Data Portfolio: instructional materials provide particle physics data in high school classrooms.

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Abstract

We discuss Data Portfolio (DP), a new suite of activities that provide experimental particle physics data to high school students and a professional development program for their teachers. DP is a website resource with a broad range of instructional materials that allows teachers to select activities of the correct level and scope for their students. Activities range from introductory to survey, investigation and exploration. DP incorporates existing elements such as masterclasses and e-Labs along with new ways of introducing students to physics concepts that underlie the data measurements and investigations. Evaluators have determined that these elements are in line with the latest standards and effective instructional models. To be successful, teachers need to be confident to use the materials, comfortable to step back so students can guide their own learning, and clever to convince administrators that they are meeting school and district requirements. Professional development workshops accompany the DP where participants experience some of these activities as their students would and plan how to use them in their classes. The first weeklong DP workshop was held in July at Fermilab. We have also held outreach workshops in conjunction with ILC workshops around the world. DP is a product of QuarkNet, a long-term professional development program embedded in the U.S. particle physics research community and funded by the National Science Foundation and the U.S. Department of Energy and supported by universities and labs across the country.

Keywords: education; high school; experimental data; classroom materials

1. Introduction

The QuarkNet Data Portfolio (DP) is a new, user-friendly online suite of activities that provide experimental particle physics data to high school students. A professional development program for teachers helps them gain confidence in using the data and analysis tools and become comfortable in stepping back to allow students to construct their own understanding.

2. Conceptual framework

Designed to provide a broad range of instructional materials for collecting, organizing and analyzing data and reporting results, the DP allows teachers to build a learning sequence for their students from simple to complex, from working with one or two variables to handling multi-variables in authentic research situations. When students progress through the sequence, they gradually accumulate content knowledge and skills necessary to handle ever more challenging assignments. Ultimately, they can begin to understand, perhaps for the first time, how scientists make discoveries.

Currently, the Data Portfolio hosts instructional materials developed around three datasets: data from the LHC and LIGO, and cosmic ray data collected by a student collaboration that uses high school classroom detectors. In addition, activities are organized into three levels of engagement and are searchable by topic.

In order to provide a contextual framework for the sequence, we look to particle physics research techniques that the activities model. Currently, we include the following:

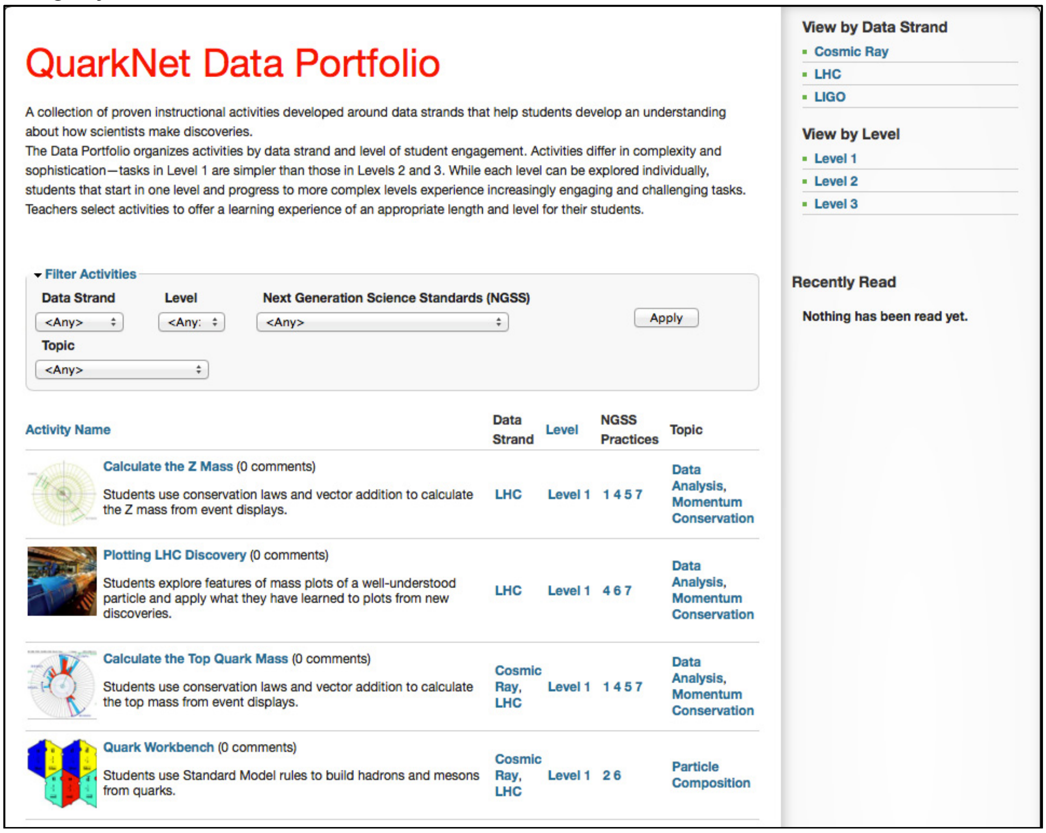
- The Standard Model organizes current knowledge.
- Electric and magnetic fields accelerate, bend and focus beams of charged particles.
- Scientists use well-understood particle masses to help calibrate detectors.
- Indirect evidence provides data to study the short-lived particles.
- Event displays visualize data.
- Histograms represent data for analysis and interpretation.

