GEORGE MASON UNIVERSITY

Quantum Resources for K -16

Jessica Rosenberg, Nancy Holincheck

QSEC

Quantum Science & Engineering Center

National Q-12 Education Partnership

Launched by the White House Office of Science and Technology Policy (OSTP) and the National Science Foundation, Q-12 is a consortium that seeks to expand access to K-12 quantum learning tools and inspire the next generation of quantum leaders.

Click on videos to watch later - they're useful, but not a good use of our time together

Quantum K-12 Framework Documents

Designed for curriculum developers and teachers

National Q-12 Education Partnership

Teacher working groups created the documents linked below. Due to the differences in readiness across the subjects of Math, Physics, CS, and Chemistry, each document takes a different form.

- The **Physics and Chemistry** documents outline an initial set of expectations and learning goals for teachers seeking to teach QIS K-12 Key Concepts.
- The **Computer Science** document provides guidance about places where high school computer science learning goals can be satisfied at the same time as content in the QIS K-12 Key Concepts.
- The Math document outlines learning trajectories and concept connections across middle and high school math topics.
- The Middle School STEM framework offers initial set of expectations and learning goals for teaching QIS Key Concepts.

Computer Science + QIS

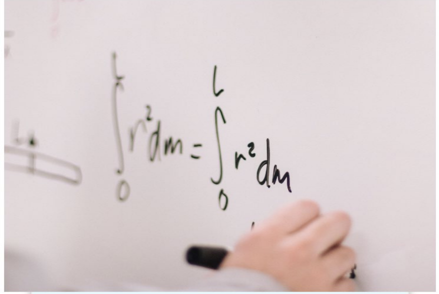
Click Here

Physics + QIS

Click Here

Chemistry + QIS

Click Here



Math + QIS

Click Here

Middle School STEM + QIS

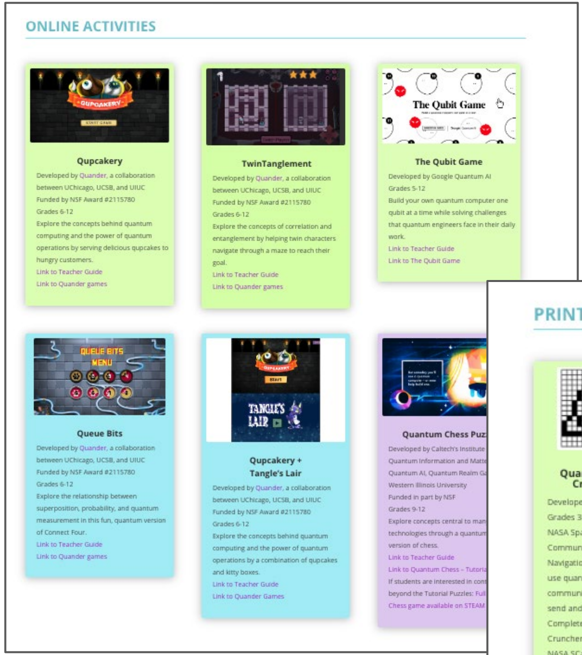
Quantum Information Science (QIS) K-12 Key Concepts

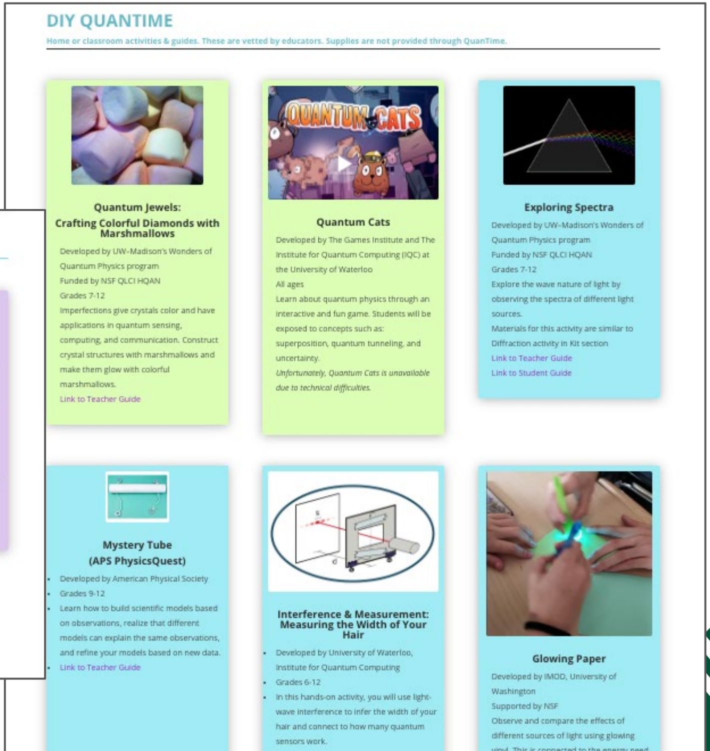
- QUANTUM INFORMATION SCIENCE
- QUANTUM STATE
- QUANTUM MEASUREMENT
- QUBIT
- ENTANGLEMENT
- COHERENCE
- QUANTUM COMPUTERS
- QUANTUM COMMUNICATION
- QUANTUM SENSORS

Q-12 Curricular Resources

QUANTIME

https://q12education.org/quantime





Quantum is Elementary

- 2-year NSF EAGER project exploring how **elementary teachers and students engage with quantum science**, with a focus on professional learning and integrating quantum concepts into the elementary school curriculum.
- Collaboration between faculty in the College of Education and Human Development and Physics and Astronomy Department at George Mason University.

