# Evaluation of the QuarkNet Program: Evaluation Report 2023-2026

Prepared by:

Kathryn E. H. Race
**Race & Associates, Ltd.**
4430 N. Winchester Avenue
Chicago, IL 60640
(773) 878-8535
www.raceassociates.com

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Race & Associates, Ltd.
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Kathryn Race
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This report highlights cumulative evaluation efforts, which began in 2018-2022 and have continued during the current funding cycle from the National Science Foundation (NSF)[1] for program years 2023 through 2026. Portions of this report have been drawn from annual evaluation reports prepared during the past grant period to reflect the continuity of these efforts (Race, 2019-2025). A distinction difference of the final report is to increase its readability and shorten its overall length; to do so, select program details, evaluation methodology and results have been bundled into appendices and/or separate reports. The summary of this report starts on page 77.

After a brief overview of the program's history, program goals and approach to evaluation, this report is organized by the following key sections:



[1]QuarkNet has been co-sponsored by the National Science Foundation. Additional funding is provided by U.S CMS and U.S. ATLAS. In-kind support is provided by Fermilab through the Department of Energy.

# **Program Design** (Sections 1-2)

## 1. QuarkNet: Professional Development for HS Teachers

Program History, Program Goals and Evaluation Themes

The QuarkNet Collaboration, referred to as QuarkNet, "is a long-term, national program that partners high school science teachers with particle physicists working in experiments at the scientific frontier." QuarkNet is a professional development program that "immerses teachers in authentic physics research and seeks to engage them in the development of instructional strategies and best practices that facilitate the implementation of these principles in their classrooms, delivering its professional development (PD) program in partnership with local centers" (Program Theory Model, PTM, 2019; 2022).

QuarkNet program efforts began in 1999; (see Appendix A for a brief history). QuarkNet is not static but reflects changes in particle physics, such as neutrinos, and improved approaches to professional development over time. As noted by Beal and Young (2017), "For nearly two decades, QuarkNet has been fully engaged in establishing a national community of researchers and educators associated with particle physics experiments" drawing from the professional development literature. These past evaluators noted that QuarkNet has "evolved to reflect changes in the education context in which the program operates, and in response to findings from formative evaluation." The current program is the focus of the present evaluation, but we draw on the program's history when relevant.

### Importance of Centers

In current form, QuarkNet is "first and foremost, a teacher professional development program" (personal communication, email December 11, 2018), with as of this writing 57 centers across the United States, where these centers "both form the essential backbone and are partners in the QuarkNet collaboration" (PTM, 2019). These centers are housed at a university or laboratory, serving primarily high school teachers who live in the nearby catchment area. Included in this number of in-person centers, there is the Virtual Center, which provides a home for teachers who do not live proximal to a particle physics research group. At centers, program leaders include one or two physicists who serve as mentor(s) and team up with one or two lead teacher(s). Each center seeks to foster lasting relationships through collaboration at the local level and through engagement with the national program (PTM, 2019, 2023).

### Program Goals

As articulated by the Principal Investigators (PIs) of the program and as stated in the Program Theory Model, the measurable program goals of QuarkNet are:

1. To continue a PD program that prepares teachers to provide opportunities for students to engage in scientific practices and discourse and to show evidence that they understand how scientists develop knowledge. To help teachers translate their

experiences into instructional strategies, which reflect guided inquiry and NGSS science and engineering practices.

2. To sustain a national network of independent centers working to achieve similar goals. To provide financial support, research internships, an instructional toolkit, student programs and professional development workshops. To investigate additional funding sources to strengthen the overall program.

3. To reenergize teachers and aid their contributions to the quality and practice of colleagues in the field of science education.

4. To provide particle physics research groups with an opportunity for a broader impact in their communities.

**Approach to Evaluation**

**Program Strategies** → **Measurable Program Outcomes**

Figure 1. Throughout the evaluation, program engagement (i.e., specifically exposure to core program strategies) provides the context in which assessment has occurred.

In support of the assessment of the program and its goals, the evaluation themes are:

1. (Develop and) Use a Program Theory Model (PTM).
2. Measure Outcomes (teacher, student and long-term).
3. Measure Center-level Program Outcomes.

During the previous grant period, new evaluation measures based on the PTM were created; these were combined with selected previous evaluation measures. The development of these measures and relevant details will be highlighted later in this report. Key to the evaluation efforts, both quantitative assessment and qualitative assessment have sought to link program engagement to expected outcomes (see Figure 1).

## 2. (Develop and) Use Program Theory Model (PTM)

Because of the significance of the PTM and its role, previous reports provided at length the history and development of the model. We have bundled this description and present this in detail in Appendix B. In short, we drew from QuarkNet staff expertise; from relevant literature (i.e., characteristics of effective professional development, Darling-Hammond, et al., 2017); Next Generation Science Standards (especially the Practices); and defined our use of the term "Guided Inquiry." We developed the content of the model through structured interviews with key stakeholders; held a face-to-face meeting with past evaluators; and through working meetings with PIs and stakeholders developed a detailed, pictorial representation of the program.

Thus, QuarkNet's PTM:

1. Offers "an approximate fit" of the theory of the QuarkNet program as *designed.*
2. Allows for a comparison between the program as *designed* and as *implemented.*
3. Links core program strategies to program outcomes.
4. Directs evaluation efforts.

