activities to help them learn.

III. THE VISUALIZATION

For an activity on collapsing wave functions and quantum measurement we chose to use the "Quantum Tunneling and

“Wave Packet” program developed by the PhET project [4]. As the name of the program and the screen capture in Fig. 1 indicate it was designed to provide interactive instruction with many quantum phenomena in addition to the wave function collapse. We use many of these other features in aspects of our teaching. However, in this paper we will focus on use of the button in the lower left of the screen – “Make a Quantum Measurement”.

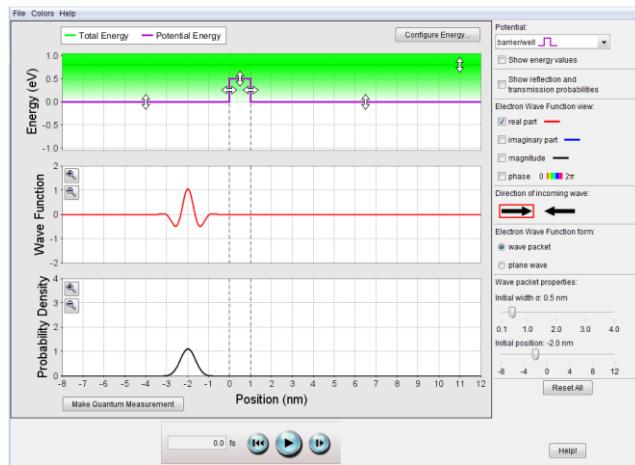


FIGURE 1. A capture of the opening screen from “Quantum Tunneling and Wave Packets”.

In a straightforward mode of using the program, the student can set the potential and total energies of the particle. Then, the student clicks the play arrow at the bottom and watches the wave function evolve in time. Fig. 2 shows a screen when the wave packet in Fig. 1 is allowed to evolve for “13 fs”.

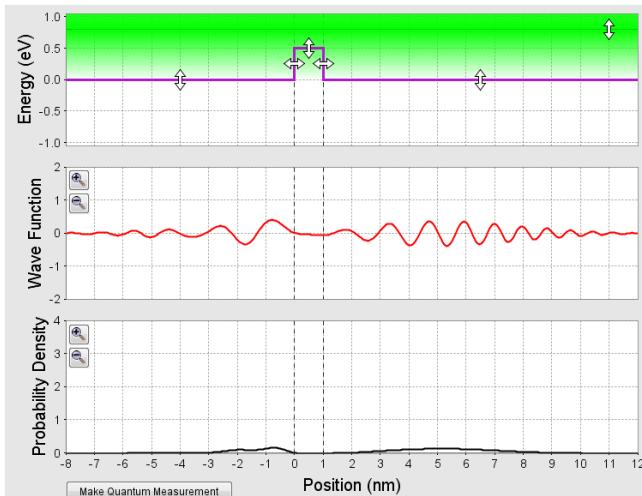


FIGURE 2. The screen a simulated 13 fs after the screen in Fig. 1.

If the student now makes a measurement, the wave function will collapse and a screen such as Fig. 3 will be shown.

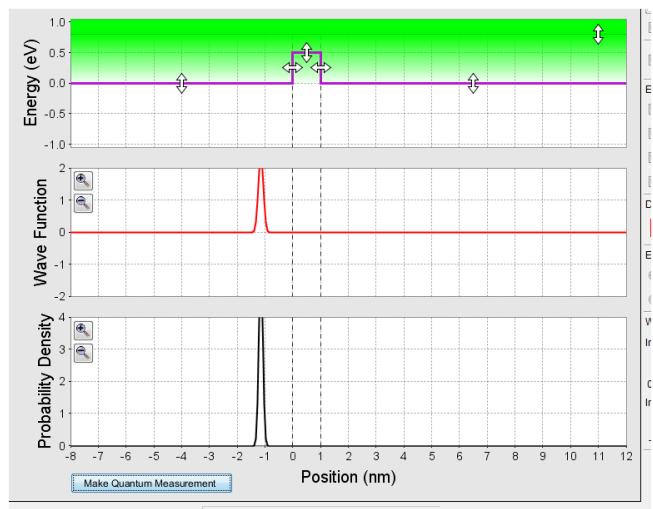


FIGURE 3. A quantum measurement based on the wave packet in Fig. 2.

However, the screen shown in Fig. 4 is also possible because the program demonstrates that wave function can be localized in each of the locations at which the wave function’s amplitude is non-zero.

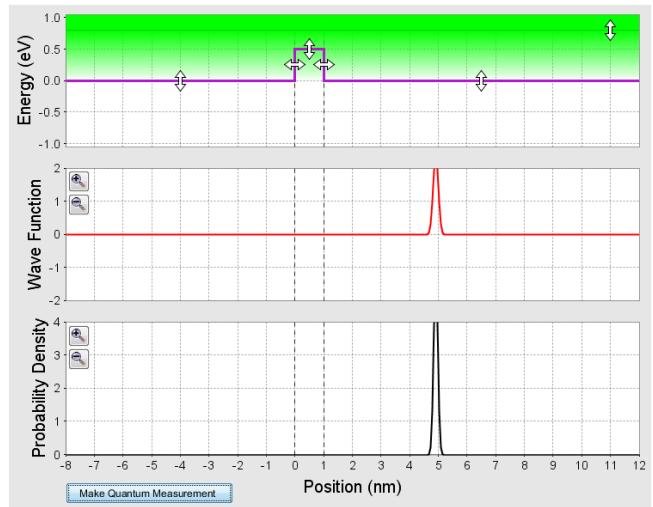


FIGURE 4. Another quantum measurement based on the wave packet in Fig. 2.

