PROCEEDINGS OF SCIENCE

Neutrinos and Dark Matter in the Classroom

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The Sanford Underground Research Facility - in collaboration with Black Hills State University - has a vibrant program in K-12 education. One cornerstone of the program are curriculum units for grade 3-12 classrooms – in depth one to two week units of study connecting directly to Sanford Lab science and the state of South Dakota science standards. The units come with complete material kits which are shipped to the schools; professional development training was made available to teachers in 2016. As an example, the middle school unit on dark matter is featured in this article.

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1. Introduction

The Sanford Underground Research Facility in Lead, South Dakota is operated by the State of South Dakota with operating funds from the U.S. Department of Energy. Sanford Lab is the home of the Large Underground Xenon (LUX) experiment (a search for dark matter), the MAJORANA Demonstrator (neutrinoless double beta decay), and the Compact Accelerator System for Performing Astrophysical Reactions (nuclear astrophysics). Future experiments are a second generation dark matter search (LUX-Zeppelin) and the Deep Underground Neutrino Experiment.

Education and outreach (E&O) has been an important component of the mission of the Sanford Lab since its inception. South Dakota and its location in the Great Plains is a region of low population density with ranching, mining and tourism comprising the primary sources of income. Having a world-class science lab in their backyard can serve as an inspiration to students to engage in science classes and to consider careers in Science, Technology, Engineering and Mathematics (STEM).

2. The Sanford Underground Research Facility E&O Program

The E&O program is a collaborative venture between the Sanford Underground Research Facility and Black Hills State University. After several years of experimenting with various ways to convey the potential and excitement of Sanford Lab science to students of all ages, the program has settled into a three-prong approach to working with K-12 classrooms across the region:

- **Classroom presentations** are short, engaging programs that E&O staff take into a school;
- **Field trips** are available for schools within driving distance of the laboratory;
- **Curriculum units** are one to two week units that give students a deeper understanding of science content connected to Sanford Lab science.

This presentation focuses on the curriculum units. More information on the other strands of work can be found on our website at www.sanfordlab.org/education.

2.1 Curriculum Units

All Sanford Lab curriculum were developed under the following guidelines:

- They are aligned with the South Dakota Science Standards [1] as adopted in 2015. These are similar but not identical to the *Next Generation Science Standards.* [2]
- They feature science and engineering practices from *A Framework for K-12 Science Education.* [3]
- They are designed following the *Tools for Ambitious Science Teaching* [4]. Each unit features an anchoring phenomenon that students will return to over the course of the unit, developing a rich causal explanation for the phenomenon.
- Each unit connects directly with some aspect of the Sanford Underground Research Facility, usually one particular experiment.

All units come with a complete materials kit for all hands-on activities. Teachers schedule a kit through an online process and kits are shipped out a week before teachers plan to start the unit. Teachers are responsible for shipping the units back to Sanford Lab.

2.2 Example Middle School Unit – The Search for Dark Matter

The Search for Dark Matter is an approximately two-week unit designed for physical science classes in grades 6-8, although it has also been used with success in high school physical science classes. The science focus of the unit addresses three questions:

- What is dark matter?
- What is the evidence that it exists?
- How are scientists searching for it?

Following the evidence for dark matter chronologically, students explore scientific concepts around the topics of matter and its interactions, as well as the scientists and technologies that made new discoveries possible. Connections to the Sanford Underground Research Facility are made through the final lesson, which introduces students to the current and future experimental searches for dark matter search.

The unit has six lessons, given in Table 1, which take from one to three class periods each. The unit was piloted in 5 schools with a total of 259 students in the 2015-2016 school year, and revised extensively for the 2016-2017 school year. The unit includes a pre- and post-assessment. These assessments as well as teacher feedback guided the current revision.

Table 1. The Search for Dark Matter

Lesson #	Lesson Title
1	Our Modern Universe
2	Exploring the Universe through Light
3	The Role of Gravity
4	Exploring the Unseen
5	Gravity and Light: Evidence of Dark Matter:
6	Going Deep for Dark Matter: The LUX Detector at the Sanford Underground Research Facility

The unit starts out with the ‘jar of beans universe’. This is the anchoring phenomenon for the unit and is adapted from the jellybean universe analogy for dark matter that has been in use for some time. This jar will sit in the front of the classroom throughout the unit and the teacher will regularly refer back to it. Lessons and learning outcomes are described in the storyline for the unit:

Lesson 1. Our Modern Universe

The vastness of the universe, from the smallest sub-atomic particle to the largest cluster of galaxies is very difficult for us humans to understand or imagine. In this lesson, students will use a scaled model of the universe to make observations and begin formulating questions. Students will visit an interactive website that they use to explore the smallest known item to the largest known item in the universe. They will see where they, as humans, fit into the scale. They will use a graphic organizer to note just how many of the objects are too small or too far away for us to see with the naked eye.

Scientist: Early Astronomers *Technology: Eyes*

Learning Outcomes:

- Students will create and use a graphic organizer to help understand complex ideas and organize information, thereby gaining an understanding and appreciation for the size and scope of the universe from the very small to the very large.

Lesson 2. Exploring the Universe through Light

This lesson covers the basics of atomic spectroscopy as a tool astronomers use to study the universe.

Students explore the nature of light and how it – as a subset of electromagnetic radiation – can be used as a 'fingerprint' of atoms. Students will learn that when energy is added to an atom, the electrons can become 'excited' and then emit light. The energy can be added in the form of electrical or thermal. The light patterns an atom emits are a source of evidence scientists use to determine what elements are in the stars.

