Proposal for the Associated Colleges of the South Teaching with Technology Fellows Program

Title: Developing Open Source Physics Curricular Material and Programs for Quantum Mechanics

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Background

We propose to develop approximately 5 new programs (applications and applets) and supporting curricular material for intermediate and advanced courses in quantum mechanics. The programs and exercises will stress visualization of advanced quantum mechanical concepts (such as two- and three-dimensional quantum mechanics) with the goal of achieving better student understanding of these concepts. The programs and curricular material will be distributed under the GNU open source model.

We have already created curricular material in support of a one-semester, intermediate course in quantum mechanics (available on the web at http://webphysics.davidson.edu/qmbook/). The interactive curricular material uses Physlets [Christian and Belloni 2000] and the Just-in-Time Teaching [Novak, Patterson, Gavrin, and Christian, 1999] approach. In addition, a 69-page Instructor's Guide has been produced and disseminated on a CD with the interactive materials. We can further enhance the effectiveness of these exercises by developing more advanced curricular material based on the tools and philosophy of the new Open Source Physics project.

Description

Although Physlets are written in Java, they are not open source. Physlets are compiled Java applets that are embedded into html pages and controlled using JavaScript. This paradigm works well for general purpose programs (such as the ones we used for our previous ACS grants) but

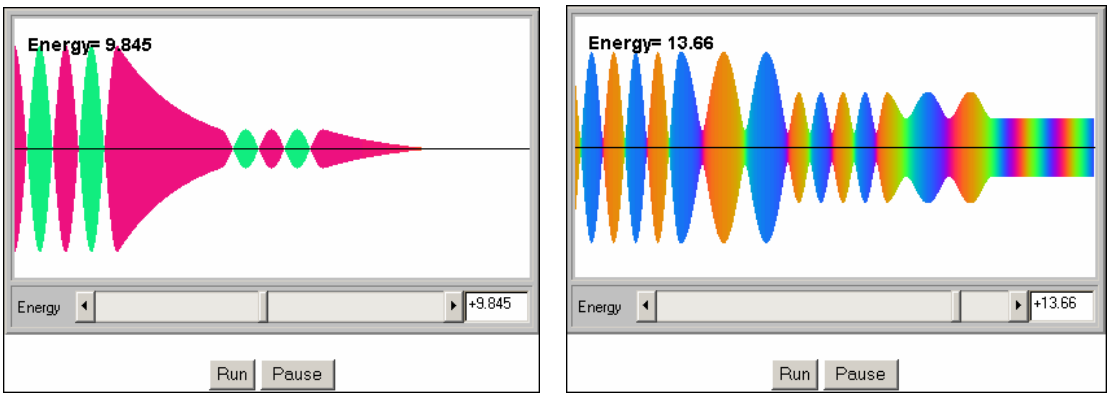

Figure 1: One of our Physlet-based JiTT questions regarding the quantum mechanical barrier problem. Students vary the energy (two such energies shown) of the incident plane wave to determine where the barrier(s) or well(s) are located.

fails for more sophisticated one-of-a-kind simulations that require advanced discipline-specific expertise. Users and developers of these types of programs often have specialized curricular needs that can only be addressed by having access to the source code.

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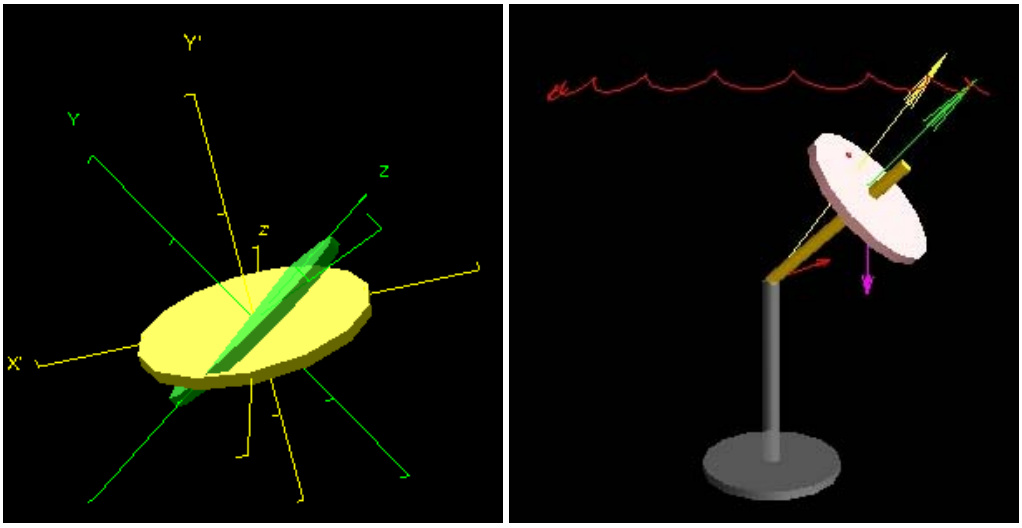