Each time that the students make a measurement they can obtain a different position for the collapse of the wave function. The location of the wave function collapse will also depend on the initial conditions such as the width of the wave function at $t=0$.

IV. GOALS OF THE ACTIVITY

This activity preceded any discussion of the reasons for the different locations or how the locations of the measurements might depend on the initial width of the wave packet. Thus it was an exploration to prepare students for learning about these issues.

We wanted the students to take sufficient measurements to see that

- The location of the collapse was probabilistic and depended on the shape of the wave packet at the time of measurement, and
- The initial width of the wave function had an effect on the measurements.

In an ideal world we could ask each student to run the program many times and record the location of the collapsed wave packet. Then have him/her change the initial wave packet and run the program many times again. Unfortunately, our students (and we) are not patient enough to complete this effort.

V. COLLABORATIVE APPROACH

To avoid long, tedious work for our students and us we created a collaborative effort in which each student completed a few measurements. Then, we combined the results by having the students enter their results into a Google docs spreadsheet.

The assignment as it was presented to the students was:

This problem will collect for data similar to those that we did in class. Use the Quantum Tunneling and Wave Packets program at <http://phet.colorado.edu/en/simulation/quantum-tunneling> and the Google spreadsheet at <https://spreadsheets.google.com/ccc?key=0ArfXfOGiWIoxdFpiRktYOG92Smxmb0JtVmFFM210a1E&hl=en&authkey=CMv8y50G#gid=0>.

To use the program set up the initial conditions as stated below and in the spreadsheet. Then, start the animation. Stop it just before each of the times listed in the spread sheet; then step forward to the correct time and make a quantum measurement. Record the measurement in the spreadsheet in the section labeled by your initials. Then, click the play arrow and let the wave packet go to the next time that is listed. Repeat the process for all times listed. Please use only the section on the spreadsheet with your initials.

- A. Use a step potential energy that changes at 0nm; left side height = 0; right side height = 1.0eV. For the wave packet: Initial position = -6.0nm; initial widths = 0.1nm; 2.0nm and 3.5nm.
- B. Double barrier potential that is inside the barrier's potential energy = 0; left and right of the barrier = -0.5eV; height of both barriers = 1.0eV; location of barriers-3nm to -2nm and +2nm to + 3nm. For the wave packet: Initial position = 0; initial widths = 0.1nm; 2.0nm and 3.5nm.

After the students completed and recorded their data, they were plotted on histograms. Results for the step potential and initial width of the wave packet set to 0.1nm are shown for elapsed times of 5, 15 and 25fs in Figs. 5.

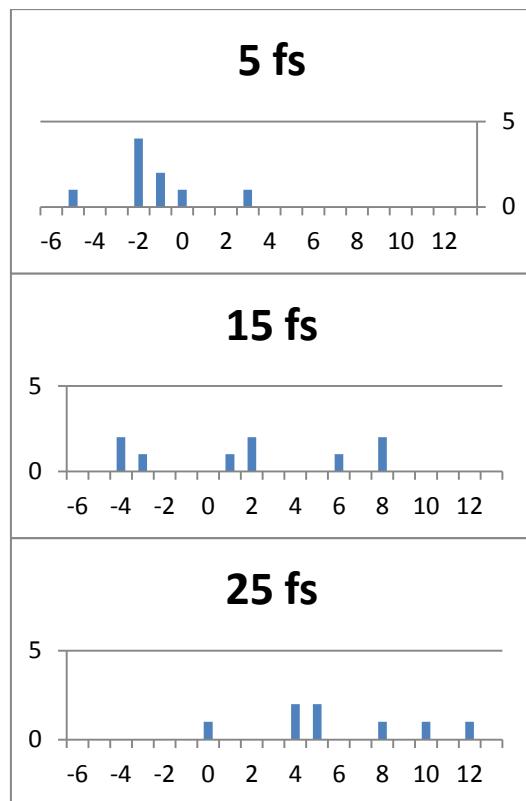


FIGURE 5. The distribution of results of multiple measurements using the same initial conditions for the elapsed times indicated in the graphs. Note that the scale on the 5fs graph is different from the other two.

These histograms and others were used in class to lead off a discussion of the probabilistic effects in measurement as well as the reasons that the initial width of the wave function was important and its relation to the Uncertainty Principle.

Results for Activity B were used as another example of similar results. In addition, it was the beginnings of a discussion about the probabilistic nature of alpha radioactivity and how quantum tunneling helps explain that effect.

VI. CONCLUSIONS

These out-of-class collaborative activities seem to provide a good starting point for a discussion on various quantum effects related to the propagation of wave packets. By making them collaborative we were able to collect enough data to use the effects without requiring the students to complete a large amount of tedious work. Thus, they kept a

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positive attitude toward the overall learning experience.

We developed this activity and used it for the first time during the past semester. Thus, we have not yet been able to complete a careful assessment of its value as a learning tool. We hope to do that in some future class.

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