The PTM is intended to reflect that *context matters* in the implementation of the program and to provide a representative picture of how *change* is expected to happen. In detail we link program strategies and program structure to expected outcomes and the measurement of these.

**Theory of Change**

The Program Theory Model elaborates on how change is expected to occur, based on the following QuarkNet Theory of Change:

*By immersing teachers in doing authentic particle physics research and by engaging them in professional development that supports guided-inquiry and standards-aligned instructional practices and materials designed for the classroom, teachers become empowered to teach particle physics to their students in ways that model the actual practices of scientists and support instructional best practices suggested by the educational research literature.* (Modified from Beal & Young, QuarkNet Summative Evaluation Report 2012-2017).

**Presentation of the PTM**

Exhibits A and B present the first two pages of the PTM. The full model is shown in Appendix C. The first two pages serve as an abbreviated version of the model and may be very useful depending upon the audience. The first page presents the context in which the program operates identifying active partners and acknowledges the oversight responsibility of the program's Advisory Board. It also highlights additional outreach efforts associated with the program that extend beyond the program's core. The second page of the PTM provides a schematic overview of the program "a map" of the elements of the model suggesting how each may relate to the other. (Graphics created by L. Hudson.)

<u>Who is the Audience</u>*?* The audience for the PTM is someone who is or is not familiar with QuarkNet and who has an interest in or a stake in the program. The abbreviated model is likely to have the widest audience; an audience who may include individual teachers, mentors, participating centers, future funders, among others.

Details in the PTM regarding program strategies and program structure are offered as a guide for the stakeholders responsible for these program components and to help in program operations and revisions; and, to help guide reflections or assessments as to whether or not the *implemented* program is aligned with the program *as designed* (i.e., its theory). For the external evaluator, the PTM has directed the outcomes-based evaluation.

# QuarkNet Partners

**NSF:** The National Science Foundation is an independent federal agency created by Congress in 1950 "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…" NSF supports basic research and people to create knowledge that transforms the future. QuarkNet is funded through NSF's Integrative Activities in Physics Program.

**Fermilab:** America's particle physics and accelerator laboratory whose vision is to solve the mysteries of matter, energy, space and time for the benefit of all. Fermilab, a co-sponsor of QuarkNet, hosts Data Camp held each summer and supports the cosmic ray studies program. Fermilab hosts DUNE and the Long-Baseline Neutrino Facility. DUNE brings together over 1,000 scientists from more than 175 institutions in over 30 countries.

**Broadening Participation and Community Outreach:** QuarkNet works on multiple fronts to help broaden participation beyond the existing community, including teachers and students who are underrepresented in physics. Examples include center needs assessment workshops that serve to identify ways to reach out to these communities. QuarkNet partners with other STEM organizations to reach more teachers and students. Recent partners are *STEP UP, STEMarts Lab, and i.am.Angel Foundation.* Many Data Activities Portfolio activities have been translated into Spanish. Often, participating teachers develop classroom implementation plans that integrate culturally sensitive content. Centers integrate QuarkNet in their community outreach efforts, partnering to reach beyond existing QuarkNet schools to students traditionally underrepresented in STEM.

**Advisory Board**: Typically, eight to ten individuals both familiar with and new to the program meet annually to review QuarkNet program achievements and make recommendations for future plans and objectives. Members represent a diverse mix of high school physics teachers, education administrators, research physicists and physics outreach leaders.

QuarkNet: The QuarkNet Collaboration is a long-term, national program that *partners high school science teachers with particle physicists* working in experiments at the scientific frontier. A professional development program, QuarkNet immerses teachers in authentic physics research and seeks to engage them in the development of instructional strategies and best practices that facilitate the implementation of these principles in their classrooms.


**QuarkNet Centers**: Centers both form the essential backbone of and are partners in QuarkNet. A center is housed at a university or laboratory, serving high school physics and physical science teachers; active local centers number 50+.

**IRIS-HEP**: A software institute funded by the National Science Foundation. It aims to develop the state-of-the-art software cyberinfrastructure required for the challenges of data intensive scientific research at the High Luminosity Large Hadron Collider (HL-LHC) at CERN, and other planned HEP experiments of the 2020's. In partnership with IRIS-HEP, QuarkNet offers professional development opportunities for teachers to improve coding skills to enhance classroom implementation of particle physics instructional materials.

**U.S. ATLAS:** A collaboration of scientists from 45 U.S. institutions. ATLAS is one of two general-purpose detectors at the Large Hadron Collider in Geneva, Switzerland. The ATLAS experiment investigates a wide range of physics, from the search for the Higgs boson to extra dimensions and particles that could make up dark matter. U.S. ATLAS is a co-sponsor of QuarkNet.

**U.S. CMS:** A collaboration of more than 900 scientists from 50 U.S. institutions who make significant contributions to the Compact Muon Solenoid (CMS) detector. Discoveries from the CMS experiment are revolutionizing our understanding of the universe. USCMS is a co-sponsor of QuarkNet.