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Quantum is Elementary: Resources Developed by Teachers

- **Age** K-12; Length 20-45 mins
- **Focus:** questioning like a scientist -- developing curiosity and scientific thinking.
- **Quantum Connection:**
  – Atoms/atomic structure
  – Relative size

LESSON PLAN ONE

- **Age**: 3rd graders and up; Length: 40-60 mins
- **Focus:** Hack the Password! - Quantum Computing
- **Quantum connection:** Quantum Encryption

LESSON PLAN TWO

- **Age**: 6 and up ; Length: 30 mins
- **Focus:** Create an emoji-- Connect Quantum Superposition with Social-Emotional Learning
- **Quantum Connection:** superposition

LESSON PLAN Three

Sample Literacy Resources Developed by Teachers

Appendix A - Quantum Cause and Effect Text

How Quantum Changed The World

Everything you can see, touch, and smell around you is made up of tiny particles called **atoms**. These atoms bond together to make everything around us. Quantum mechanics is the study of the smallest particles in the universe. Quantum scientists study how atoms behave and are formed.

For a long time, scientists thought atoms were like tiny solid balls. They believed that atoms behaved the same way as a ball, table, or any other item in the world. In 1908, Ernest Rutherford tested this idea by firing small particles at an atom. He expected them to bounce back, like if you threw a ball at a wall. Instead, the particles went through the atom. This discovery showed Rutherford and other scientists that atoms are not solid like other things we can see. These small particles do not follow the same rules of physics as larger objects. Scientists have had to change how they view, study, and understand the world because of these discoveries.

Quantum mechanics also introduced the idea that particles like **electrons** do not have specific locations until they are observed. An electron can be in multiple places at once, a phenomenon known as **superposition**. This might sound strange, but many experiments have proved it! Because of this, scientists had to rethink many of the rules that apply to the physical world. For example, the classical idea that objects can only be in one place at a time isn't true at the quantum level. This discovery has led to new ways of thinking about information and communication.

One major effect of understanding superposition is the development of quantum computing. Unlike traditional computers, which use bits as the smallest unit of data (which can be either 0 or 1), quantum computers use quantum bits, or **qubits**, which can be both 0 and 1 at the same time. This allows quantum computers to process a vast amount of information at once, making them potentially much more powerful than current computers. This could revolutionize fields like healthcare, where they could help design new medicine much faster than before.

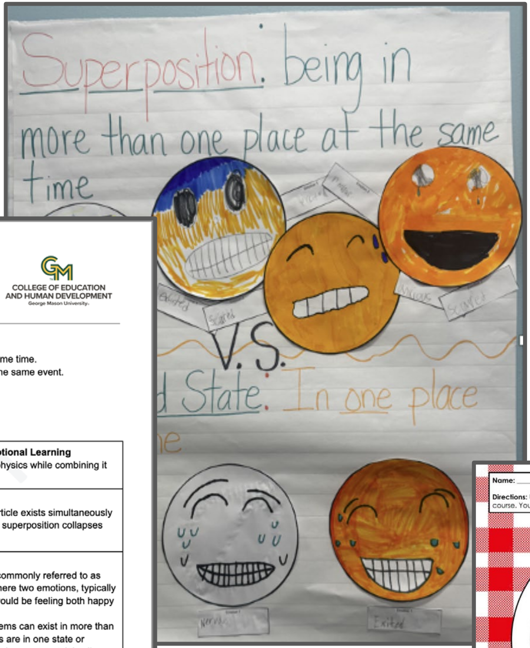
Another important area affected by quantum discoveries is cryptography, which is the art of writing and solving codes. Before quantum mechanics, people sent encrypted messages based on mathematical equations. These encrypted messages could be decoded and read if someone discovered the rule to decode in. Quantum mechanics has led to the development of quantum cryptography, which uses the principles of quantum mechanics to create codes that are almost impossible to break without detection. This means that messages and information can be made much more secure, which is very important in our digital world.