Day 1 - Scientist: Galileo *Technology: Telescopes*
Day 2 - Scientist: Fritz Zwicky *Technology: Telescopes*

Learning Outcomes:

- Students will realize the contribution of telescopes in pioneering the exploration of the universe.
- Students will be able to explain the electromagnetic spectrum and how scientists use spectroscopy to determine the composition of stars.

Lesson 3. The Role of Gravity

In this lesson, students learn about gravity and orbital motion.

Scientist: Vera Rubin *Technology: Telescopes/Spectroscopy*

Learning Outcomes:

- Students will be able to discuss forces in orbital motion.
- Students will apply the knowledge gained to predict what would happen if orbital balances are unbalanced.
- They will then hypothesize why stars near the edges of the galaxy that would seem to have unbalanced orbital speeds are not escaping the galaxy.

Lesson 4. Exploring the Unseen

Students are learning that scientists often have to observe and study objects that are impossible or improbable to see directly. Probes have been developed to map surfaces as small as an atom and as big as our universe. Sanford Lab began this study more than 50 years ago when the lab was Homestake Mine and scientists Ray Davis and John Bahcall built the first detector a mile underground.

In this lesson, students will use probes to explore a black box just as the Sanford Lab scientists use their tools to explore subatomic particles.

Scientist: Ray Davis *Technology: underground detectors*

Learning Outcomes:

- Students will plan and carry out an investigation using indirect evidence, and use it to construct a mathematical model of an unseen landscape.
- They will relate this experience to the work scientists must do to develop theories about things too small, too far away or unable to be seen due to other reasons.

Lesson 5. Gravity and Light: Evidence of Dark Matter

In Lesson 3, students learned about the attraction of gravity on objects; in this lesson they learn about the effect of gravity on light. Bundles of light energy – photons – respond to the gravitational attraction of large masses, including dark matter. Gravitational lensing is an effect whereby light from very distant galaxies bend and distort due to dark matter between the observer (us) and the galaxy, providing one of the key pieces of evidence for dark matter. Students will model gravitational lensing through comparisons with the refraction of light at a boundary between two mediums.

Scientist: Albert Einstein *Technology: Hubble Space Telescope*

Learning Outcome:

Students will construct arguments from evidence that there is much more matter in the universe that we cannot see than matter that we can (our bean jar model of a universe).

Lesson 6. Going Deep for Dark Matter: The LUX Experiment at Sanford Lab

In this lesson, students will make the connection to the searches for dark matter at the Sanford Underground Research Facility using the Large Underground Xenon (LUX) detector. They will explore Sanford Lab and how the detector works, and possibly take part in a videoconference or Skype connection to scientists at the Lab for a virtual tour of LUX.

Scientist: LUX Graduate Student *Technology: Cryogenic (cold) underground detector*

Learning Outcomes:

- Students will explain how the LUX detector at Sanford Lab is attempting to 'directly' detect dark matter through indirect means.
- Students will demonstrate their new understanding of the size and scope of the universe and the evidence for dark matter on the unit post-assessment.

All six lessons include inquiry-based activities for the students, modeled after the science and engineering practices of the Framework for K-12 Education. Some of these are hands-on, for example atomic spectroscopy, indirect evidence and gravitational lensing. Some lessons utilize online inquiry-based resources which are given in Table 2. In addition, the unit contains a number of videos.

3. Conclusion

The unit featured here is only one example of the six curriculum units piloted in 2015-2016 and revised for 2016-2017 – two each for grade bands 3-5, 6-8 and 9-12. Thirty-eight teachers from across the region were trained in the use of the units in the summer of 2016. Two new units are under development and will be piloted in the spring of 2017.

In addition to the curriculum units, six assembly/classroom presentations are touching thousands of students per year. For more information about the Sanford Lab E&O programs, consult the website at www.sanfordlab.org/education.

Table 2. Online resources – The Search for Dark Matter

Lesson	Resource Description
1	Scale of the Universe 2 [5]: An exploration of the scale of things from the very large to the very small.
3	Gravity Launch [6]: A simulation of gravity and orbitals in the format of a game.
3	Dark Matter [7]: A simulation of the effect of dark matter on the orbital velocities of stars in a spiral galaxy.
4	Quarked [8]: An exploration of the subatomic universe.

4. Acknowledgements

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References

[1] South Dakota Department of Education, *South Dakota Science Standards,* http://doe.sd.gov/contentstandards/documents/sdSciStnd.pdf

[2] NGSS Lead States, *The Next Generation Science Standards: For States, By States,*, National Academies Press (2013), https://www.nap.edu/read/18290/chapter/1

[3] National Research Council, *A Framework for K-12 Science Education: Practices, Cross-cutting Concepts and Core Ideas*, National Academies Press (2012), https://www.nap.edu/read/13165/chapter/1

[4] University of Washington, www.ambitiousscienceteaching.org

[5] Scale of the Universe website, developed by Cary and Michael Huang: http://htwins.net/scale2/

[6] Gravity Launch website: http://sciencenetlinks.com/interactives/gravity.html

[7] Dark Matter Simulation website, developed by McGraw-Hill: http://highered.mheducation.com/olcweb/cgi/pluginpop.cgi?it=swf::100%25::100%25::/sites/dl/free/0072482621/78778/DarkMatter_Nav.swf::Dark%20Matter%20Interactive

[8] Quarked Website, developed by Alice Bean, Univ of Kansas, 2003 : http://quarked.org/roadmap/