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RECEIVED 09 October 2023

ACCEPTED 27 November 2023

PUBLISHED 15 December 2023

## CITATION

Horn M and Woodward EL (2023),  
Sanford Underground Research Facility's  
approach to school education,  
community activities, and  
public outreach.  
*Front. Phys.* 11:1310451.  
doi: 10.3389/fphy.2023.1310451

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# Sanford Underground Research Facility's approach to school education, community activities, and public outreach

Markus Horn\* and Erin Lorraine Woodward

Sanford Underground Research Facility, Lead, SD, United States

The Sanford Underground Research Facility (SURF) is the deepest underground science facility in the United States. SURF hosts world-leading experiments in neutrino, astroparticle and nuclear physics, as well as projects in biology, geology, and engineering, and is home to a major excavation project making space for Fermi National Accelerator Laboratory's Long-Baseline Neutrino Facility (LBNF), which will power the Deep Underground Neutrino Experiment (DUNE). An emphasis on outreach and education is embedded in SURF's mission statement: "to advance world-class science and inspire learning across generations." To achieve this mission, SURF goes beyond established science communication methods, including operating an open-to-the-public visitor center, hosting multiple public outreach events per month, and an annual city-wide science festival. Furthermore, SURF is training K-12 science educators, developing school curriculum units, and providing classroom materials, based on science researched at the laboratory. The strategic approach, specific methods, and successful outcomes of these programs, which are based on SURF's science, location, and community, may serve as examples for effective science education, public outreach, and community engagement.

## KEYWORDS

astroparticle physics, underground laboratories, multidisciplinary science, education, public outreach

## 1 SURF overview

### 1.1 History, legacy and context of the underground facility

The Black Hills, a mountain range rising from the Great Plains of North America, is located in the western region of South Dakota. Called Paha Sapa, "The Heart of Everything That Is", in Lakota language, the Black Hills are considered sacred to many Native American tribes, primarily of the Lakota and Dakota nations, and the core of their spiritual inheritance. The region's complex geology and discovery of gold eroded from hard-rock deposits, lead to extensive mineral exploration in the 19th century. Starting in 1876, the Homestake Gold Mine in Lead, South Dakota, became the largest and deepest gold mine in North America until it ceased mining operations in 2001. Long before it was transformed into a dedicated underground laboratory, the Homestake Gold Mine had a notable scientific legacy [1]. Starting in the late 1960s, Dr. Raymond Davis Jr. counted neutrinos from the Sun in a laboratory on the 4850-foot level of the mine [2]. The experiment operated continuously from 1967 until 1994 and earned Davis a share of the 2002 Nobel Prize in Physics. Due to a

sharp decrease in the value of gold, Homestake was forced to close the operation of the mine; initially mining in 2001, and all other operations, including dewatering the underground, in 2003. However, discussions about the mine's future as a research facility were already underway. A few years later, with a generous donation from the facility's namesake T. Denny Sanford, a land donation from mine owner Barrick Gold Corporation and the formation of a governmental entity by the State of South Dakota, the South Dakota Science and Technology Authority (SDSTA), to manage the facility, the science facility was officially opened in 2007 and access for researchers to the 4850-foot level was restored in 2009.

## 1.2 SURF structure and affiliated organizations

SURF is operated by the SDSTA, under the direction of the SDSTA Board of Directors with funding from the U.S. Department of Energy's Office of Science. In 2020, the SDSTA established the SURF Foundation, a tax-exempt non-profit organization to raise funds in support of the science and education goals of the SDSTA. The SURF Foundation is separate from SURF and has its own Board of Directors. The Institute for Underground Science at SURF (The Institute), which aims to provide a space for intellectual communities to come together and have truly transformative conversations, was launched in June 2023 by the SDSTA. The Institute's inaugural event was the Center for Theoretical Underground Physics and Related Areas (CETUP\*) conference<sup>1</sup> in June 2023. The conference, which had been held annually from 2011 through 2016, was revived under the umbrella of The Institute, to engage researchers from all areas of underground science, including physics, biology, geology, and engineering, to participate in conversations about the future of their research. The 2023 conference drew nearly 70 theorists, experimentalists, and students representing 47 institutions. The future program of The Institute, including conferences, graduate and undergraduate summer schools and expansion of collaborative programs with other institutions, are currently under development.