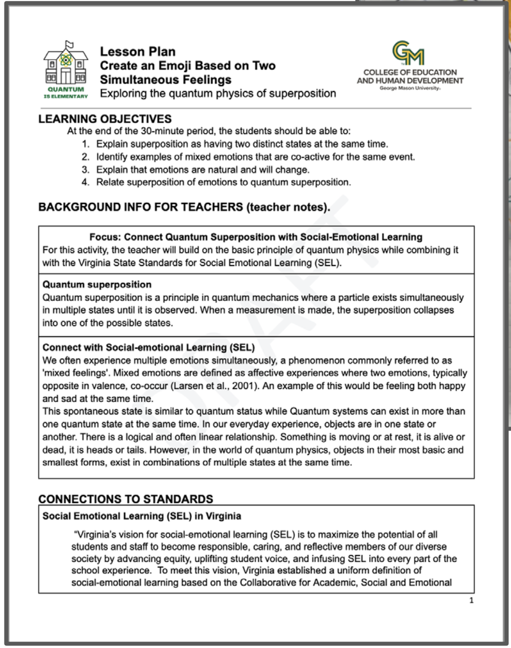
Name: ______________________ Date: ______________

How Quantum Changed the World

Rutherford fired particles at an atom and they passed through instead of bouncing back. →	Scientists learned that atoms are made of many smaller particles.
Scientists discovered superposition - that particles can be in multiple places at once →	Quantum computers are faster than normal computers.
Quantum cryptography encoded messages that are harder to break. →	Messages are more secure.
Quantum mechanics lets us see inside bodies without cutting them open. →	Doctors can see inside someone's body without surgery.

Lesson plans are available on our website





Lesson Plan
Create an Emoji Based on Two Simultaneous Feelings
Exploring the quantum physics of superposition

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COLLEGE OF EDUCATION AND HUMAN DEVELOPMENT
George Mason University

LEARNING OBJECTIVES
At the end of the 30-minute period, the students should be able to:
1. Explain superposition as having two distinct states at the same time.
2. Identify examples of mixed emotions that are co-active for the same event.
3. Explain that emotions are natural and will change.
4. Relate superposition of emotions to quantum superposition.

BACKGROUND INFO FOR TEACHERS (teacher notes).

Focus: Connect Quantum Superposition with Social-Emotional Learning For this activity, the teacher will build on the basic principle of quantum physics while combining it with the Virginia State Standards for Social Emotional Learning (SEL).
Quantum superposition Quantum superposition is a principle in quantum mechanics where a particle exists simultaneously in multiple states until it is observed. When a measurement is made, the superposition collapses into one of the possible states.
Connect with Social-emotional Learning (SEL) We often experience multiple emotions simultaneously, a phenomenon commonly referred to as 'mixed feelings'. Mixed emotions are defined as affective experiences where two emotions, typically opposite in valence, co-occur (Larsen et al., 2001). An example of this would be feeling both happy and sad at the same time. This spontaneous state is similar to quantum status while Quantum systems can exist in more than one quantum state at the same time. In our everyday experience, objects are in one state or another. There is a logical and often linear relationship. Something is moving or at rest, it is alive or dead, it is heads or tails. However, in the world of quantum physics, objects in their most basic and smallest forms, exist in combinations of multiple states at the same time.

CONNECTIONS TO STANDARDS

Social Emotional Learning (SEL) in Virginia "Virginia's vision for social-emotional learning (SEL) is to maximize the potential of all students and staff to become responsible, caring, and reflective members of our diverse society by advancing equity, uplifting student voice, and infusing SEL into every part of the school experience. To meet this vision, Virginia established a uniform definition of social-emotional learning based on the Collaborative for Academic, Social and Emotional

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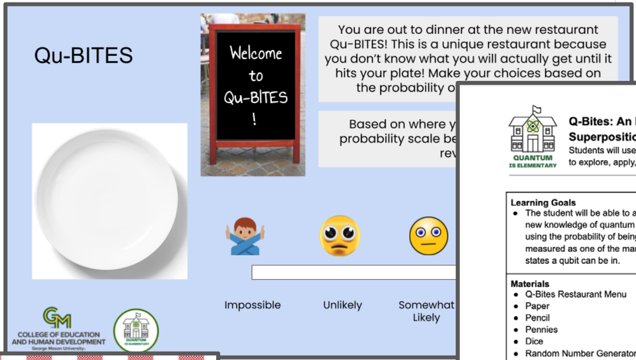

