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

Open Source Physics Curricular Material and Programs for Teaching Spin in Quantum Mechanics

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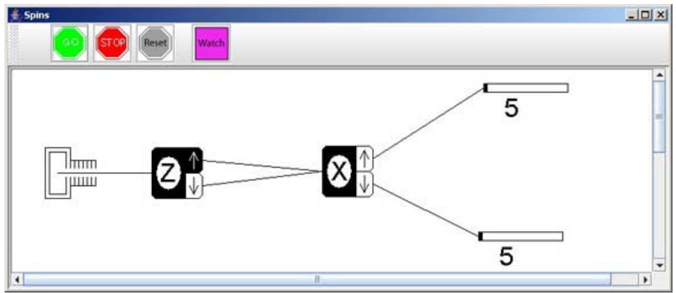

Figure 1: Screen shot of the new xml-based open source Java program, OSP Spins, which simulates the measurement of an ensemble of spin-1/2 quantum-mechanical particles. This example simulates a 'which-way' experiment in which the outcome of the experiment is changed by watching which ideal Stern-Gerlach apparatus the beam passes through. The program's user interface can now be configured to reduce the number of options available which allows teachers to write curricular material that forces students to interact with the simulation in a specific way. These configurations and customizations can be saved in xml files and then loaded as shown in this example.

Background

We proposed to adapt and develop new programs (applications and applets) and supporting curricular material for intermediate and advanced courses in quantum mechanics. The programs and exercises stress the conceptual understanding of spin (intrinsic) angular momentum in quantum mechanics. The programs and curricular material are distributed under the GNU open source model. In addition to a self-contained executable file which distributes the interactive materials (called `osp_spins.jar`); we have also created a 55-page printable version of the materials available in PDF format from our Web site and soon available in a printed version from www.lulu.com. These materials can be found on our quantum mechanics Web site:

http://www.opensourcephysics.org/apps/qm/index.html

with the spin-1/2 materials at

http://www.opensourcephysics.org/apps/qm_spins/index.html

and also on the ComPADRE quantum mechanics digital library (*The Quantum Exchange*) at

http://thequantumexchange.org/

With previous ACS Teaching with Technology Fellowships, we created curricular material in support of a one-semester, intermediate course in quantum mechanics [1-2]. This work was also summarized in an invited paper for ACS's on-line journal *Transformations* [3] and much of it also appears in the new textbook *Physlet Quantum Physics* [4]. The interactive curricular material uses Physlets [5] and Open Source Physics applets [6-8] to visualize standard one-, two-, and three-dimensional problems in quantum mechanics. We have further enhanced the completeness and effectiveness of these exercises by developing new advanced exercises dealing with spin angular momentum.

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Description

The Open Source Physics (OSP) project [6-8] 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. The material is part of OSP's growing set of open-source programs and curricular material. This project focuses on spin angular momentum, in particular individual particles and ensembles of particles as shown in Figures 1.

Programs Completed

- **Spin State Program**: This program simulates multiple spin measurements on a *single* quantum-mechanical particle. This is accomplished by allowing students to make measurements of spin in a particular direction. In addition to determining what happens after measurement, we also include the quantum-mechanical time evolution of the state.

- **OSP Spins program:** This program simulates the measurement of the components of spin on an ensemble of particles (a virtual Stern-Gerlach experiment). The original Spins program [9] was written for the Macintosh and was then ported to Java and called SPINS by David McIntyre of Oregon State University. Both of these versions were open source. We have made extensive modifications to the Java version of the SPINS program. With the original version, one had to manually set up scenarios within the applet; these scenarios were then lost when the applet was closed, thereby limiting the effectiveness of the program. Our improvements, which appear as the OSP Spins program, include the ability to script the program using an extensible markup language (xml) data file to enable different scenarios to be saved and then loaded quickly and easily. This allows instructors to construct and distribute more interesting virtual experiments (see Figure 1) and allows students to spend more time on the physics. In addition, the user interface can be customized within the xml data file to reduce the number of options available. This allows teachers to write curricular material that forces students to interact with the simulation in a specific way.

The OSP Spins program can be run as a stand alone application, a browser-based applet, and a Java Web Start application. Because each of these distribution mechanisms has strengths and weaknesses, we support all three mechanisms. All versions are available on the Open Source Physics website and the stand alone version is available on the CD accompanying this report.

A Java application is a program that runs just like any other installed program. Running an application is the simplest most reliable way to access the OSP Spins curricular material because the program has complete access to local resources consistent with the user's file (security) permissions. Double-click on the `osp_spins.jar` file on the accompanying CD to execute the program if the file system browser associates the "`jar`" extension with the Java VM.

Curricular Modules Completed

OSP curricular material is organized using the OSP Launcher program written by Doug Brown. Launcher allows us to distribute programs, documentation, and curricular material in a single easily modifiable package. The OSP Spins Launcher package can be accessed by double clicking on the osp_spins.jar file. Click on the **Exercises** button near the bottom of the splash screen in order to load curricular materials for spin-1/2 systems into Launcher. This material is organized using tabs which appear at the bottom of the program as follows:

- **Spin-1/2: Tutorial:** An interactive self-contained tutorial on spin-1/2 systems. This tutorial contains the necessary theory required to understand and complete the exercises.
- **Spin-1/2: Single Measurement:** Single measurement exercises in which a beam of spin-1/2 particles is incident on one ideal Stern-Gerlach apparatus. These exercises show how a single measurement of spin affects the original spin state. These exercises include those that require students to determine either the original spin state or the orientation of an unknown analyzer.
- **Spin-1/2: Multiple Measurement:** Multiple measurement exercises. These exercises show how multiple measurements of spin affect the original spin state. These exercises include those with two and three ideal Stern-Gerlach apparatus and a 'which-way?' experiment in which the outcome of the experiment is changed by watching the ideal Stern-Gerlach apparatus.
- **Spin-1/2: Spin Precession:** Spin precession exercises in which a beam of spin-1/2 particles passes through a magnetic field for a given time, causing the beam to 'precess.' These exercises show how an additional magnetic field affects the original spin state.
- **About:** Gives an overview of the curricular materials, describes the OSP Spins and Launcher programs, and gives author credits and version information.

