Teaching Quantum Mechanics through Project-based Learning

Summer AAPT Meeting
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Motivation

- PER/cognitive science research has established the need for active learning (e.g. Hake[1])

Active engagement strategies → Increased Student Learning

- Are traditional approaches radical enough?

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[1]Am. J. Phys. **66 (1)**, (1998) 64-74.

Project-based Learning in a Nutshell

1. Learning initiated by a project/problem.
2. Projects are complex and based on the real-world.
3. All needed information is not given.
4. Students identify, find, and use appropriate resources.
5. Students work in rotating teams.
6. Learning is active and connected.

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From U. Delaware Institute for Transforming Undergrad. Educ.

Project-based Learning Outcomes

1. Think critically and solve real-world problems
2. Find, evaluate, and use appropriate sources
3. Work cooperatively in small groups/teams
4. Demonstrate effective communication skills
5. Become active and reflective learners: SDL + SRL

Bottom line: Students do physics as physics is done in the "real world"

Not much PER work done on PBL in upper division courses

The Context

- Junior/Senior level, one-semester quantum mechanics course
- 6-10 students per semester since 2011
- Topics: 1D Schrodinger Equation, Scattering, Time Evolution, Harmonic Oscillator, spectroscopy, Hydrogen atom …

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Course Structure

- **No lectures!**
- Project introduces and motivates the learning in each module
  - Module 1: Why is Energy Quantized?
  - Module 2: How do systems evolve in time?
  - Module 3: What is spin?
  - Module 4: What happens in 3D?
- Weekly HELL Packets
  - Provide scaffolding

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No lectures?

Students are expected to set their own pace, utilize class time effectively, and plan for due dates.

Lecture Tutorials

- 1-3 lecture tutorials per week
- Guided derivation/exploration of the material
- Revision and addition to basic set of tutorials by Todd Timberlake[2]

- Learning Objectives are clearly spelled out for students in each tutorial

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[2]http://facultyweb.berry.edu/ttimberlake/active_quantum/

Lecture Tutorials

Lecture Tutorial: The Finite Square Well

In this tutorial we will investigate the energy eigenvalues and eigenstates for *bound states* in a finite square well. This system is a bit more realistic than the particle in a box model (infinite well) and we'll discover that it has some interesting and unexpected properties. Additionally we'll be introduced to what role symmetry can play in quantum systems.

The learning objectives for this tutorial are:

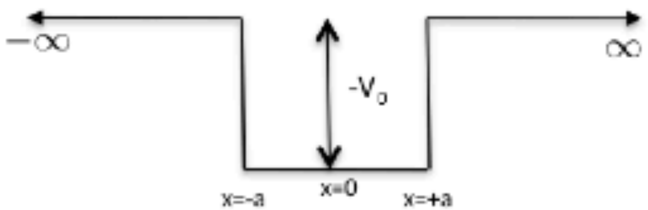
1. To solve the 1D time independent Schrodinger Equation for the finite square well potential in all regions.
2. To observe in another context how energy quantization arises as a result of boundary conditions.
3. To find allowed energies through graphical solutions of transcendental equations.
4. To explore and calculate the number of bound states that a given finite well can support.
5. To discover and quantify the role of symmetry in 1D potential problems in quantum mechanics.

Let's begin:

The finite square well is a system defined by the potential function

$$V(x) = \begin{cases} -V_0, & |x| < a \\ 0, & |x| \geq a, \end{cases}$$

which is symmetric about $x = 0$.



Metacognitive Self-Monitoring

Finite Well Tutorial Self-Assessment

Please rate yourself on the learning objectives of the tutorial using the scale provided. Be honest and identify areas in which you are still struggling!

Objective (Students will be able ...)	Did not Meet Objective	Need more help to meet objective	Met Objective
1. To solve the 1D time independent Schrodinger Equation for the finite square well potential in all regions.			
2. To demonstrate in another context how energy quantization arises as a result of boundary conditions.			
3. To find allowed energies through graphical solutions of transcendental equations.			
4. To explore and calculate the number of bound states that a given finite well can support.			
5. To discover and quantify the role of symmetry in 1D potential problems in quantum mechanics.			

After completing the tutorial, where are you still struggling? What are you still confused about and what questions do you have?