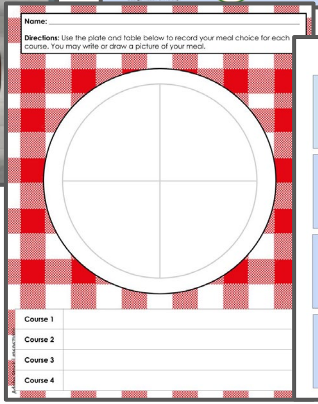

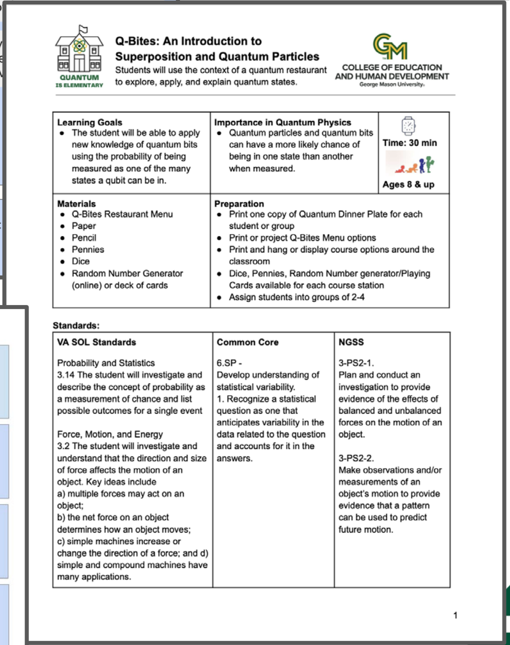

Q-Bites: An Introduction to Superposition and Quantum Particles
Students will use the context of a quantum restaurant to explore, apply, and explain quantum states.

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George Mason University

Learning Goals	Importance in Quantum Physics	
• The student will be able to apply new knowledge of quantum bits using the probability of being measured as one of the many states a qubit can be in.	• Quantum particles and quantum bits can have a more likely chance of being in one state than another when measured.	Time: 30 min Ages 8 & up
Materials • Q-Bites Restaurant Menu • Paper • Pencil • Pennies • Dice • Random Number Generator (online) or deck of cards	**Preparation** • Print one copy of Quantum Dinner Plate for each student or group • Print or project Q-Bites Menu options • Print and hang or display course options around the classroom • Dice, Pennies, Random Number generator/Playing Cards available for each course station • Assign students into groups of 2-4	

Standards:

VA SOL Standards	Common Core	NGSS
Probability and Statistics 3.14 The student will investigate and describe the concept of probability as a measurement of chance and list possible outcomes for a single event Force, Motion, and Energy 3.2 The student will investigate and understand that the direction and size of force affects the motion of an object. Key ideas include a) multiple forces may act on an object; b) the net force on an object determines how an object moves; c) simple machines increase or change the direction of a force; and d) simple and compound machines have many applications.	6.SP - Develop understanding of statistical variability. 1. Recognize a statistical question as one that anticipates variability in the data related to the question and accounts for it in the answers.	3-PS2-1. Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object. 3-PS2-2. Make observations and/or measurements of an object's motion to provide evidence that a pattern can be used to predict future motion.

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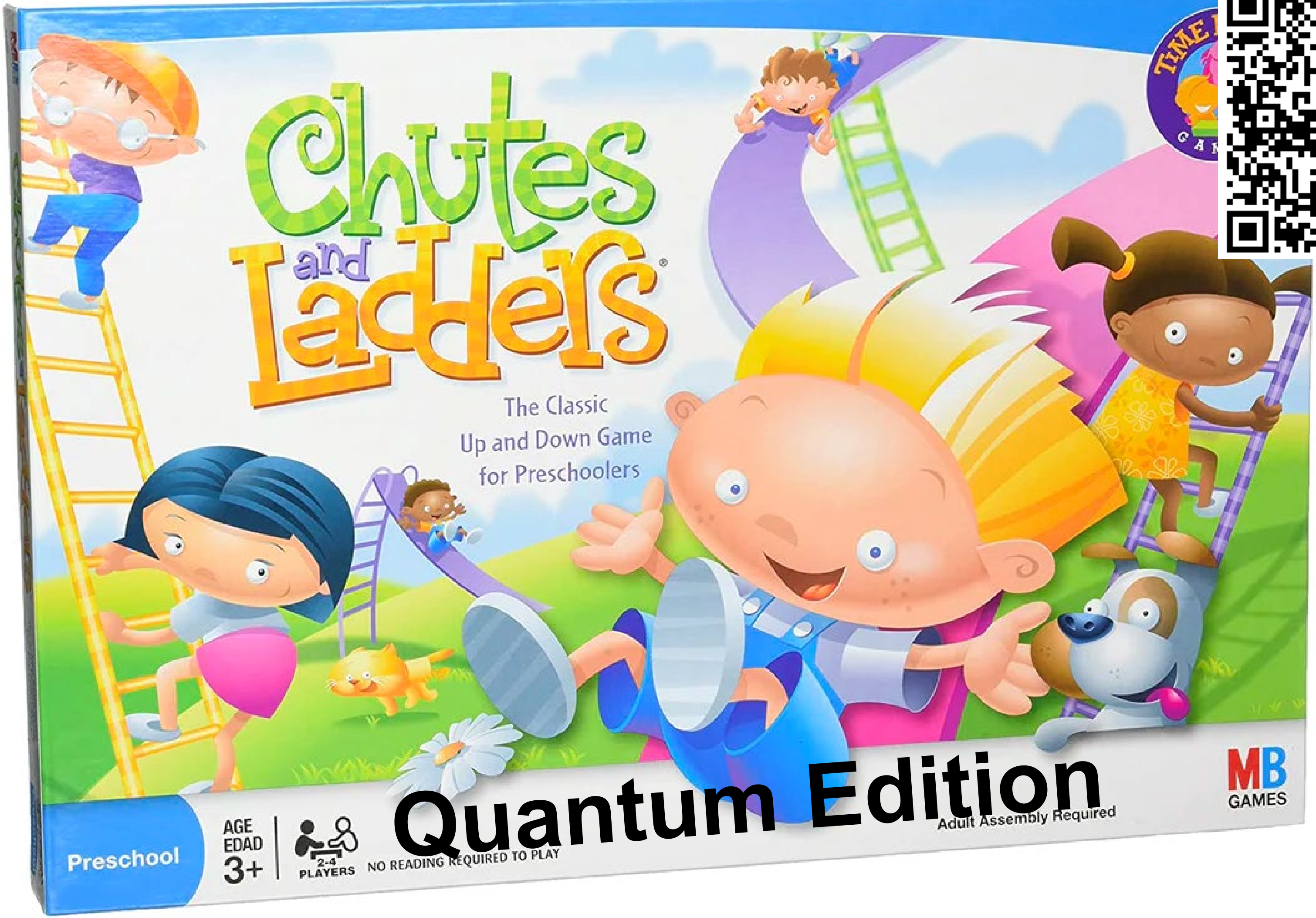
Chutes and Ladders®
The Classic
Up and Down Game
for Preschoolers
Quantum Edition
Adult Assembly Required
MB
GAMES
Preschool
AGE
EDAD
3+
2-4
PLAYERS
NO READING REQUIRED TO PLAY