**Broader Impacts:** QuarkNet has led in facilitating the public use of large particle physics datasets. Working within the International Particle Physics Outreach group (IPPOG), QuarkNet shares the overall central coordination of International Masterclasses (IMC). QuarkNet schedules and coordinates ATLAS, CMS, MINERvA and NOvA International Masterclasses with videoconferences based at Fermilab. Also, QuarkNet develops and coordinates World Wide Data Day, an IMC extension, and shares leadership in the global cosmic ray studies project. QuarkNet provides a wealth of information for IPPOG members to consider in their own education and outreach programs. QuarkNet staff and teachers attend and present at meetings of the American Association of Physics Teachers and the American Physical Society. These presentations have highlighted how QuarkNet works, e-Labs, the Data Activities Portfolio and scientific discovery for students.

Exhibit A. The first page of the PTM highlights key partners and outreach efforts.

QUARKNET

**QuarkNet Program Theory Model**

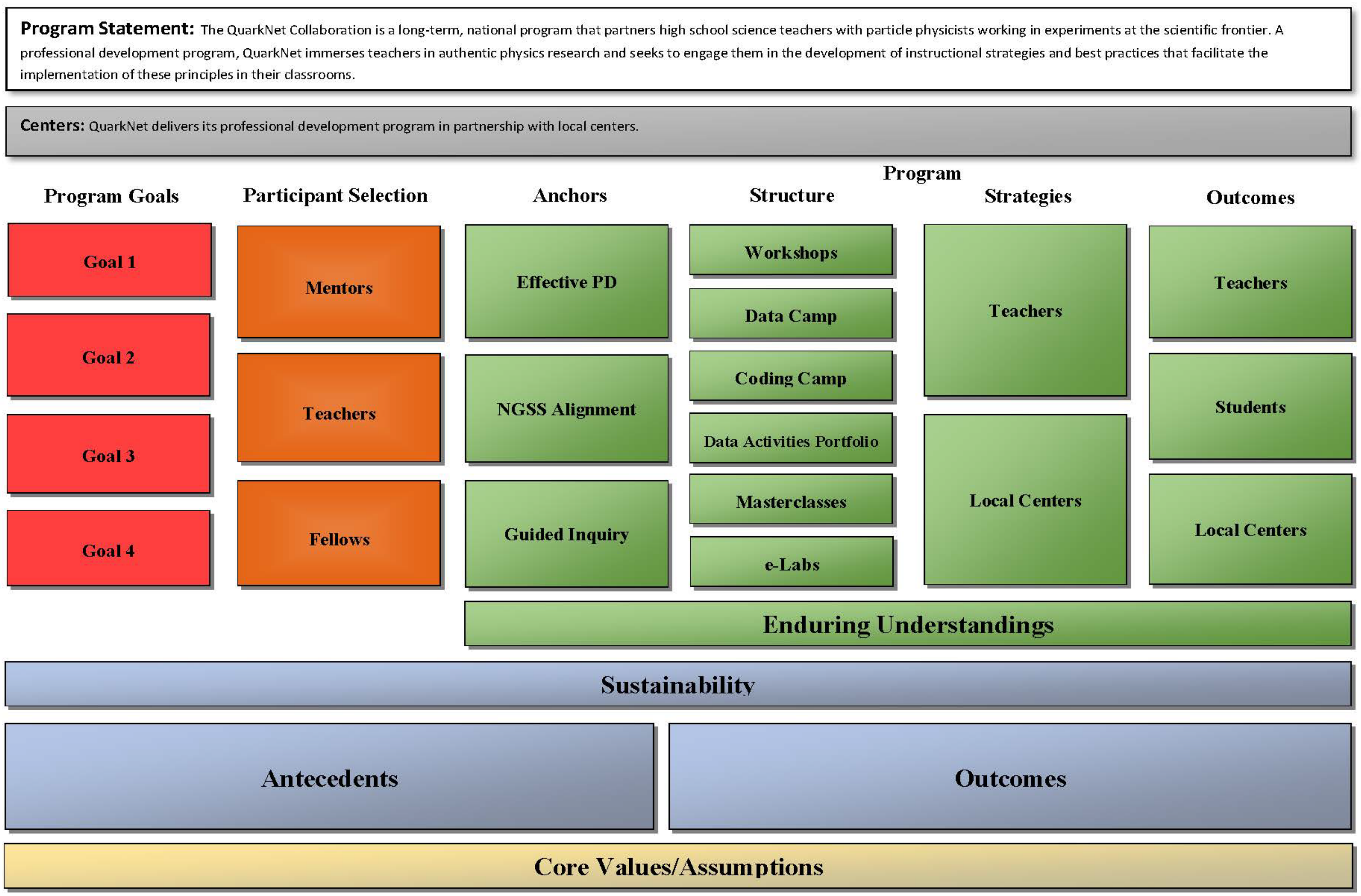



Exhibit B. The second page of the PTM overviews its component parts.

## Program Structure

**Data Camp:** Offered annually at Fermilab, this 1-week summer program is an introductory workshop for teachers of physics and physical science who either have had little-to-no experience with particle physics and/or who have had little experience with quantitative analysis of LHC data. The camp emphasizes an authentic data analysis experience in which teachers engage as active learners (as students) of a challenging topic they may have known very little about. In the beginning of the week, teachers receive an authentic CMS dataset and work in small groups to determine the mass of particles produced during LHC proton-proton collisions. Successful completion of this phase of the workshop culminates in each group presenting and explaining their analyses. In the second half of the week, teachers explore various instructional materials in the Data Activities Portfolio that help incorporate particle physics concepts into their everyday lessons and propose an implementation plan for their classrooms. Throughout the week, teachers take tours and participate in seminars from theoretical and experimental physicists.

