LEARNING MATHEMATICS THROUGH WEB-BASED EXPERIMENTS

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1. INTRODUCTION

This article illustrates the feasibility of hands-on experimentation and data generation through the use of web-based implementation of an experiment. Using the technology developed, students are able to conduct an on-line experiment to gain familiarity with important experimental concepts and generate data that can be used as part of a mathematics or statistics course. Students are able to collect data without the constraints of possessing specialized equipment or having been trained to use specific data acquisition devices.

The authors' long-term goal is to develop sustainable, experimenter friendly and web-accessible experiments. The experiment described was developed to allow students to drop a steel ball onto a force sensor from various heights. The sensor records the force exerted on the ball during the short time interval required to stop the ball. The web interface allows students to investigate force versus time data on the web site or download the data for further analysis on their local computer.

With this project, the authors have aspired to develop a reliable, understandable, repeatable and low maintenance on-line experiment on a limited budget. The experiment generates real-time data and is not simply a simulation or a presentation of previously generated data.

The web site supporting the experiment may be found at http://dropball.cs.emporia.edu. The experiment is available to all interested.

2. BACKGROUND

Through the use of web-based experimentation, the authors are expanding the learning environment by making experimental activities available through the World Wide Web for on-campus students and for those at off-site locations with Internet access. Using techniques developed in this undertaking, students are able to perform hands-on experiments as easily as they access other web-based instruction. In addition, courses that do not contain a laboratory or an experimentation component may easily add experimental activities to their courses through the use of web-based experimentation.

The use of experimentation in introductory statistics courses, and the motivation for such an approach, has been aptly summarized by Cabilio and Farrell (2001). Oldford (1995) and Spurrier, Edwards, and Thombs (1995) have proposed physical experimentation as an adjunct to the teaching component of statistics courses. Science is experimental. Hands-on laboratory experience is an invaluable part of an education in the sciences. Web-based experiments allow anyone with access to the World Wide Web the opportunity to perform real experiments via remote control.

This implementation facilitates the student laboratory experience. This experiment:

- is actually taking place when the user enters the experimental parameters.
- can be viewed by the user during execution of the experiment.
- can return actual experimental data to users either on-line or via e-mail.

In the past several years, experimental simulations have appeared with discipline specific texts, such as Jones and Childers (2001) and Christian and Belloni (2001) or on the World Wide Web at sites such as the Physical Sciences Resource Center at http://www.psrc-online.org. Many of these simulations are implemented using Java applets, and are well designed and executed. However, in the end they are still simulations of experimental situations and fail to provide the "look and feel" of actual experimentation. The focus here is on implementing an experiment which provides data acquisition, archiving, processing, and presentation for both on and off-campus users. To this end, the authors have integrated a data archiving and review capability to allow experimenters to have access to both their own experimental results as well as previously conducted experiments.

The idea of on-line experimentation is not unique to this undertaking. A number of sites have implemented the notion of on-line experimentation. Examples include:

- Stevens Institute of Technology in their Remote Dynamical Systems Laboratory at http://dynamics.soe.stevens-tech.edu, has implemented an excellent site incorporating several on-line experiments. However, users are limited to only having access to their own results. In addition, most results must be emailed to experimenters, making the data acquisition process rather cumbersome.

- Mercer University has implemented the Online Interactive Chaotic Pendulum, which is available at http://physics.mercer.edu/pendulum. The site has an exemplary interface and data presentation, but doesn't provide easy access to data that can be analyzed.

Several mechanical engineering graduate courses have implemented on-line experimentation, including http://www.cage.curtin.edu.au/mechanical/info/vibrations and http://weblab.iit.edu. These sites tend to be highly technical and their on-line availability appears to be limited. Their work is commendable, but well beyond the understanding of the typical undergraduate student.

3. IMPLEMENTATION

The apparatus and supporting software are generically called DropBall. It is an online physics experiment in Newtonian mechanics. Data collected by the apparatus is force in Newtons versus time in seconds. The experiment was implemented using a network-connected computer (web-server) with two Vernier LabPro data acquisition devices from Vernier Software & Technology (http://www.vernier.com/), and a control system for the apparatus using a Basic Stamp from Parallax, Inc. (http://www.parallax.com/). Custom software was written to control the apparatus, manage data storage and generate the web interface. A diagram of the mechanical portions of the apparatus is provided in Figure 1.