Quantum Chutes and Ladders: How to Play

Premise:

Your character has been shrunk down to the size of an electron and now behaves as a quantum particle. When you move, your quantum particle can be in a superposition of states, represented by the separate positions on the board the character occupies.

Measurements are made on playing pieces to determine which state they are in. When the measurement is made, the superposition collapses and the pieces are at the same position (“state”) on the board. Good luck getting your character to the end!

Quantum Chutes and Ladders: How to Play

Superposition vs collapsed state:

Your character can be in one of two types of states during the game – collapsed or superposition. In the collapsed state, you know exactly where your character is. This is the state in which you start the game and the state you will be in after making a measurement of your character’s position. In the superposition state, your character is in a superposition of locations on the board, with a 50/50 probability of being measured to be in either of those positions.

Quantum Board Game Challenge

Create a quantum board game - new rules for an existing game (recommended) or a game of your own creation.

1. Tell the story of the game
2. Explain the rules and how they illustrate the key quantum principles
3. Explain your game and its rules to the judges - prize for the winning team!

Easier games: Sorry, Trouble, Connect Four

Harder: Battleships, Monopoly, Backgammon, Chess

Building Quantum In Your Classroom:

High School curricula for Physics, Chemistry, and CS

Physics Lesson #1	Physics Lesson #2	Physics Lesson #3	Physics Lesson #4
Superposition	Measurement and Probability	Entanglement	Photoelectric Effect
Intro to why classical mechanics isn't enough to understand quantum systems Introduces superposition through a guided consideration of electron sorting experiments Meant to inspire curiosity about deviations from classical model	A continuation of Lesson #1, furthering discussions of quantum mechanics as probabilistic Uses polarization of light as hands-on demonstration of superposition, probability and measurement Quantum measurement game adapted from Gomoku / Five-in-a-Row	A continuation of Lesson #2, introduces spin and entanglement of electrons Shows entanglement violates classical mechanics via discussion of Bell's Inequality Quantum measurement game adapted from Gomoku / Five-in-a-Row *now with added entanglement aspect*	Quantum Extension for an Optics or Modern Physics U Students investigate particl behavior of light through photoelectric effect demonstration Relate particle behavior of light to that of electrons

George Mason University's Quantum Science & Engineering Center's K-12 Quantum Initiative

Brandon Harvey
Physics Teacher, Oakton High School

Physics Lesson #1

Superposition

Intro to why classical mechanics isn't enough to understand quantum systems

Introduces superposition through a guided consideration of electron sorting experiments

Meant to inspire curiosity about deviations from classical model

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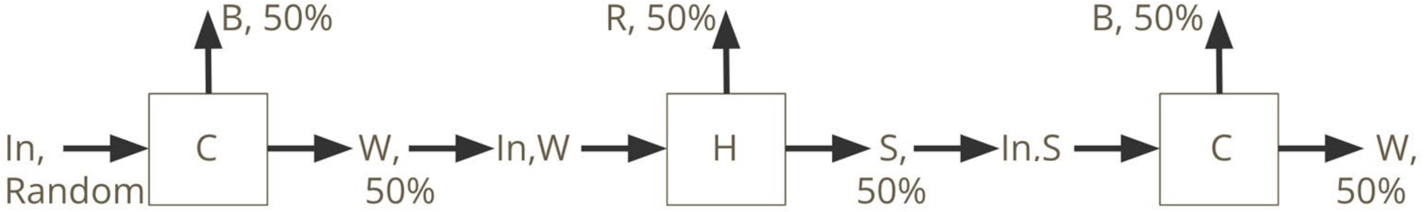
Electron Sorting Think-Pair-Shares