**Coding Camp**: A virtual 1-week program offered annually in the summer for teachers of physics and physical science with little-to-no experience in computer programming and/or incorporating computer science into their courses. The camp emphasizes an authentic data analysis experience in which teachers engage as active learners (as students) using common scientific programming software (e.g., Jupyter, Python, & SciPy) to analyze and visualize large datasets from various scientific disciplines, including particle physics, astronomy, and geology. Like Data Camp, during the first half of the week, teachers are learners of challenging content. In the second half, they use reformed pedagogy in planning how to integrate coding into their courses. Throughout the week, teachers participate in virtual seminars with scientists and programmers working in various fields.

**Data Activities Portfolio:** An online compendium of particle physics classroom instructional materials organized by data strand, level of student engagement, curriculum topics and NGSS Standards. Instructional materials conform to a specific instructional design and are aligned with NGSS and AP science standards (Physics 1 and Physics 2) as relevant. Materials are based on authentic experimental data used by teachers to give students an opportunity to learn how scientists make discoveries. Strands include LHC, Cosmic Ray Studies, and Neutrino. Level descriptions, 0 to 4, explain the data analysis skills that students apply at each level: tasks in Level 0 are simpler than those in Levels 1 and 2. While each level can be explored individually, students who start in one level and progress to more complex levels experience increasingly engaging and challenging tasks.

Each curriculum topic provides connections between topics routinely covered in physics class and particle physics content and methods. The drop-down menus identify activities related to desired content and student skill sets. Teacher, student resources and data sets are available for each activity. In the Curriculum Topic drop-down menu, Spanish Language versions are available for some activities. Also, coding activities are available.

**Masterclass, QuarkNet Model:** A one-day event in which students become "particle physicists for a day." Teachers and mentors participate in an orientation, either remote or in person, by QuarkNet staff or fellows. Teachers implement up to three hours of classroom activities prior to a masterclass. Then, during the masterclass that usually takes place at a center, mentors introduce students to particle physics, and teachers explain the measurements they will make using authentic particle physics data. Working in pairs, students analyze data from visual event displays, characterize the events, pool their data with peers, and draw conclusions. Students are helped by and discuss interpretation of data with one or more particle physicists and their peers and teachers. At the end of the day, students may gather by videoconference with students at other sites to discuss results with moderators, who are particle physicists, at Fermilab, CERN, or another high energy physics facility. Some masterclasses take place at school with teachers providing the particle physics and measurement information. QuarkNet Masterclasses are part of a larger program, International Masterclasses.

**Workshops:** The primary vehicle through which participating QuarkNet teachers receive professional development. Teachers engage in QuarkNet workshops when new to the program and often over multiple years.

Workshops are in-person events held at a center. (A virtual center accommodates teachers from a dispersed area.) QuarkNet staff work with individual centers to build this experience with considerable flexibility to organize workshops that meet local needs and interests. Workshops vary in length, from 1-to-5 days, typically occur during the summer, but many centers may meet during the summer and school year. Workshops can be locally led or nationally led and are often a combination of the two, thus varying in content and structure. Nationally-led workshops, conducted by QuarkNet staff and/or fellows, cover content including, for example, cosmic ray studies, LHC or neutrino data, coding in support of particle physics, and related activities from the Data Activities Portfolio. Nationally-led workshops support opportunities for teachers to engage as active learners, as students, engage in activities from the Data Activities Portfolio, collect and analyze data, work in a learning-community environment, learn and share ideas related to content and pedagogy, and build collegial relationships with other teachers, fellows and mentors. Of importance, teachers have time to develop and discuss classroom implementation plans. Often locally- led workshops mirror these components and offer opportunities for teachers to tour local research labs, participate in unique events, and/or hear presentations by local physicists and students.

Staff encourage centers to post their agendas and annual reports on the QuarkNet website to share this engagement with other centers. Often, centers collaborate with other centers (e.g., rotating host responsibilities from one year to the next), join together through shared interests or content needs and other opportunities for multi-center engagement.

**e-Lab:** A browser-based online platform in which students can access and analyze data in a guided-inquiry scientific investigation. An e-Lab provides a framework and pathway as well as resources for students to conduct their own investigations. e-Lab users share results through online plots and posters. In the CMS e-Lab, data are available from the Compact Muon Solenoid (CMS) experiment at CERN[2]'s Large Hadron Collider (LHC). In the Cosmic Ray e-Lab, users upload data from QuarkNet cosmic ray detectors located at high schools, and once uploaded, the data are available to any and all users.

[2] Conseil Européen pour la Recherche Nucléaire

**Cosmic Ray Studies**: Across most centers, QuarkNet supports a high school long-term collaboration based on the High Energy Physics model using particle detectors provided in kit form. In this hands-on learning opportunity, students assemble the parts into a working scientific instrument based on the design used in the Collider Detector at Fermilab. Students and their teachers use the detectors for inquiry-based learning involving authentic research tasks and experiments such as muon flux, muon lifetime, and speed of muons, using data they collect themselves. Their data can be uploaded to the cosmic ray e-Lab for analysis, creating graphed plots to display results.