In the United States, it is also important that activities support the *Next Generation Science Standards* (http://www.nextgenscience.org/next-generation-science-standards) and the *Common Core* (http://www.corestandards.org). These new standards provide learning goals that are aligned with college and career expectations. To support this alignment, activities have the following characteristics:

- Learning objectives are behavioral.
- Learners work in pairs or groups.
- Activities use guided inquiry. (In advanced activities students ask their own questions.)
- Learners support claims with evidence derived from data.

3. Website and activities

The Data Portfolio is online at http://quarknet.i2u2.org, the QuarkNet community-based website developed using Drupal Commons (http://www.acquia.com/products-services/drupal-commons-social-business-software). Available to QuarkNet members and non-members alike, the DP activities display in list format with the ability to organize the list alphabetically by activity name and numerically by level. One can also view the activities by data strand or level. Eventually, developers will add a view by topic. Users can filter the activities applying more than one characteristic, for example, the LHC data strand and a topic of momentum conservation. Pdf files provide teacher notes and lesson plans; and links take users to more extensive online activities.



The Data Portfolio learning sequence begins with activities in which students analyze one variable. They determine patterns, organize data into a table or graphical representation and perform simple calculations.

At Level 1 most are lessons that can be completed in one class period. A teacher can choose lessons that support topics they cover in a more traditional introductory physics class. To follow the DP model, a teacher or professional development instructor would build a series of lessons that meets the objectives of a Level 2 or Level 3 activity and meets requirements for time, technology and appropriateness.

Currently, there are about a dozen Level 1 activities either online or in the final stages of development. Staff has worked with an instructional designer to ensure that they meet high design standards and are appropriately aligned with science, technology, engineering and mathematics (STEM) standards. This list is organized by particle physics research technique.

Quark Workbench: The Standard Model organizes current knowledge.

Making it ‘Round the Bend: Electric and magnetic fields accelerate, bend and focus beams of charged particles.

Plotting LHC Discovery: Scientists use well-understood particle masses to help calibrate detectors.

Rolling with Rutherford; Cosmic Pulse: Indirect evidence provides data to study the short-lived particles.

Calculate the Top Quark Mass; Calculate the Z Mass: Event displays visualize data.

Mass of U.S. Pennies: Histograms represent data for analysis and interpretation.

In Level 2 activities, students analyze a “good” dataset with one or two variables. They calculate descriptive statistics, seek patterns, identify outliers, confounding variables and perform calculations to reach findings. They also may create graphical representations of the data. Currently, Level 2 links to LHC International Masterclasses for ATLAS, ALICE, CMS and LHCb at http://physicsmasterclasses.org offered through the International Particle Physics Outreach Group (IPPOG: http://ippog.web.cern.ch) .

Masterclasses allow high school students to be scientists for a day. Most go to a research center near their home where after a short introduction to particle physics and a detector, they learn how to examine large samples of recent data, mastering real event-display programs, software tools and analysis methods. Lectures from active scientists give insight in topics and methods of basic particle physics research. Students perform one of six measurements on real data with help from mentor physicists. They use event displays to build up statistics through event-by-event analysis. In ATLAS and CMS masterclasses, students study (mostly) leptonic decays to determine lepton ID (electron, muon) and candidate particle ID (J/Psi, Upsilon, W, Z, Higgs). Students create mass plots to find the mass of the Z boson and a possible Higgs signal but also other peaks in the mass plot to reveal additional particles. In ALICE, students look for strange matter and the effect of the quark-gluon plasma on particle production. In LHCb, they look for displaced vertices in B decays.

In each case, the students combine the results of their analyses with their peers to draw conclusions based on statistics that they could not do working alone with a relatively small number of events. The keys to a successful measurement are interaction with physicists as students work and a robust group discussion to conclude the analysis. In addition, students may have lunch with some physicists and go on a short tour. At the end of the day, they join in a videoconference for discussion and combination of their results with students at other sites just as particle physics collaborations do.

Level 3 is for students who are ready to perform authentic research. They make correlations, transform provided data into usable form, and calibrate or determine useful data. Students draw conclusions supported by evidence and provide reasoning. Currently, Level 3 links to three “e-Labs,” for studies with cosmic ray, CMS and LIGO data.

e-Labs, delivered as Web-based portals accessible in the classroom and at home, are implemented with the ever-expanding capabilities of Web-based media. e-Labs explore the potential of using the Internet and distributed computing in high school classes and provide an opportunity for students to:

- Organize and conduct authentic research.
- Experience the environment of scientific collaborations.
- Possibly to make real contributions to a burgeoning scientific field.