## 1.3 Science at SURF

Central to SURF's core institutional mission is the advancement of compelling underground and multidisciplinary research. Once underground access was re-established, science efforts have seen consistent growth [3]. Since then, a total of 64 groups have conducted underground research programs at SURF across a range of laboratory elevations from the surface to the 5000-foot level (with a major footprint on the 4850-foot level). At present, a total of 32 research programs are ongoing, with 22 of these programs maintaining a regular onsite presence. Excluding DUNE, the facility accommodates approximately 400 individual researchers from a larger pool of over 700 collaboration members contributing to the

experiments at SURF. Nine U.S. National Laboratories are represented among a network of over 100 institutions from 9 countries.

Among the experiments at SURF are the LUX-ZEPLIN (LZ) dark matter experiment collecting WIMP search data since 2021, with world-leading results published recently [4]. The MAJORANA DEMONSTRATOR focusing on neutrinoless double-beta-decay published final results in 2023 [5] and is presently searching for the decay of  $^{180\text{m}}\text{Ta}$  [6]. The Enhanced Geothermal System (EGS) Collab-SIGMA-V project completed two rock stimulation and flow tests in different rock formations [7], one of which will be repurposed starting late 2023 to conduct research in underground thermal energy storage technologies. The Compact Accelerator System for Performing Astrophysical Research (CASPAR) is concentrating on nuclear astrophysics research ([8], including recent results [9]). CASPAR is at present mothballed due to the excavation activities for the DUNE experiment, but is planning to resume activities in 2024.

Low background assays of materials, available to all users and experiments, not limited to SURF projects, are conducted through the Black Hill State University (BHSU) Underground Campus (BHUC). The BHUC is currently operating six radioassay instruments. In addition, local universities have supplemental material screening capabilities: ICP-MS (BHSU) and radon-emanation characterization (South Dakota Mines). Production of electroformed copper is also performed at SURF. The Majorana collaboration has produced electroformed copper since mid-2011, a total of 2,500 kg for the MAJORANA DEMONSTRATOR, and is presently continuing for LEGEND [10]. Upcoming, DUNE will investigate neutrino properties (oscillations, CP violation, mass hierarchy), nucleon decay and study supernovae neutrinos [11].

Due to the vast underground network of more than 600 km of tunnels extending to over 2,450 m below ground (not all currently accessible), a wide variety of environmental and geochemical conditions and a large network of legacy boreholes from Homestake mining exploration, researchers studying extremophilic organisms and biofilms represent a vital part of SURF's multidisciplinary community with high-impact scientific results.

## 2 SURF school education and curriculum development

An emphasis on education and public outreach is embedded in SURF's mission statement since its inception: "to advance world-class science and inspire learning across generations." The dedicated Education and Outreach (E&O) department at SURF has worked with schools (kindergarten to grade 12 or K-12) and post-secondary learning institutions across South Dakota. The SURF E&O department at its core mission believes that every student deserves high quality, rigorous, relevant, equitable, and engaging science learning opportunities. The efforts of the department include four main categories: 1) hosting school field trips to SURF and delivering in-school presentations (in-person or virtual); 2) the development and deployment of no-cost curriculum units to classrooms across the state, 3) the creation of career exploration opportunities, and 4) teacher professional development and support. Much of this work is done in partnership with BHSU.

<sup>1</sup> <https://indico.sanfordlab.org/event/53>

## 2.1 Field trips and in-school presentations

SURF field trips include tours of surface facilities, including the Yates hoistroom (one of the two available hoists at SURF), where students see the large machinery that powers travel in and out of the underground, and SURF's own wastewater treatment plant, which manages water pumped from the underground before it is returned to local waterways. Field trips also include hands-on activities which engage students with the scientific and engineering concepts being studied at the facility. In-school presentations delivered to individual classrooms or large-group auditoriums, also include hands-on learning experiences for students. These presentations are predominantly given in person, by members of the SURF E&O team traveling to schools (including very remote schools in rural counties in South Dakota). Although, the inherent time, distance, and frequency restrictions of these presentations and field trips may limit the impact of these programs, the E&O team leverages these to establish connections with educators and school districts, which in turn can lead to sustained, high-impact relationships.

## 2.2 Curriculum modules

The SURF E&O team develops and ships school curriculum modules addressing science, technology, engineering, and math (STEM) concepts to classrooms across South Dakota and the surrounding region. The curriculum modules are provided at no cost to the educators, who often are required to purchase their own materials for classroom instruction. These modules leverage phenomena being studied at SURF—from dark matter and neutrinos to hoist engineering challenges—to connect students with the world-class research being pursued in their home state of South Dakota. Each module includes all the tools a school teacher needs for 10–20 h of instruction. The modules are developed with input from teachers across the state, aligned with South Dakota's K-12 Science Standards, and employ best practices in pedagogy, including phenomena-based, three-dimensional instruction [12]. This approach shifts science education from rote memorization to thinking like a scientist, investigating scientific concepts and solving problems.