**Cosmic Watches**: Smaller more portable particle detectors, cosmic watches extend the reach of authentic research activity to all students, not just research groups, by moving cosmic ray studies into classrooms increasing the number of teachers using cosmic rays to teach about elementary particles and observing the invisible.

**Exhibit C. Program Structure of QuarkNet's Program Model as described on page 3 of the model.**

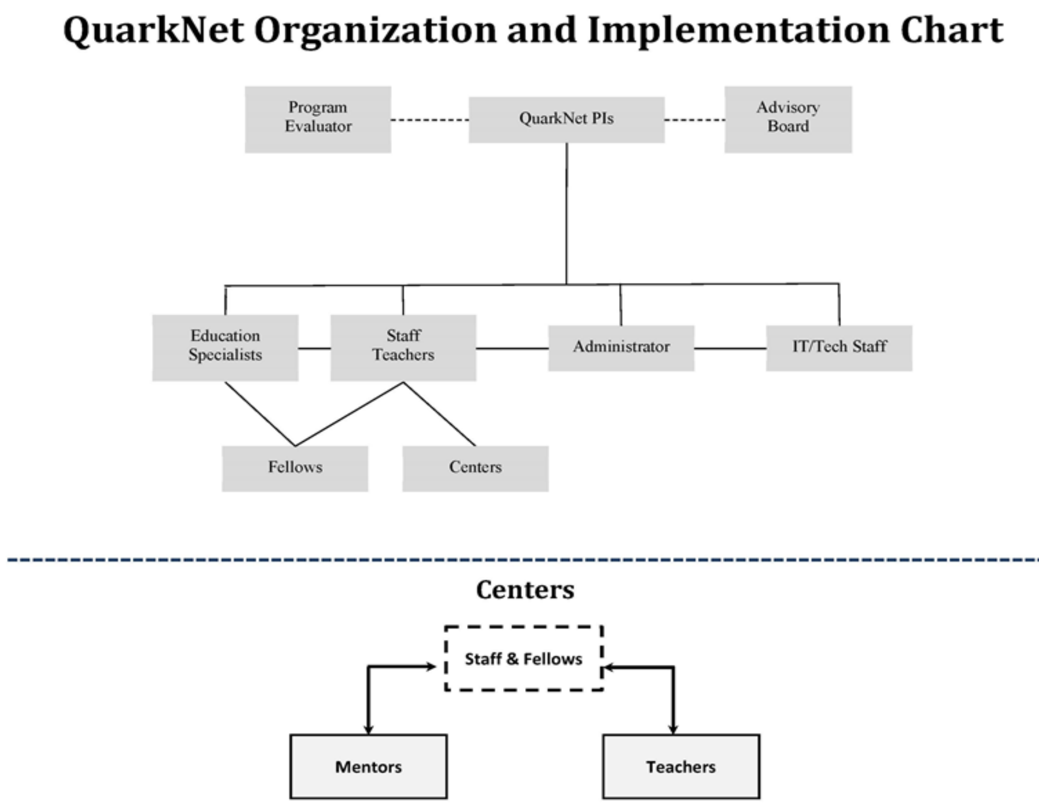



Figure 2. An overview of the organization and implementation of the QuarkNet Program.

Exhibit C (previous page) provides a graphic presentation of the program structure of QuarkNet. These program components are:

- Workshops
- Data Camp
- Coding Camp
- Data Activities Portfolio
- Masterclasses
- e-Labs (as well as cosmic ray studies, cosmic watches)

## **Program Fidelity** (Sections 3-5)

### 3. QuarkNet Program Organization

An overview of the roles and responsibilities of key QuarkNet stakeholders is shown in Figure 2. Also shown is a depiction of a typical center that is comprised of a mentor(s) and teachers with support from QuarkNet staff and fellows. As already stated, these centers are housed at a university or laboratory; serving primarily teachers who live within reasonable commuting distances. Initially, mentors interested in QuarkNet submitted a proposed research project, identified a mentor team, and described previous outreach experience.

As part of the implementation of the QuarkNet program, staff members hold weekly meetings, that is, a staff-wide meeting focused on program-wide issues and discussions. Weekly meetings with IT QuarkNet developers focused on IT needs and updates; similarly, a curriculum development team meets weekly focused on workshop content and activity development of the Data Activities Portfolio (personal communication, email M. Bardeen, April 17, 2019). All meetings are on-going.

**Centers**

Typically, at centers (as already noted) program leaders include one or two physicists who serve as mentor(s) who team up with one or two lead teacher(s). Teachers, whether individually a lead teacher or participant, are high school physics or physical science teachers who express interest in QuarkNet and who may be invited to participate through staff, fellows, or mentor/center teachers. Mentors often know high school teachers who are good additions to their research teams and/or who may become lead teachers at the center. Fellows are teachers who are invited by staff to become fellows based on participants' experience working with a local center or on national programs such as Data Camp (PTM, 2023). Fellows may interact with any of the centers. As already stated, the primary vehicle through which participating QuarkNet teachers receive professional development is workshop(s) conducted through the national program or that is center run.

In an email distributed by the co-PIs (Wayne, Bardeen and Swartz, December 2018), a center is operationally defined as active "if they provide at least one day of teacher development (not in a student workshop) and 'semi-active' if they and their teachers participate only in International Masterclasses, International Muon Week, World Wide Data Day, International Cosmic Day, or an equivalent activity which they indicate." (See Table 1.)