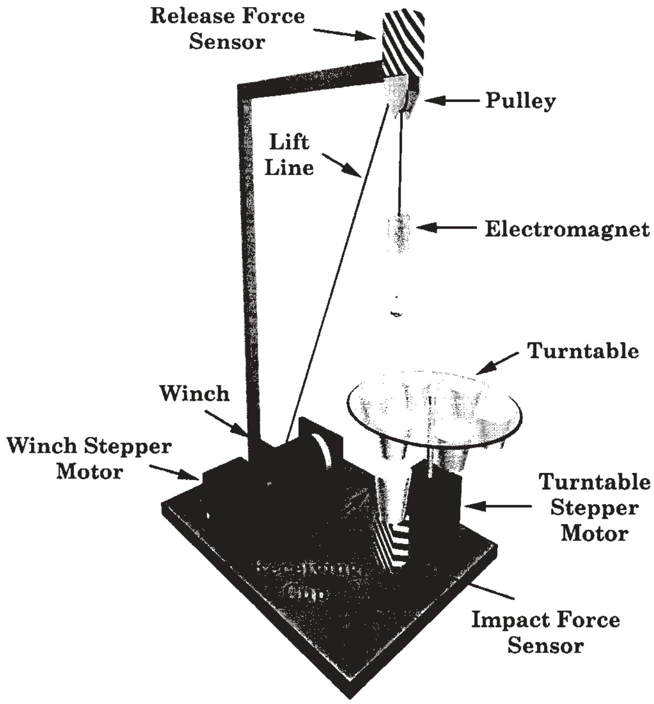

Figure 1 – DropBall Apparatus

Initiation of experiments is controlled from any standard web browser. The data that are acquired may be sent via e-mail or displayed to the remote user shortly after the apparatus generates it. With the ability to control experimental apparatus remotely, the equipment described can be easily operated, and the data rapidly acquired and analyzed.

5. USER INTERFACE

The DropBall implementation has a number of screens from which the experimenter may run an experiment or view experimental results. To perform an experiment, the user may go to "Run Experiment" screen and specify a ball drop height between 0 and 100 cm. Heights may be specified to an accuracy of 0.1 cm. In addition the user must specify the type of ball to drop (designated 1-5). The user may enter a text note to identify the data, or specify an e-mail address to which results may be sent. When the options have been selected, the user clicks "Submit". The request is then placed in the experiment run queue. Once the experiment has been submitted, a screen confirming the run parameters and the run ID number will be displayed. The run ID or a user-entered note can be used to identify the experiment. All user runs are recorded in a database that may be queried.

After submitting an experiment the user may watch a streaming video of the experiment currently being conducted. The video camera is placed on the upper arm of the apparatus giving an overview of the experimental area. A maximum of 5 users may view the experimental setting simultaneously.

6. EXAMPLE ACTIVITY

In this section, we provide an excerpt from one laboratory activity available on the DropBall site. The DropBall activities are available in an editable form so that instructors may modify the activities to suit their specific course needs

Verifying Free Fall Time

This is a somewhat more advanced activity asking the student to estimate coefficients in a non-linear equation. This is applicable to advanced undergraduate or graduate students.

If an object is released with no initial velocity from the drop point, the position y (drop height in meters) is related to the time t by:

$$y = \frac{1}{2} g t^2 \qquad (1)$$

where y is the drop height.

In the DropBall apparatus, the two force sensors in the apparatus generate force profiles.

- The release force sensor is used to determine when the ball has actually departed from the magnet. Residual magnetism in the ball and electromagnet cause the ball to be retained by the electromagnet even after current has been switched off.
- The impact force sensor measures the impact of the ball on the receiving cup.

The typical force profile presented in DropBall adjusts the impact force profile for retention using the release force sensor information. If we just use the raw impact force sensor information, the drop profile contains a bias (retention time, t_R) due to the residual magnetism.

We can modify equation (4) to include the retention time term as:

$$y = \frac{1}{2} g (t + t_R)^2 \qquad (2)$$

We now have a non-linear model of height versus time. We may fit the model:

$$y = \beta \ (t + t_R)^2 \qquad (3)$$

Estimate β and t_R. Choose at least 8 drop heights and a ball type.

7. DISCUSSION AND CONCLUSION

The question of experimental reality concerns the issue of how close does a student need to be to an experiment to gain the experience of actually conducting an experiment. The Virtual Frog Dissection Kit of Lawrence Berkeley National Laboratory (http://www-itg.lbl.gov/ITG.hm.pg.docs/dissect/) raises similar questions. Can a student remotely gain the same experience as one who is physically performing the experiment? Any time a computer is introduced into an experimental setting, researchers are one-step removed from the data acquisition process. Based on the author's observations, students that have used the device appear to quickly discard any feelings about the remoteness of the experiment and focus on generating data and assessing their experiments.

The authors have used DropBall experimentation in several courses as well as asking colleagues to experiment in their classes with the apparatus. Overall student response to using this approach has been very favorable. As with most student experimentation, actually generating the data provides students with ownership of their data and analysis and transcends simply analyzing canned or textbook data. At this time we feel that the apparatus can be successfully used to introduce a hands-on experimentation component into a course or to act as an adjunct to a course incorporating experimentation.

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