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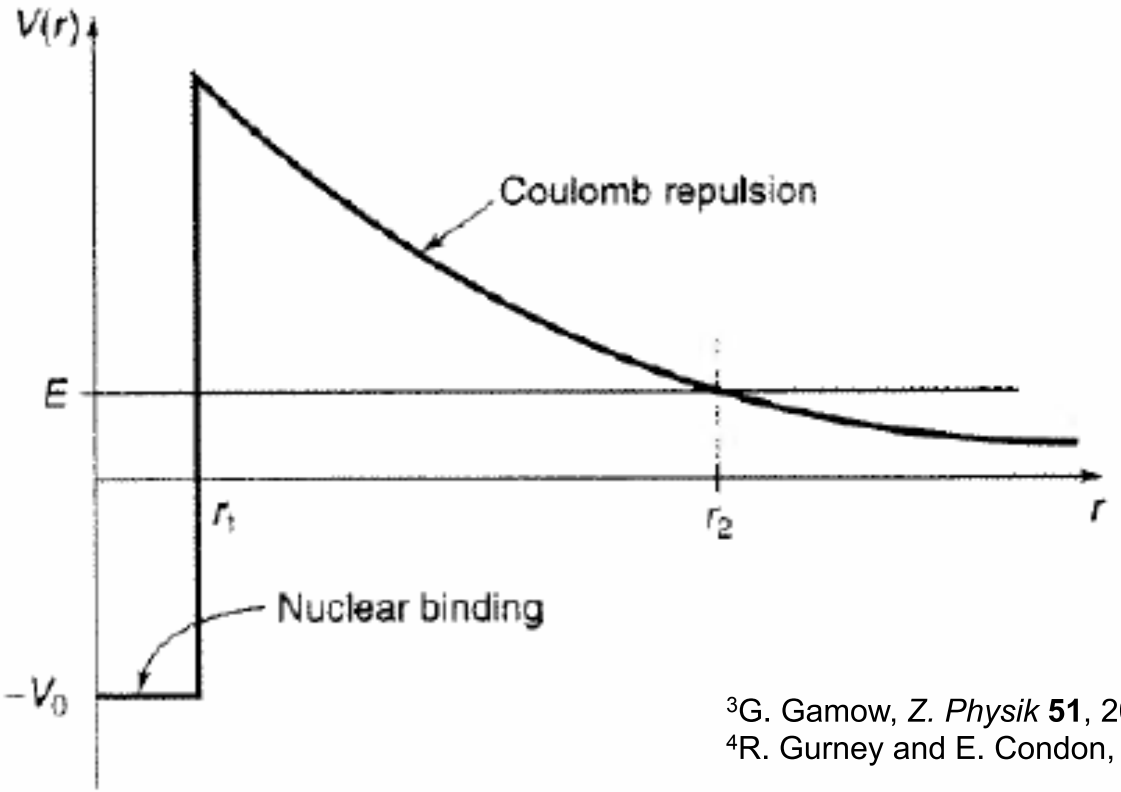
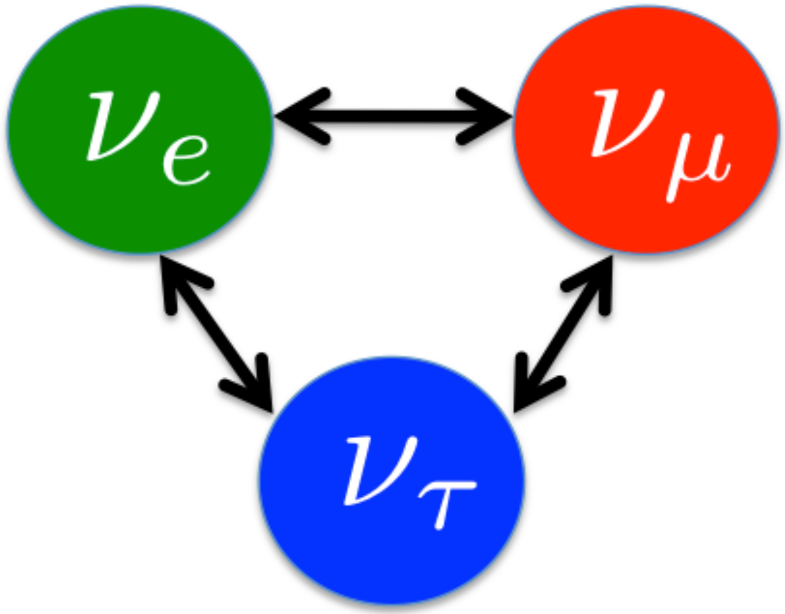
Project Example



α-decay of Uranium by quantum tunneling[3,4]

[3]G. Gamow, *Z. Physik* **51**, 204 (1928)
[4]R. Gurney and E. Condon, Phys. Rev. **33**, 127-140 (1929).

Project Example



Students learn time dependence from exploring neutrino oscillations[5]

Students evaluated on teamwork through CATME[6]

[5]C. Waltham, Am. J. Phys. 72, 742 (2004)
[6]http://info.catme.org/

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Student Reflections and Assessment

- Student reflection is a key element of the course
- End of project reflections
- Goal setting (pre) and final reflection (post)
- QMAT[7] is used as a midterm diagnostic
- QMS[8] survey given pre and post
- CLASS[9] is given pre and post

[7] S. Goldhaber et al., 2009 PERC Proceedings

[8] C. Singh and G. Zhu, Am. J. Phys. **80** (3), 252-259.

[9] http://www.colorado.edu/sei/class/

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Reflections

- Reflections were analyzed using a framework from the literature[10]
- Categories
    1. Technical
    2. In and On Action
    3. Personal
    4. Deliberative
    5. Critical
- Evidence for epistemological growth – see our PERC poster!

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Assessment Results

- Performance on common final exam
- QMAT scores
- QMS scores
- Other important elements – more difficult to quantify:
  - Teaming Abilities
  - Scientific Writing
  - Self-directed Learning and Self-Regulated Learning
  - Shift in motivation

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Conclusions

- PBL offers a way to engage students with real-world problems in a 100% active environment
- Physics is done the way physics is practiced
- Highly motivated students emerge
  - But not all students thrive in this environment
- Class sizes are small (typically 6-10) – difficult to gather statistics on assessment exams
- Reflections give evidence of student epistemological growth and increases in intrinsic motivation

http://physicsweb.creighton.edu/pbl_quantum

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