## 2.3 Educator professional development

The SURF E&O team creates and hosts professional development workshops that use tested teaching techniques and innovative science to transform the teaching of K-12 science in South Dakota. These workshops utilize a three-dimensional teaching and learning approach; employ real phenomena and unsolved questions being explored underground; shift students from “learning about” a topic to “figuring out” for themselves; and connect teachers to the innovative science at SURF. Through grants and partnerships with several statewide entities, the E&O team offers no-cost programming, lodging, and, in some cases, stipends to workshop participants, especially important for rural and underserved communities. Upon completion of workshops, participants qualify for graduate credits from BHSU. Since 2020, the E&O team has implemented in-person, virtual, and hybrid

options for workshops; these flexible options help remove cost, time, and travel barriers for participants.

## 2.4 Career exploration

The SURF E&O team creates career exploration opportunities for South Dakota's post-secondary students, including an internship program, the Davis-Bahcall Scholars Program, and pre-service educator training. SURF's summer internship program<sup>2</sup> offers paid, 10-week internships in a variety of disciplines, including science, engineering, education, communications, operations, underground access, and environment, health and safety. Undergraduate and graduate interns work with experts from around the globe, gaining real-world experience while helping SURF meet the challenges of operating the facility. The Davis-Bahcall Scholars program<sup>3</sup> is an all-expense-paid, 4-week tour of university, laboratory, and industry research centers throughout the United States and abroad. The program is designed to help first- and second-year university students who are entering science, technology, engineering, and math fields to gain insight of potential career paths. The E&O team partners with faculty from five South Dakota universities to provide training to pre-service teachers. These trainings familiarize future teachers with best practices for science education, as well as the resources available to them through SURF.

## 2.5 Results

The SURF E&O team collects quantitative data on K-12 student participation in field trips and in-school presentations; university student participation in career exploration programs; educator participation in professional development workshops; and curriculum module usage; as well as the percentage of school districts reached in South Dakota. The team also collects qualitative data through presentations from career exploration participants; real-time discussions and surveys from professional development participants; and feedback from education faculty whose classes are involved in preservice teacher training programs. In 2022–23 (July to July), the E&O team reached via the various avenues, over 17,000 students, covering every, even the remotest county of a mostly rural and sparsely populated state of South Dakota (and nearby counties of some neighboring states); see also Figure 1. These numbers follow a trend of steady, significant growth over the last 15 years, despite the unique challenges since 2020 introduced by the COVID-19 pandemic, which necessitated a swift adaptation to virtual in-school presentations. Since then, the E&O team has resumed its focus on in-person field trips and presentations with the focus on more rural and historically underserved communities, and often schools with very small student enrollments.

<sup>2</sup> <https://sanfordlab.org/internships>

<sup>3</sup> <https://sanfordlab.org/dbs>

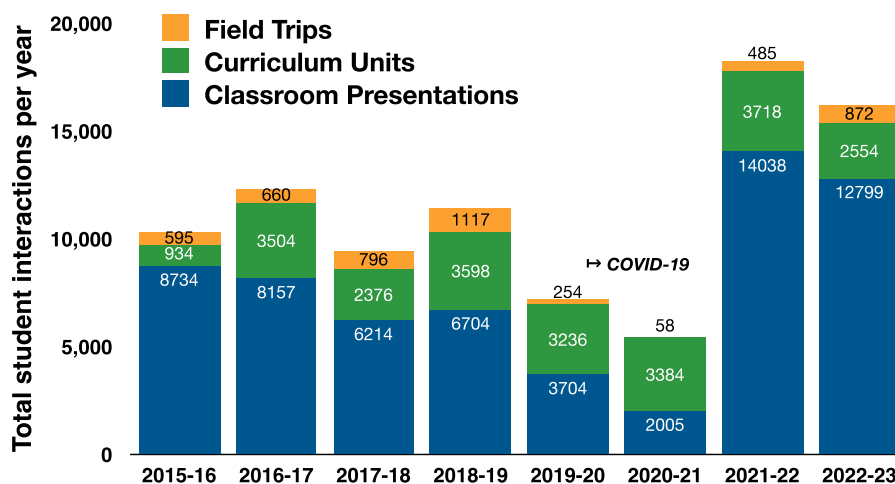


FIGURE 1

Total student interaction numbers per year (July to July) constituted by the number of students on field trips visiting SURF, students participating in curriculum units developed by the SURF E&O team, and students reached by SURF E&O classroom presentations (in person and virtual).