Figure 2: Two OSP 3D applets. The figure on the left shows Euler angles (a group of three rotations about a set of body-frame axes). The figure on the right shows a top's precession and nutation. The OSP 3D framework utilizes Java 3D to create and manipulate 3D worlds for physics simulations.

The Open Source Physics (OSP) project, http://www.orpensourcephysics.org, provides a synergy of curriculum development, computational physics, computer science, and physics education for scientists and students wishing to write their own simulations. The core of this project is a collection of educational programs being distributed under the GNU Open Source license agreement. A number of software developers and have already adopted the OSP model for their own development projects. These projects include *Simulations in Physics* (3rd Ed.) by Harvey Gould, Jan Tobochnik, and Wolfgang Christian, *Statistical and Thermal Physics* by Harvey Gould and Jan Tobochnik, *Easy Java Simulations* by Francisco Esquembre, and OSP 3D applet by Adam Abele and Wolfgang Christian.

The material we create will be part of OSP's growing set of open-source programs and curricular material. This project will focus on momentum-space representations of the wave function and representations of wave functions in two and three dimensions (both topics students have a hard time understanding and visualizing). A list of proposed simulations is described below:

- Wave Function in Position and Momentum Space Simulation: this program will simultaneously show the wave function and its Fourier transform for the quantum harmonic oscillator.
- Two-dimensional Quantum Mechanics Simulations: these programs will show the wave function of a particle confined to a ring, the wave function of a 2D infinite square well, and the wave function of a 2D simple harmonic oscillator potential well.
- Three-dimensional Quantum Mechanics Simulation: this program will show three-dimensional representations of various atomic wave functions.

Timeline

The new material will be completed by September 2003.

Technology

The Physics Department maintains its own servers and therefore server space and server access is not an issue. Both of us have office computers powerful enough to complete this project. In

addition, the College supports our preferred authoring tools, such as Borland JBuilder and Microsoft FrontPage. In addition Wolfgang Christian is author of much of the OSP libraries.

Other Support
2001 and 2002 ACS Teaching with Technology fellowships have already supported our work. Please see the attached grant summary for details.

Learning Outcomes
Learning advanced concepts in quantum mechanics is difficult for many students. Much of the difficulty comes from the fact that students have a hard time visualizing wave functions in momentum space and also visualizing wave functions in two- and three-dimensions. There is clearly a need for better visualization techniques. The visual nature of Open Source Physics programs (especially OSP 3D) and exercises we create will aid students in understanding both the concepts and the mathematics behind advanced quantum theory.

Curriculum
WC is currently teaching the intermediate course in quantum mechanics and MB will do so next year. Consequently, we will be using the materials developed from this grant during fall 2003.

Assessment
We will evaluate our materials by administering the Quantum Mechanics Visualization Instrument [Cataloglu and Robinett, 2002]. We will administer the QMVI as a pre-test and re-administer it as a post-test. We will calculate the normalized gain from the pre- and post-test results (See Eric Mazur, *Peer Instruction*, Prentice-Hall Upper Saddle River, NJ, 1996) to evaluate the effectiveness of our materials. Preliminary results will be available December 2003.

Dissemination
Our materials will be available on the OSP website. Chairs will be sent a letter with the link and asked to distribute the materials to their colleagues. In addition, MB and WC will disseminate the materials developed from this grant through talks and workshops at local and national meetings. WC and MB are also leading the Open Source Physics Workshop at Davidson College July 2003 and will also use this opportunity to assess and disseminate the material as well.

Please see the attached summary report of our 2001 and 2002 Teaching with Technology Fellowships for a more detailed description of our previous assessment outcomes and dissemination activities.