The default setting of osp_spins.jar loads a splash screen with three buttons: **Exercises**, **Tutorial**, and **About**. These buttons load custom launch sets (called xsets because they are loaded into Launcher using a file with an "xset" extension) which can be accessed once the Launcher is running. These custom launch sets create a table of contents with links to programs and html documents. These launch sets also allow instructors to launch only one piece of curricular material, a related group of materials, or the entire package of curricular materials.

Executing the osp_spins.jar file and either clicking a button, or using the **File|Open Internal** menu item, accesses the following modules:

- **osp_spins:** the default, loads the main splash screen with buttons.
- **osp_spins_ex:** loads all the spin exercises (**Exercises** button).
- **osp_spins_tutorial:** loads only the **Tutorial** tab (**Tutorial** button).
- **osp_spins_all:** loads all the materials.
- **osp_about:** loads the **About OSP Spins** tab (**About OSP Spins** button).

Printed Support Materials

We have also created a 55-page printable version (in PDF) of the curricular materials in the osp_spins.jar available for from our Web site. After class testing and getting feedback, we will also produce a printed version which will be available as a mini-book from www.lulu.com.

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 quantum-mechanical concepts and spin angular momentum is no exception. There is clearly a need for better visualization techniques. The visual nature of Open Source Physics programs and exercises we create will aid students in understanding both the concepts and the mathematics behind advanced quantum theory.

Curriculum

MB and WC have alternated teaching the intermediate course in quantum mechanics for the past 6 years and WC will be teaching this course next year. Consequently, we will be using the materials developed from this grant during fall 2006.

Assessment

We will continue to evaluate our materials by administering the Quantum Mechanics Visualization Instrument [10]. We will administer the QMVI (which has some spin-related questions) as a post-test at the end of the Fall 2006 semester. Preliminary results will be available December 2006. The results from the Fall 2001-2003 Davidson College undergraduate quantum mechanics courses (66.3, 57.0, and 70.7, respectively) and the average of all three courses (63.0) compare favorably to the results (out of 100) presented in Ref. [10] for modern physics (28.5), undergraduate quantum mechanics (51.1) and graduate quantum mechanics (55.5).

Dissemination

Our materials will be available on the OSP website. In addition, MB and WC will disseminate the materials developed from this grant through talks and workshops at local and national meetings. Below is a list of venues in which this material has been or will be disseminated.

<u>August 2005:</u> Professional development workshop, "Open Source Physics," Summer Meeting of the AAPT.

<u>September 2005:</u> Invited Talk, "Using Open Source Physics to Visualize Advanced Problems from Classical to Quantum Mechanics," 10th Workshop on Multimedia in Physics Teaching and Learning of the European Physical Society, Berlin, Germany.

<u>November 2005:</u> Invited Talk, "Making Quantum Mechanics Visual and Interactive with Physlet- and OSP-Based Curricular Material," Joint Meeting of the Southeastern Section of the American Physical Society and the Florida Section of the American Association of Physics Teachers, Gainesville, Florida.

<u>January 2006:</u> Invited Talk, "Making Quantum Mechanics Visual and Interactive with Physlet- and OSP-Based Curricular Material," Winter Meeting of the American Association of Physics Teachers, Anchorage, Alaska.

<u>January 2006:</u> Professional development workshop, "Time-dependent Phenomena in Quantum Mechanics: Theory, Experiment, and Computer Tools," Winter Meeting of the AAPT.

<u>March 2006:</u> Professional development workshop, "Quantum Mechanics With Interactive Computer-based Tutorials," March APS Meeting Baltimore, MD (sponsored by the APS Forum on Education).

Bibliography

[1] The results from our first two Teaching with Technology Fellowship (the curricular material and the Instructor's manual) are available at: http://webphysics.davidson.edu/qmbook/.

[2] The results from our third Teaching with Technology Fellowship are available on the Web at: http://www.opensourcephysics.org/applets/ospqm/default.html.

[3] "Using Physlets and Open Source Physics to Make Quantum Mechanics Visual and Interactive," M. Belloni, W. Christian, and L. Cain, *Transformations: Liberal Arts in the Digital Age*, Volume 2, Number 1 (2004). Paper is available on the Web at: http://www.colleges.org/transformations/index.php?q=node/view/77.

[4] *Physlet Quantum Physics: An Interactive Introduction*, M. Belloni, W. Christian, and A. J. Cox. Prentice Hall, Upper Saddle River, NJ, 2006. ISBN 0-13-101970-8.

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

[6] The Open Source Physics project is available on the Web at: http://www.opensourcephysics.org/.

[7] *An Introduction to Computer Simulation Methods: Applications to Physical Systems* 3/e, H. Gould, J. Tobochnik, W. Christian, Addison Wesley 2007.

[8] *Open Source Physics: A Users Guide with Examples*, W. Christian, Addison Wesley 2007.

[9] "A computer-simulated Stern–Gerlach laboratory," D. Schroeder and T. A. Moore, *Am. J. Phys.*, **61** 798 (1993).

[10] "Testing the Development of Student Conceptual and Visualization Understanding in Quantum Mechanics through the Undergraduate Career," E. Cataloglu and R. Robinett, *Am. J. Phys.*, **70** 238 (2002).