Several strategies and lessons learned have emerged that may be helpful for other institutions looking to expand their education programming.

- Identifying high-leverage opportunities:  
The E&O team continually evaluates the relative impacts of their program offerings in order to focus on high-leverage, transformational efforts. For example, while field trips and in-school presentations generate an impressive number of direct interactions with students, the short-term nature of those interactions do not create sustained, long-term impacts. Rather than striving to increase those numbers, the E&O team sees these programs as an opportunity to establish relationships with educators and school districts. The team focuses their efforts on curriculum modules, which generate up to 20 h of classroom science instruction, and on professional development workshops, which train cohorts of educators with a sustained impact towards student science education.
- Designing “place-based” content:  
SURF increased audience engagement and relevance by designing content with direct connections to our local community and environment. South Dakota is a rural state that is widely known for its agriculture and tourism industries. The E&O team leverages science taking place at SURF by tying content to research at a world-leading research facility located in their home state. This inspires a sense of ownership and relevance to audiences.
- Increasing accessibility:  
The E&O team uses state demographic data and self-reported data from educators to target efforts to those who need it most. In South Dakota, rural and remote school districts often have fewer resources than school districts in urban areas. Though giving presentations in urban schools results in higher student interaction numbers, the E&O team chooses to focus their

efforts in rural and remote districts. Additionally, in many US schools, teachers in classrooms with students under the age of 12 typically have less time to devote to science education than middle and high school educators do; thus, the E&O team focuses their efforts on designing curriculum models and professional development programs for educators working with younger students.

### 3 Sanford Lab Homestake Visitor Center

In 2015, the Sanford Lab Homestake Visitor Center (Visitor Center) was built with SDSTA funds to commemorate the history of Lead, South Dakota, and to highlight scientific discoveries related to SURF. The approx. 750 m<sup>2</sup> (8,000 sq ft) building features a gift shop, conference rooms, and an exhibit hall that highlights the history of the Lead area, as well as the research taking place at SURF.

The Visitor Center was owned and operated by the Lead Area Chamber of Commerce from 2015 until 2022. In January 2022, ownership transferred to the SDSTA. Since 2022, the SDSTA has updated facility infrastructure, updated exhibits, and increased tour offerings and event programming. The location of the Visitor Center on Main Street in Lead, has uniquely positioned it to be both a hub for outreach of the laboratory, as well as a vital community information resource and tourism destination attracting nearly a total 55,000 visitors in the year 2022. The Visitor Center exhibits include panels with photography, graphics, and information about the Black Hills’s unique geology, the 1870s gold rush, the Homestake Gold Mine and its influence on the region, the history of science at the mine, the Nobel Prize-winning Solar Neutrino Experiment of Dr. Raymond Davis Jr., and current science taking place underground. Exhibits also include a suspended scale model of the underground workings, a cage conveyance that once transported people and equipment in and out of the underground, the LUX

**FIGURE 2**

The Sanford Lab Homestake Visitor Center is located on the southern edge of the historic mining pit (“Open Cut”) of the Homestake Gold Mine in downtown Lead, South Dakota. It is a space for SURF to connect with the local community, host events and tours, and provide information to locals and tourists. Reproduced with permission from Stephen Kenny (SDSTA), Sanford Underground Research Facility, June 2023.

**FIGURE 3**

SURF’s Artists in Residence create a collection inspired by the science, history, and community of SURF. Reproduced with permission from Ashley Beguin (SDSTA), Sanford Underground Research Facility, July 2023.

detector, which was the world’s most sensitive dark matter detector from 2013 until 2017, and the “Davis Ring”, an original piece of the experiment’s water tank now displayed outside next to the building. The Visitor Center also offers a view of Homestake Gold Mine’s historic mining pit (“Open Cut”) from an observation deck (see [Figure 2](#)).