Studies are problem-based, student driven and technology dependent. Students reach beyond classroom walls to explore data with other students and experts and share results, publishing work to a worldwide audience. Students can discover and extend the research of other students, modeling the processes of modern, large-scale research projects.

From start to finish e-Labs are student-led, teacher-guided projects. Students need only a Web browser to access a project map with milestones that allows *students* to set the research plan rather than follow a step-by-step process common in other online projects. Most importantly, e-Labs build the learning experience around the students' own questions and let them use the very tools that scientists use.

Students contribute to and access shared data, most derived from professional research databases. They use common analysis tools, store their work and use metadata to discover, replicate and confirm the research of others. Teaching tools such as student and teacher logbooks, pre- and post-tests and an assessment rubric aligned with learner outcomes help teachers guide student work. Constraints on interface designs and administrative tools such as registration databases give teachers the "one-stop-shopping" they seek for multiple e-Labs. Teaching and administrative tools also allow staff to track usage and assess the impact on student learning. (text from https://www.i2u2.org/elab/)

4. Professional development

QuarkNet staff and fellows who are master teachers offer professional development for teachers interested in using authentic experimental data in their classrooms. There are three formats: Data Camp, a weeklong workshop held at Fermilab, two- or three-day workshops held in conjunction with QuarkNet center meetings, and workshops that have been held in conjunction with ILC meetings around the world.

In Data Camp teachers work in teams on a data analysis project using CMS data. The filtered data contain information about indirectly observed particles. The groups discern as many of the particle's properties as they can. Their work is guided by a series of milestones and seminars. After this experience using data—learning to analyze data, produce and interpret graphs based on these data and providing evidence and reasoning to support claims based on their data analysis—they learn how to use the Data Portfolio to build a learning sequence appropriate for their students and contribute to the DP by sharing notes on their classroom experience. Data Camp also includes tours and talks from physicists working at the Lab. Details are available on the Data Camp website: http://quarknet.fnal.gov/projects/summer14/index.shtml.

Shorter workshops help teachers gain knowledge and skills to teach successfully using a specific dataset. For example, in an LHC data workshop, teachers complete an investigation using LHC data—learning to interpret event displays and explain their meaning, to conduct LHC investigations with students and successfully prepare them for masterclass, and to assist physicists in organizing and facilitating an LHC masterclass. In another workshop teachers complete an investigation using cosmic day detectors to collect data and the Cosmic Ray e-Lab to upload, analyze and publish results. They assemble and plateau a detector, take data overnight, upload the data to the website, and design an e-Lab investigation. Using the e-Lab, they select a small dataset, run an analysis, save plots, and create a poster about their study. They learn how to capture that experience in a classroom activity and how to guide their students through an investigation.

To support the International Linear Collider project, we have offered many short workshops at locations around the world where ILC meetings have been held. In the most recent example, two staff teachers and two fellows facilitated workshops for Japanese high school teachers and students in June 2014. They started with a full-day workshop at the University of Tokyo for 17 teachers. University of Tokyo physicist Tomohiko Tanabe gave an overview of the ILC project. The focus was on what teachers could do with students with limited class periods and prep time using the QuarkNet cosmic ray detector and e-Lab for in-school experiments. The detector exercise gave students a hands-on experience with a detector similar to those that will be used in ILC experiments and a chance to become a detector expert back at school. The teachers were enthusiastic about the workshop!

The group facilitated two more one-day workshops: one for students at Shizuoka Kita High School in Shizuoka (a fairly large city about 150 km southwest of Tokyo) and the next at Gakugeidai High School in Tokyo. In these, ILC mini-masterclasses were added to the cosmic ray agenda. The group gave a similar two-day workshop at Sendai Daiichi High School; there, they used an express version of the ILC mini-masterclass to serve 160 students in four classes—and it worked! Tohoku University physicist Akimasa Ishikawa treated the students to an explanation of ILC.

In each case, the workshop leaders devised cosmic ray exercises and the ILC mini-masterclasses to fit the goals of the ILC workshops in Japan. Each of the high schools had a dedicated cosmic ray detector; at each of these schools, a small group of equally dedicated students worked in parallel with the main group as specialists learning all they could about using and maintaining their detector as well as uploading data to the Cosmic Ray e-Lab.

5. Conclusion

The QuarkNet Data Portfolio is a user-friendly website where teachers can select activities to build learning sequences that provide students with experiences over time. They gradually develop knowledge and skills to handle challenging assignments using real particle physics experimental data. Professional development workshops help teachers become familiar with the activities so they can implement them successfully with their students.

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