Bibliography
Physlets: Teaching Physics with Interactive Curricular Material, W. Christian and M. Belloni, Prentice Hall, Upper Saddle River, NJ, 2000.

Just-in-Time Teaching: Blending Active Learning with Web Technology, G. Novak, E. Patterson, A. Gavrin, and W. Christian, Prentice Hall, Upper Saddle River, NJ, 1999.

"Testing the Development of Student Conceptual and Visualization Understanding in Quantum Mechanics through the Undergraduate Career," E. Cataloglu and R. Robinett, *American Journal of Physics* **70**, p. 238, 2002.

Hyperlink References
http://www.opensourcephysics.org, the Open Source Physics website.

Previous Grant's Summary Report (as of 10/11/02)

Grant Title: Using Physlets and Just-in-Time Teaching in Quantum Mechanics I and II

Principal Investigators: Mario Belloni (MB)[2], Larry Cain (LC)[3], and Wolfgang Christian (WC)[4]
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Summary Report for Summer 2001 and Summer 2002 Mellon Fellowships

Abstract
We have developed curricular material in support of a one-semester, intermediate course in quantum mechanics. This curricular material uses the Just-in-Time Teaching (JiTT) technique and, where applicable, Physlets to actively engage students outside of the classroom to enhance their in-class experience. Forty-six such JiTT exercises and in-class interactive demonstrations have been developed to stress the visualization of quantum mechanical concepts with the goal of achieving better student understanding of these concepts. In addition, a 69-page Instructor's Guide has been produced and disseminated on a CD with the interactive materials.

Student Learning of Quantum Mechanics

Learning quantum mechanics is difficult for many students. There are three main reasons for this:

- Quantum mechanics is not like classical mechanics (uncertainty versus determinism).
- Quantum mechanics is one level (at least) divorced from the world we live in.
- Quantum mechanics is inherently mathematical.

The exercises we have developed are geared to address these difficulties. Daily JiTT exercises (WarmUps) help students prepare for class. Students prepared for class by doing these targeted exercises are more motivated to understand the material presented and actively participate in class. Given how difficult quantum mechanics is to comprehend, this preparation and motivation is crucial. In addition, the visual nature of the Physlet-based exercises aids students in understanding both the concepts and the mathematics behind quantum theory.

Integration into the Curriculum

MB and WC are currently teaching the intermediate-level course in quantum mechanics and will continue to do so this year and next. MB used the materials developed from this grant in his intermediate quantum mechanics course during fall 2001 and his advanced quantum mechanics course during spring 2002. WC is using the materials in his intermediate quantum mechanics course during fall 2002. Several colleagues from colleges and universities across the country are using these materials. In addition, some of these materials have "trickled down" to the sophomore-level modern physics course at Davidson and "laterally moved" to the junior-level physical chemistry course at Davidson.

Evaluation and Dissemination

We are evaluating our materials by administering the Quantum Mechanics Visualization Instrument (QMVI) developed by Richard W. Robinett of Pennsylvania State University. This test is available upon request. Students performed better on the QMVI than graduate students

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after a graduate course in quantum mechanics. Our data from the fall 2001 course is also available upon request.

We have e-mailed the Physics department chairs of the ACS and the members of the ACS-PHYSICS e-mail list with the web address: http://webphysics.davidson.edu/qmbook where they may access our materials. We have mastered our materials---both the Instructor's Guide and the interactive materials---onto a CD which we sent to the chairs. (Last year we sent the preliminary materials to the chairs as well.) Chairs have been asked to distribute the materials to their colleagues.

In addition, MB, LC, and WC have widely publicized these materials outside of the ACS. Specifically:

- February, 2001: Syllabus column in the Chronicle of Higher Education. Profiled teaching methods (Physlets and Just-in-Time Teaching) and the (then) future work on quantum mechanics. This article is available at: http://webphysics.davidson.edu/mjb/syllabus_02_16_01.html.

- March, 2001: *Contributed Talk*, "Enhancing Student Learning with Interactive Curricular Material," North Carolina Section of the American Association of Physics Teachers. The talk is available at the address: http://webphysics.davidson.edu/mjb/ncssm_aapt_talk.

- July, 2001: Handed out 30 CDs containing the preliminary exercises to our (WC and MB) workshop (Physlets: Teaching with Interactive Curricular Material, W33) participants at the national American Association of Physics Teachers meeting in Rochester, NY.