Among the many offerings of the Visitor Center are trolley tours of the City of Lead, which include a visit to one of two hoistrooms on

SURF property. Built in the 1930s to support gold mining operations, the hoists are still in use today to transport scientists and research equipment to laboratories up to the 5000-foot level, approx. 1.5 km below the surface. The Visitor Center hosts events for a variety of audiences, from locals to tourists, technical and non-technical alike. “Deep Talks”, a monthly lecture series, invites local audiences of scientific and non-scientific backgrounds to learn more about research taking place underground and across the state. The



**FIGURE 4**

At SURF's Neutrino Day, visitors of all ages get hands-on science experiences. Reproduced with permission from Stephen Kenny (SDSTA), Sanford Underground Research Facility, July 2023.

monthly “Ask-A-Scientist” series gives audiences the opportunity to chat informally with a scientist who conducts research at SURF. Other community events include book signings with local authors, a Fourth of July fireworks viewing party near the Open Cut, and “Trunk-or-Treat”, a Halloween-themed event which invites children to dress up and “trick-or-treat” safely in the Visitor Center parking lot as well as participation in many other City of Lead events. Furthermore, due to its unique location and scenic backdrop near the Open Cut, the Visitor Center is also a popular venue for private events.

### 3.1 Impact and insights

The Visitor Center has become a very popular tourism destination by itself in the Black Hills of South Dakota, attracting solo travelers and families to organized charter tours. Key performance indicators for public outreach include length of time of visits, return visitation, number of visits, event attendance, informal surveying, online reviews (Google, Facebook, Yelp, etc.), number of bus tours that seek this location out, and the frequency of private rentals.

For other institutions seeking to expand their outreach programming, here are several strategies and lessons learned that have emerged from the operation of the Sanford Lab Homestake Visitor Center.

- **Intergenerational learning:**  
As a general public visitor center, guests often travel in family units, meaning each group includes visitors of various ages and a range of technical backgrounds. To create an engaging attraction, a visitor center must offer a range of experiences. To appeal to diverse audiences, the Visitor Center offers scavenger hunts for young guests, 3-D virtual reality headsets offering virtual underground tours, and exhibits that capture the attention of adult visitors. Some offers, such as the “Ask-a-Scientist” series or

guided tours can be adjusted to engage visitors of diverse ages and backgrounds, as determined by the scientist and/or guide.

- **Dynamic offerings:**  
The Visitor Center seeks to offer a new experience to people every time they visit. This has inspired the Visitor Center staff to think outside the box, offering talks with experts, interactive exhibits, and increased tour offerings that are captivating, even for repeat visitors.
- **Focus on audience needs:**  
The Visitor Center’s location on Main Street in Lead, along with its history as the city’s sole visitor center, has uniquely positioned it to be both a hub for lab outreach, as well as a vital community information resource and tourism destination. This multi-purpose space has enhanced SURF’s ability to communicate and build relationships within its local community.
- **Room for future growth:**  
SURF leadership acknowledges that more work can be done to acknowledge the complex history and cultural significance of the Black Hills area, especially to the indigenous population. A strategy is currently under development to achieve this mission.

## 4 SURF artist-in-residence program

SURF’s unique location in the Black Hills of South Dakota and history as a former gold mine and home to Nobel Prize-winning physics experiment make it an ideal place for creative work. The SURF Artist-in-Residence (AiR) program invites artists to create work inspired by SURF, leveraging the unique characteristics of the underground facility and the science experiments it hosts to create awareness and encourage interdisciplinary work. The program is open to artists in all media; this includes, but is not limited to, visual artists, filmmakers, writers, and musicians. The program has a rigorous application and selection process. The selection committee considers each applicant’s professional record including major regional, national or international exhibitions, or similarly documented experience. The SURF AiR program provides

transportation, housing, per diem for visits, studio space, and stipends for their work.

## 4.1 Outcome

This program includes several key deliverables, including the exhibition, artwork in SURF's permanent collection, and public outreach events, such as artist talks and open studio days, see [Figure 3](#). The SURF AiR includes a 4-week on-site visit during the summer and a 1-week art installation/guest lecture visit during the fall. The artist will have an art exhibition and up to two lectures based on the artist's proposal during the fall. In addition to the lectures, each artist will provide promotional or outreach events within the local community. Each artist will donate at least one piece of artwork to the facility to be included in the SURF permanent art collection. In previous years, artists also secured exhibitions and events at universities across South Dakota as well as other institutions with a strong connection to underground science, further increasing the impact of the program, as described below.

Since the creation of this program in 2019, several best practices have enhanced SURF's AiR program, including the following.