It is important to note that the lion share of centers listed in Table 1 are long-term but Table 1 does include new centers (e.g., North Carolina A & T) and centers that are no longer participants in QuarkNet as well as centers that have been rejuvenated during the course of these grant periods. This representation is intended to reflect that participating QuarkNet centers are not a static entity, the list and number of centers can change over the years for a variety of reasons such as changes in mentor, lead teacher involvement and other factors. In addition, a given center may participate in QuarkNet several times during a year, yearly, or every other year. Also, participating teachers within a given center can and likely do differ year to year, often with a combination of returning and new-to-the-program teachers. We will see later in this report, when quantitative and qualitative analyses of outcomes data are presented, that centers play a key role in the delivery as well as the measured outcomes of the program.

Table 1
QuarkNet Centers through Program Years 2019-2025: 57 Total

| Single or combined[a] | Center | Single or combined[a] | Center |
|---|---|---|---|
| 1 | Black Hills State University | 1 | University of California -- Irvine |
| 2 | Boston/Brown University/ Northeastern University | | ~~University of California -- Riverside~~ |
| 2 | Brookhaven National Laboratory/Stony Brook University | 1 | University of California -- Santa Cruz |
| 1 | The Catholic University of America | 1 | University of Cincinnati |
| 1 | Colorado State University | 1 | University of Florida/Middle Florida |
| 1 | Drew University | 1 | University of Hawai'i |
| 2 | Fermilab/University of Chicago/College of DuPage | 2 | University of Illinois at Chicago/ Chicago State University |
| | ~~Florida Institute of Technology~~ | 2 | University of Iowa/Iowa State University |
| 1 | Florida International University | 1 | University of Kansas |
| 1 | Florida State University | 1 | University of Maryland |
| 1 | Idaho State University | 1 | University of Minnesota |
| 2 | Johns Hopkins University | 1 | University of Mississippi |
| 1 | Kansas State University | 1 | University of New Mexico |
| 1 | Lawrence Berkeley National Laboratory | 1 | University of Notre Dame |
| 1 | Louisiana Tech University | 1 | University of Oklahoma |
| 1 | North Carolina A & T | 1 | University of Oregon |
| 1 | Northern Illinois University | | ~~University of Pennsylvania~~ |
| 1 | Oklahoma State University | 1 | University of Puerto Rico at Mayaguez |
| 1 | Purdue University | | ~~University of Rochester~~ |
| 1 | Purdue University Northwest | 1 | University of South Dakota |
| 1 | Queensborough Community College | | ~~University of Tennessee~~ |
| 2 | Rice University/University of Houston | 1 | University of Washington |
| 1 | Rutgers University | | ~~University of Wisconsin - Madison~~ |
| 2 | Southern Methodist University | 1 | Vanderbilt University |
| 1 | Syracuse University | 1 | Virginia Center (Hampton, George Mason, William & Mary Universities) |
| 1 | Texas Tech University | 1 | Virginia Tech |
| 1 | University at Buffalo – SUNY | 1 | Virtual Center |
| 1 | University of Alabama | | ~~Wayne State University~~ |

[a]A center is noted as a combined center if two (or more) centers work together to hold a QuarkNet workshop or event. Combined centers receive additional funds to support more teachers and/or more days to hold these events. ~~Center~~ denotes a center that is no longer active (as of November 2025).

**The Program's Website**

The QuarkNet website (https://quarknet.org/) can be accessed with or without a user account (a guest user account is available) where a visitor to the QuarkNet website (https://quarknet.org/) can learn and/or access all information about the program. This includes activities in the Data Activities Portfolio, Masterclasses, and e-Labs along with supportive documents and resources. There are also listings and links to QuarkNet centers and created groups, where website center-wide information is shared by a specific center (such as agendas, annual reports) or, where information about a specific need or activity is provided (e.g., Planning the Masterclass 2019). Expectations for mentors are provided; as well as a summary of award support (e.g., stipends for teachers); and how mentors and teachers can become involved in the program. National workshops opportunities for QuarkNet centers and mentor "must-do lists" are posted. Teachers and students can upload data and conduct analyses. There is contact information for key program stakeholders; a place to post questions or problems with the website; and testimonials from teachers, students and international partners reflecting their engagement in the program.

Thus, the website offers teachers, students, and research groups a rich resource of information, whether or not the individual and/or the group are directly engaged in the QuarkNet program.

## 4. Data Activities Portfolio: Brief History and Development

As stated on the QuarkNet website: *The Data Portfolio is a compendium of particle physics classroom activities organized by Data Strand, Level of student engagement, Curriculum Topics and NGSS Standards.* (Data Activities Portfolio | QuarkNet)

The process used to develop and review activities for inclusion in the Data Activities Portfolio, which follows the design recommendations by Wiggins and McTighe (2005) is schematically depicted in Appendix D along with the complete document that describes this protocol in detail. This process has evolved since the start of QuarkNet, outlined in 2015, by Young, Roudebush and Bardeen; and later updated in 2019. The protocol's intent is to help ensure the quality of developed activities; the criteria used to determine NGSS alignment (Table 2); the actual alignment of these activities with the science practices of NGSS (Table 3); alignment with Enduring Understandings (Table 4); and to provide a standardized template and format.