- July, 2001: *Invited Talk*, "Using Physlets and Just-in-Time Teaching in Quantum Mechanics," national American Association of Physics Teachers meeting, Rochester, NY. The talk is available at: http://webphysics.davidson.edu/mjb/rochester2001.

- September, 2001: Web site, http://webphysics.davidson.edu/qmbook/, officially on-line with the quantum mechanics exercises. We e-mailed a letter to each physics department chair in the ACS and the members of the ACS-PHYSICS e-mail list to inform them of our work. We sent our materials on a CD to ACS physics chairs.

- November 3, 2001: *Contributed Talk*, "Using Just-in-Time Teaching and Physlets in Undergraduate Quantum Mechanics," Southeastern Section of the American Physical Society, Charlottesville, Virginia.

- December, 2002: QMVI results tallied. Students performed better on the QMVI than graduate students after a graduate course in quantum mechanics. This data is available upon request.

- January, 2002: *Workshop*, "Using Interactive Java-based Pedagogies in the Classroom" winter meeting of the American Association of Physics Teachers Philadelphia, PA. 50 CDs were distributed to workshop participants and other interested faculty from around the country.

- February, 2002: CDs sent to the 15 ACS Chairs and also GLCA Chairs.

- February, 2002: *Invited Talk*, "Enhancing Student Learning with Physlet-based Just-in-Time Teaching," Invitational Conference on K-12 Outreach from University Science Departments: Using Technology to Link the Classroom to the Laboratory (and Murphy to Manteo), Raleigh, North Carolina.

- March 2002, *Contributed Talk*, "Using a Computer-Rich Curriculum to Teach Quantum Mechanics," North Carolina Section of the American Association of Physics Teachers, Winston Salem, North Carolina.

- April 2002: *Invited Talk*, "Using Physlet-Based Interactive Exercises to Enhance Student Learning," Spring Meeting of the Southern Atlantic Coast Section of the American Association of Physics Teachers, Gainesville, GA.

- April 2002: *Invited Colloquium*, "Making Quantum Mechanics Interactive with Physlets and Just-in-Time Teaching," Physics Department, Indiana University-Purdue University, Indianapolis, Indianapolis, IN.

- June 2002: *Contributed Poster*, "Time-Dependent Superpositions in Symmetric Potentials: How the Parity of the Wave Function Affects Expectation Values," Gordon Research Conference on Physics Research and Education: Quantum Mechanics, South Hadley, MA.

- June 2002: *Invited Special Curriculum Session*, "Physlet-Based Media-Focused Education: Making Quantum Mechanics Visual and Interactive," Gordon Research Conference on Physics Research and Education: Quantum Mechanics, South Hadley, MA.

- August, 2002: Handed out 30 CDs containing the QM exercises to our (WC and MB) workshop (Physlets: Developing Interactive Curricular Material, W32) participants at the national American Association of Physics Teachers meeting in Boise, ID.

- August 2002: *Invited Talk*, "The Development and Assessment of Interactive Exercises for Quantum Mechanics," Summer Meeting of the American Association of Physics Teachers, Boise, ID.

- August, 2002: CDs sent to the 15 ACS Chairs.

- August, 2002: Material posted on the MERLOT (Multimedia Educational Resource for Learning and Online Teaching) Digital Library.

- September, 2002: *Opening Plenary Talk,* "Using Physlets to Teach Quantum Mechanics," 7th Workshop on Multimedia in Physics Teaching and Learning, Parma, Italy.

This work is referenced in:

- "Physlets: Web-based Java Applets for Physics Education," Wolfgang Christian, Mario Belloni, and Melissa Dancy, *Fall 2001 Newsletter of the American Physical Society Forum on Education*. Web Address: http://www.aps.org/units/fed/fall2001/index.html.

- "Enhancing Student Learning with Physlet-based Just-in-Time Teaching," Mario Belloni, Wolfgang Christian and Aaron Titus, *Proceeding of the Invitational Conference on K-12 Outreach from University Science Departments: Using Technology to Link the Classroom to the Laboratory (and Murphy to Manteo)*. Submitted March 2002.

- "Teaching with Physlets®: Examples from Optics," Melissa Dancy, Wolfgang Christian, and Mario Belloni, *The Physics Teacher*, November 2002.