- Leveraging partnerships with the arts to engage new audiences:  
As research facilities strive to attract attention to STEM subjects, partnerships with artists or art institutions can broaden the appeal of facility offerings, connect new audiences to the research taking place at a facility, and even propel new discoveries through inter-departmental collaboration.
- Extending the life of an exhibit:  
The impact of an art exhibit can be strengthened by advertising the collection and advancing opportunities for repeat exhibitions at partner institutions. Gina Gibson, SURF's 2019 artist in residence, created her original SURF-inspired exhibit in 2020. The exhibition was hosted virtually, due to the COVID-19 pandemic. Through SURF's continued promotion of the collection, Gibson was invited to bring the collection to the University of Michigan for a 1-year exhibition. This extended life of the exhibit is now inviting audiences in Michigan to learn about science at SURF through art.
- Engaging the general public:  
In addition to attending a final exhibition, there are ample opportunities for the general public to engage with the artist. SURF has hosted open studio sessions, meet-and-greets, and virtual Q&A sessions to increase the visibility and impact of a visiting artist.

## 5 SURF Neutrino Day

Neutrino Day is SURF's signature public outreach event, a free science festival that takes place annually throughout Lead on the second Saturday of July. The event invites attendees to take part in hoistroom tours, science activities and exhibits for all ages, live video chats with scientists underground at SURF, and engaging talks about the research happening deep underground beneath

their feet, see [Figure 4](#). Over the past 15 years, Neutrino Day has grown to include dozens of activities in several locations within the community. Building on that success, SURF is envisioning Neutrino Day to become one of the world's premiere science festivals and establishing Lead and the South Dakota Black Hills as a science destination. As the SURF team works toward that vision, Neutrino Day efforts build brand recognition for the organization as a whole; offer greater opportunities to partner with local, regional and international communities, create additional opportunities for fundraising, bring greater attention to the Visitor Center, the SURF Foundation, and the Institute for Underground Science at SURF; and foster planned and organic interactions between the arts and sciences.

## 5.1 Participation and review

SURF tracks the number of in-person and virtual attendees, as well as attendee feedback, volunteer feedback, and repeat partner participation rate. In 2023, more than 2,000 visitors participated in the activities at Neutrino Day, as estimated by free wrist-bands given to each visitor checking in at multiple welcome stations. (For context, the total population of Lead-Deadwood and surrounding communities is approximately 5,000).

After 15 years celebrating Neutrino Day, SURF as the coordinating organization learned that large-scale events are largely more successful when the planning achieves the following:

- Achieving brand recognition:  
For all previous years, Neutrino Day had a unique theme and brand each year. As the event grew, drawing reliably more than 1,000 attendees from around the globe each year, the planning committee acknowledged the need for a consistent, recognizable brand. In 2022, SURF trademarked the name "Neutrino Day" and developed a new brand identity and website for the event with the help of a third-party design group<sup>4</sup>. By adopting a high-quality, consistent brand, SURF hopes to increase brand recognition and spur repeat attendance.
- Strong partnerships with local, regional, and international communities:  
Neutrino Day would not be possible without the contribution of our donors and partners. Each year, the event is supported by volunteers who host booths, give talks, set up and tear down, and help guests navigate the event. These partnerships range from local businesses and regional education organizations to international science partners, like STFC in the United Kingdom and CERN in Switzerland.

## 6 Conclusion

The Sanford Underground Research Facility, in addition to being home to a large variety of world-leading research in multiple science

<sup>4</sup> <https://neutrinode.com>

disciplines, strives to improve public outreach and community engagement. SURF aims to meet audiences where they are. That means leveraging their curiosity and making the science approachable to the general public, to teachers and to students. With every outreach activity, SURF tries to make the learning relevant and engaging to science-curious learners of all ages by connecting the science to South Dakota—and to people's interests, including art, history, and culture. In this way, SURF reaches a much broader audience. This approach and the methods described, may serve as examples for effective science education, public outreach, and community engagement to research facilities and underground laboratories specifically.

## Data availability statement

The original contributions presented in the study are included in the article/[Supplementary Material](#), further inquiries can be directed to the corresponding author.

## Ethics statement

Written informed consent was obtained from the individual(s), and minor(s)' legal guardian/next of kin, for the publication of any potentially identifiable images or data included in this article.

## Author contributions

MH: Writing—original draft. EW: Writing—original draft.

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## Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. This material is based upon work supported by the U.S. Department of Energy Office of Science under award number DE-SC0020216.

## Conflict of interest

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## Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fphys.2023.1310451/full#supplementary-material>

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