Introducing the idea of measurement yielding determination of quantum state

Modeling two properties of electrons as simplified examples - color and hardness

Providing quantum results that don't feel logical to students based on classical understanding

C = Color Box
W = White
B = Black
H = Hardness Box
R = Rigid
S = Soft

Brandon Harvey
Physics Teacher, Oakton High School

Object of the Game

Be the first player to achieve five stones of one's own color in a row, wherein said row may be vertical, horizontal, or diagonal.

Gameplay

Players take turns placing stones at line intersections on the game board. Stones may be placed on any intersection, including on edges and in corners.

In this version of the game, the step before placing a stone is where "measurement" occurs. Once an intersection is selected, the active player must "measure" the resultant stone they will be placing.

Physics Lesson #2

Measurement and Probability

A continuation of Lesson #1, furthering discussions of quantum mechanics as probabilistic

Uses polarization of light as hands-on demonstration of superposition, probability and measurement

Quantum measurement game adapted from Gomoku / Five-in-a-Row

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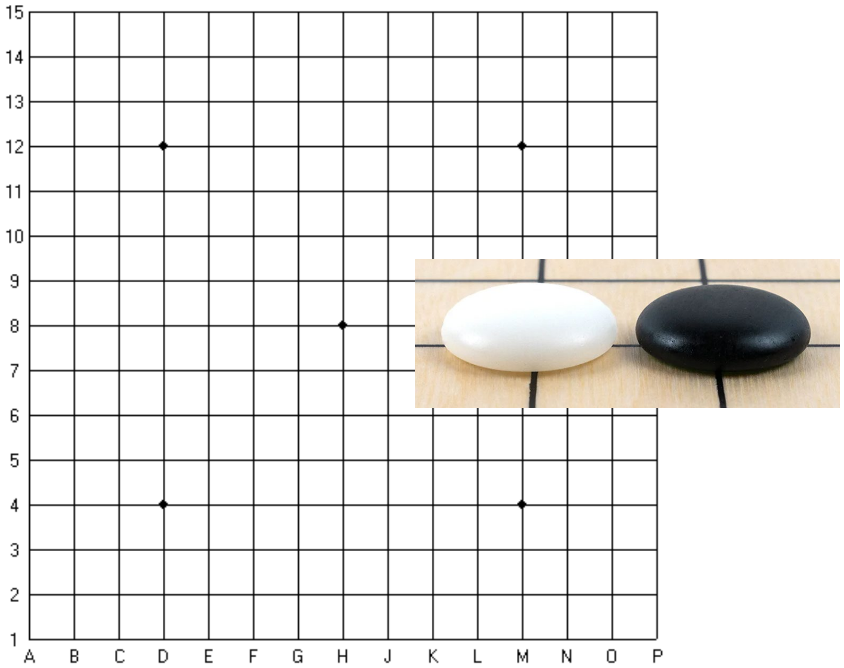
Physics Teacher, Oakton High School



There are three types of possible measurement in the game: 100, 75/25, and 50/50.

Players must use at least one 50/50 measurement and at least three 75/25 measurements for every ten stones placed.

If the player does not select a 100 stone, they must roll an, eight-sided die.

- For the 75/25 measurement, rolling a result of 3-8 results in placing the player's own color stone. Meanwhile, a result of 1-2 results in placing the *other player's* color stone.
- For the 50/50 measurement, rolling a result of 5-8 results in placing the player's own color stone. Meanwhile, a result of 1-4 results in placing the *other player's* color stone.

Chemistry Lesson #1	Chemistry Lesson #2	Chemistry Lesson #3	Chemistry Lesson #4
Wave-Particle Duality	Emission Spectrum of Hydrogen	Wavefunctions and Orbitals	Superposition and Entanglement
Intro to why classical mechanics isn't enough to understand the atom Students investigate particle behavior of light through photoelectric effect simulation Relates wave-particle duality of light to behavior of	Classic introductory chemistry experience of viewing spectrum of hydrogen via discharge tube Connects to honors-level light equation calculations Introduces new aspect of this classic lesson, using the observations as support for Schrodinger's equation	Classic introductory chemistry content of electron configurations and orbital notations Approached from perspective of wavefunctions and probability densities Students consider how probability densities (common "shapes" depicted of orbitals) translate to radial probability distributions	Extension beyond all introductory chemistry content Hands-on activity where one student acts as observer, others act as the orbitals, simulating superposition and entanglement of electrons Activity script provides discussion after each round of activity to highlight key introductory points of concepts Provides bridge at end to quantum computing

George Mason University's Quantum Science & Engineering Center's K-12 Quantum Initiative

