Some PER-based teaching materials for quantum physics

General notes: Most materials have been written by myself or co-written with PER colleagues. Some have been adapted by myself after their initial development from others. All materials have been tested with multiple classes. Many tutorials have corresponding pretests and homework sets.

Physical optics and wave properties of matter:

Title	Specific notes
Wave-particle duality	• Tutorial adapted from the U. Maryland quantum physics materials,[1] with extensions and HW questions from materials I developed at UWPEG.[2] • Students need to be familiar with deBroglie wavelength prior to this tutorial. Double-slit, single-slit, and Bragg scattering examples are included in tutorial and associated HW.
Spectroscopy	• Lab-tutorial (intended for a 3-hr lab period) on use of spectrometer in analyzing H and He emission spectra. • Adapted in part from UWPEG tutorial on multiple slit interference.[3]

Schrodinger equation in one dimension:

Title	Specific notes
Classical probability	• A tutorial co-authored by me and included in the U. Maryland quantum physics project.[1] Introduces students to probability (from a classical standpoint) and probability density in 1D. • Homework problems include applications to potential energy diagrams.
Shape of the wave function	A tutorial developed as part of the U. Maryland quantum physics project and adapted by me for GVSU. Students work out that $\psi(x)$ must be sinusoidal for classically allowed regions and exponentially increasing or decreasing for classically forbidden regions. • Students need to be familiar with time-independent Schrodinger equation in 1D prior to this tutorial.
Relating classical and quantum mechanics	• Originally part my Ph.D. work, this tutorial (since revised by me) guides students through the semi-classical reasoning to account for the shape of excited bound state (large n) wave functions. Includes Physlet exercise as "check point" at end. • Students should have already thought about classical probability distribution for a simple harmonic oscillator (a homework problem for "Classical probability" tutorial).

[1] FIPSE grant #116B70186, "A New Model Course in Quantum Physics," E.F. Redish, R.N. Steinberg, and M.C. Wittmann (2000 – 2003).

[2] Research toward development and assessment of the original UWPEG version of the tutorial is discussed in S. Vokos, P.S. Shaffer, B.S. Ambrose, L.C. McDermott, Phys. Ed. Res., Am. J. Phys. Suppl. **68**, S42 – S51 (2000).

[3] *Tutorials in Introductory Physics,* L.C. McDermott, P.S. Shaffer, and the Physics Education Group at the University of Washington (Prentice Hall, 2004).