The development of activities in the Data Activities Portfolio has been a dynamic process; including the review or re-review of all activities, in particular older activities, before their posting on the website; and that these aligned with the review guidelines just discussed. Other activities, for example, were split to accommodate either the required student-skills level or skill-level gaps (introducing level 0) or split because the content suggested the need for this (e.g., masterclasses split by data strand such as ATLAS Z-path or CMS-WZH-path). As the science (or availability of data) evolved, physicists helped to add activities (e.g., 3-D puzzle activity and creating a simulation) and to advise

Table 2
Criteria Used to Align Data Activities Portfolio Activities with the
Science and Engineering Practices in the Next Generation Science Standards (NGSS)

| NGSS Practice | Alignment Criteria (Provide opportunity for required/ recommended engagement by students) |
|---|---|
| 1. Asking questions (for science) and defining problems (for engineering) | • Students must determine the problem for which questions and answers lead to solutions. |
| 2. Developing and using models | • Students must use data to develop a qualitative or quantitative model that explains the data and predicts subsequent data. |
| 3. Planning and carrying out investigations | • Students may receive a research question for which they must develop and carry out a plan for their own investigation. Or the students may receive preliminary data from which they develop and carry out a plan for their investigation. |
| 4. Analyzing and interpreting data | • Students must either collect data or receive data which they analyze qualitatively or quantitatively. |
| 5. Using mathematics and computational thinking | • Students must use mathematical techniques for interpreting graphs and histograms including linearization and correct histogram uncertainties. |
| 6. Constructing explanations and designing solutions | • Students must gather and analyze data and report out either to their group, the teacher or the class. |
| 7. Engaging in argument from evidence | • Students must justify their claims with evidence and reasoning that is derived from the data. |
| 8. Obtaining, evaluating, and communicating Information | • Students must gather and analyze data and report out either to their group, the teacher or the class. |

Criteria articulated by D. Roudebush and M. Bardeen August 18, 2020.

on existing ones. Over time, curriculum topics were created to help teachers envision and plan for sequencing lessons (and facilitate the development of necessary student skills).

Current on-going efforts have included the re-review of previously posted activities; filling in gaps for improved sequencing; developing neutrino materials; and creating activities at level 4. Most recently, coding activities and resources have been added fostered by coding skill development workshops added to QuarkNet’s repertoire. In addition, several activities have been translated into Spanish as well.  A brief history of the Data Activities Portfolio is highlighted in Appendix E.

The total number of DAP activities is 43 (as of October 2025).

Table 3
Instructional Materials in the Data Activities Portfolio

| Level | Activity | Data Strand | NGSS Practices |
|---|---|---|---|
| 0 | Mass of U. S. Pennies | Cosmic Ray, LHC | 1,2,3,4,6,7,8 |
| 0 | Quark Workbench 2D/3D | Cosmic Ray, LHC | 1,2,4,5,6,7 |
| 0 | Dice, Histogram and Probability | Cosmic Ray, LHC | 1,2,3,4,5,6,7,8 |
| 0 | Shuffling the Particle Deck | LHC | 1,2,4,5,6,7 |
| 0 | Mapping the Poles | LHC | 2,4,6,7 |
| 0 | Signal and Noise: The Basics | Cosmic Ray, LHC | 4,5,6,7,8 |
| 0 | Histograms: The Basics | Cosmic Ray, LHC, Neutrino | 4,5,7 |
| 0 | Making Tracks I | Cosmic Ray, LHC, Neutrino | 1,2,4,6,7 |
| 0 | Introduction to Coding Using Jupyter | Cosmic Ray, LHC, Neutrino | 1,2,4 |
| 0 | Plotting a Consensus | LHC | 3,4,5 |
| 1 | What Heisenberg Knew | Neutrino | 2,4,5,6,7,8 |
| 1 | The Case of the Hidden Neutrino | LHC, Neutrino | 2,4,5,6,7 |
| 1 | Making it ‘Round the Bend – Qualitative | LHC | 1,2,3,4,6,7 |
| 1 | Rolling with Rutherford | Cosmic Ray, LHC | 1,3,4,5,7 |
| 1 | Signal and Noise: Cosmic Muons | Cosmic Ray | 4,5,6,7,8 |
| 1 | Mean Lifetime Part 1: Dice | Cosmic Ray, LHC | 2,4,5,7 |
| 1 | Histograms: Uncertainty | Cosmic Ray, LHC, Neutrino | 4,5 |
| 1 | Energy, Momentum, and Mass | Cosmic Ray, LHC, Neutrino | 2,4,5,7,8 |
| 1 | Making Tracks II | Cosmic Ray, LHC, Neutrino | 1,2,4,6,7 |
| 1 | Particle Transformations | Cosmic Ray, LHC, Neutrino | 1,2,4,6,7 |
| 1 | Angles and Dimuons | Cosmic Ray, LHC | 2,4,5,6,7,8 |
| 1 | How Speedy are These Muons? | Cosmic Ray | 2,3,4,5,7,8 |
| 1 | TOTEM 1 | LHC | 4,5,8 |
| 1 | Cosmic Watch Lab Suite | Cosmic Ray | 1,2,4,5,6,7 |
| 2 | Calculate the Z Mass | LHC | 1,2,4,5,6,7,8 |
| 2 | Calculate the Top Quark Mass | Cosmic Ray, LHC | 1,4,5,7 |
| 2 | Making it ‘Round the Bend – Quantitative | LHC | 1,2,3,4,5,6,7,8 |
| 2 | CMS Data Express | LHC | 1,2,4,5,7,8 |
| 2 | TOTEM 2 | LHC | 2,4,5,6,7,8 |
| 2 | ATLAS Z-path Masterclass | LHC | 1,2,4,5,6,7,8 |
| 2 | CMS Masterclass WZH-path | LHC | 1,2,4,5,6,7,8 |
| 2 | Mean Lifetime Part 2: Cosmic Muons | Cosmic Ray | 2,3,4,5,7,8 |
| 2 | Mean Lifetime Part 3: MINVERvA | Cosmic Ray, Neutrino | 2,3,4,5,7,8 |
| 2 | ATLAS Data Express | LHC | 1,2,4,5,7,8 |
| 2 | ATLAS W-path Masterclass | LHC | 1,2,4,5,6,7,8 |
| 2 | CMS Masterclass J/Psi | LHC | 1,2,4,5,6,7,8 |
| 2 | Z Mass Spreadsheet Extension | LHC | 2,3,4,5,6,7,8 |
| 2 | Heisenberg’s Laser | Cosmic Ray, LHC, Neutrino | 4,5,8 |
| 3 | Cosmic Ray e-Lab | Cosmic Ray | 1,2,3,4,5,6,7,8 |
| 3 | CMS e-Lab | LHC | 1,2,3,4,5,6,7,8 |
| 4 | Research Using Coding | Cosmic Ray, LHC, Neutrino | 1,2,3,4,5,6,7,8 |