Emily Owens, M.S., M.Ed.
Thomas Jefferson High School for Science and Technology

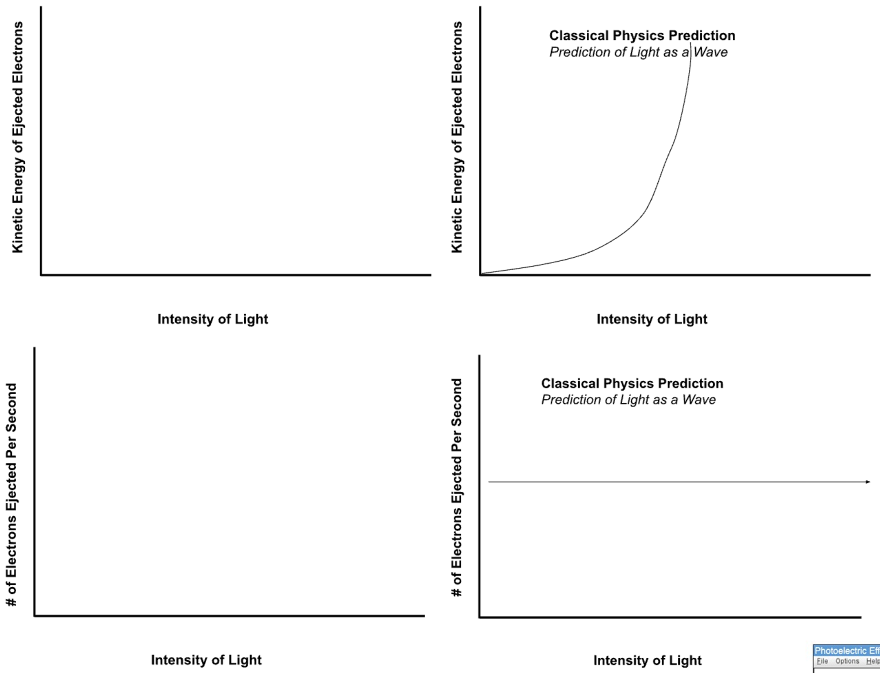
Chemistry Lesson

Wave-Particle Duality

Intro to why classical mechanics isn't enough to understand the atom

Students investigate particle behavior of light through photoelectric effect simulation

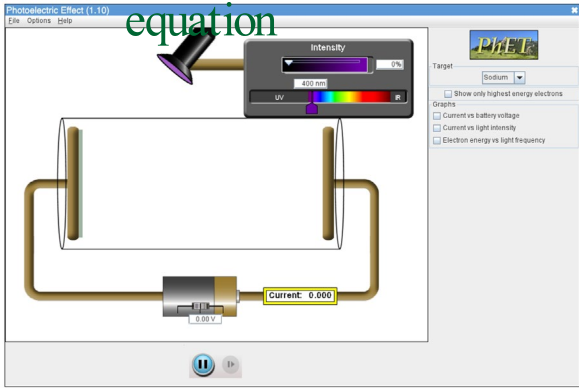
Relates wave-particle duality of light to behavior of



Inspired by [MIT OpenCourseWare 5.111 Principles of Chemical Science Fall 2014 Course, Lecture Summary #]

Gives students the experience of seeing their observations **not** align with earlier models and understanding why the model then has to change

Provides greater context to E=h*ν* equation



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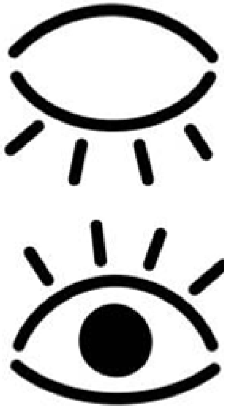
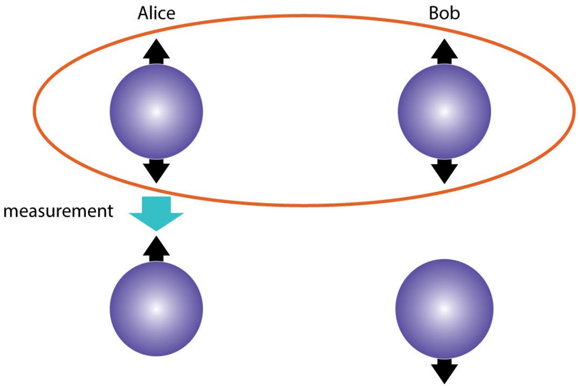
Introduces key quantum concept that **measurement is not a neutral action**- it transforms the quantum system from having multiple outcomes to having only one





Activity slides are scripted so that teachers new to these concepts can still implement it and learn from it, too!

Chemistry Lesson #4

Superposition and Entanglement

Extension beyond all introductory chemistry content

Hands-on activity where one student acts as observer, others act as the orbitals, simulating superposition and entanglement of electrons

Activity script provides discussion after each round of activity to highlight key introductory points of concepts

Provides bridge at end to quantum computing

George Mason University's Quantum Science & Engineering Center's K-12 Quantum Initiative

Emily Owens, M.S., M.Ed.
Thomas Jefferson High School for Science and Technology

University of Waterloo Resources

https://uwaterloo.ca/institute-for-quantum-computing/outreach/quantum-educators

Higher-level quantum resources including QKD kit and other hands-on experiments 3D printer files

Lesson

THE TWO GOLDEN RULES OF QUANTUM MECHANICS WITH LIGHT POLARIZATION

Created by the IQC Scientific Outreach team
Contact: iqc-outreach@uwaterloo.ca

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Waterloo, Ontario, Canada N2L 3G1
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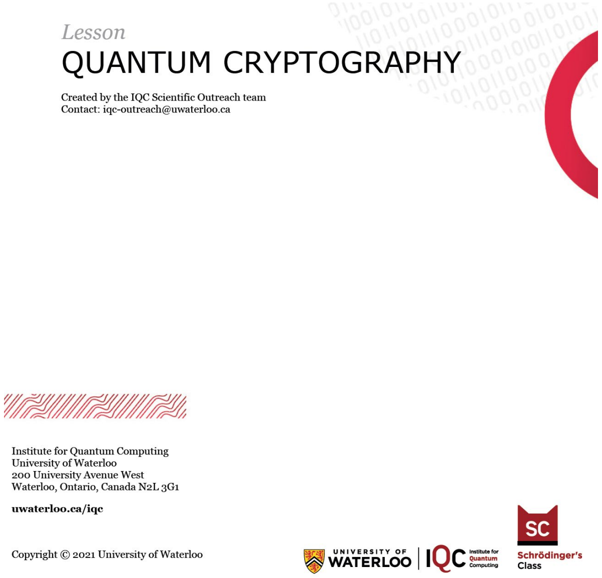

Lesson

QUANTUM CRYPTOGRAPHY

Created by the IQC Scientific Outreach team
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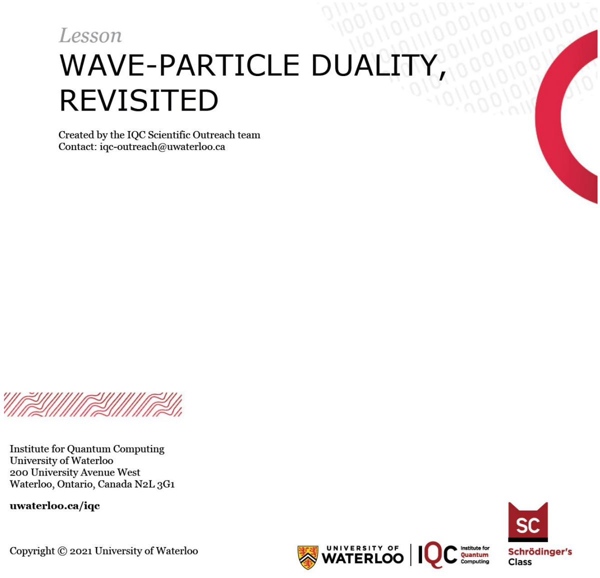

Lesson

WAVE-PARTICLE DUALITY, REVISITED

Created by the IQC Scientific Outreach team
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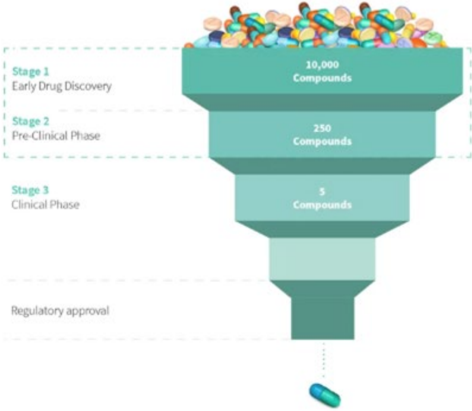
Ideas in Quantum Science and Technology Project

- Identify a societal challenge on which quantum sensing, computing, or cryptography might have an impact
- Identify experts on the topic that you can talk to about the current challenges to progress
- What are the classical bottlenecks?
- What can quantum technologies do to make progress?
- What are the barriers to quantum progress?
- What are the ethical issues as this technology advances?

So, what is Drug Discovery?

1. Early Drug Discovery
2. Pre-Clinical Phase
3. Clinical Phases
4. Regulatory Approval



Motivation: DC Emergency Response Problem

- Allow us to check each fish caught for contaminants
- Fishing zones updated each excursion
- Faster cleanup and more toxin detection
- Less DDT/PCB in foods

TOPIC: QUANTUM SENSOR SOLVE PATIENT WITH PTSD IN SLEEP?

BY JUDY YANG PHYS-391-DL1 4/29/2024

GEORGE MASON UNIVERSITY

Quantum Resources for K -16

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Quantum is Elementary

Secondary Quantum Resources

Chutes and Ladders

QSEC

Quantum Science & Engineering Center