Note: List of activities taken from QuarkNet website https://quarknet.org/data-portfolio. Does not include STEP UP activities: QuarkNet: Changing the Culture (0): and QuarkNet STEP UP: Careers in Physics (1). (As of October 2025.)

NGSS Practices: 1. Asking questions and defining problems. 2. Developing and using models. 3. Planning and carrying out investigations. 4. Analyzing and interpreting data. 5. Using mathematics and computational thinking. 6. Constructing explanations and designing solutions. 7. Engaging in argument from evident. 8. Obtaining, evaluating, and communicating information. (https://www.nextgenscience.org/)

Table 4
Enduring Understandings: Alignment of Activities in the Data Activities Portfolio

| Enduring Understandings | QuarkNet Activity | Level |
|---|---|---|
| 1. Scientists make a claim based on data that comprise the evidence for the claim. | • ATLAS Z-path Masterclass<br>• CMS Masterclass WZH-path<br>• How Speedy are These Muons> | 2<br>2<br>1 |
| 2. Scientists use models to make predictions about and explain natural phenomena. | • Cosmic Ray e-Lab<br>• CMS e-Lab | 3<br>3 |
| 3. Scientists can use data to develop models based on patterns in the data. | • Mapping the Poles<br>• Making it 'Round the Bend – Qualitative<br>• Introduction to Coding Using Jupyter<br>• Angles and Dimuons<br>• Mean Lifetime Part 1: Dice<br>• Coding Watch Lab Suite<br>• Making it 'Round the Bend – Quantitative<br>• Mean Lifetime Part 2: Cosmic Muons<br>• Mean Lifetime Part 3: MINERvA | 0<br>0<br>0<br>1<br>1<br>1<br>2<br>2<br>2 |
| 4. Particle physicists use data to determine conservation rules. | • Making Tracks I<br>• Making Tracks II<br>• Rolling with Rutherford<br>• The Case of the Hidden Neutrino<br>• ATLAS Z-path Masterclass<br>• TOTEM 1 | 0<br>1<br>1<br>1<br>2<br>1 |
| 5. Indirect evidence provides data to study phenomena that cannot be directly observed. | • Making Tracks I<br>• Making Traces II<br>• Rolling with Rutherford<br>• The Case of the Hidden Neutrino<br>• ATLAS Z-path Masterclass | 0<br>1<br>1<br>1<br>2 |
| 6. Scientists can analyze data more effectively when they are properly organized; charts and histograms provide methods of finding patterns in large datasets. | • Mass of U.S. Pennies<br>• Dice, Histograms & Probability<br>• Histograms: The Basics<br>• Z Mass Spreadsheet Extension | 0<br>0<br>0<br>2 |
| 7. Scientists form and refine research questions, experiments and models using observed patterns in large data sets. | • Cosmic e-Lab<br>• CMS e-Lab<br>• Research Using Coding | 3<br>3<br>4 |
| 8. The Standard Model provides a framework for our understanding of matter at its most fundamental level. | • Quark Workbench 2D/3D<br>• Particle Transformations<br>• Cosmic e-Lab<br>• CMS e-Lab | 0<br>1<br>3<br>3 |
| 9. The fundamental particles are organized according to their characteristics in the Standard Model. | • Shuffling the Particle Deck | 0 |
| 10. Particle physicists use conservation of energy and momentum to measure the mass of fundamental particles. | • Calculate the Z Mass<br>• Calculate the Top Quark Mass<br>• Energy, Momentum, and Mass<br>• CMS Masterclass WZH-path<br>• CMS Masterclass J/Psi | 1<br>1<br>1<br>2<br>2 |
| 11. Fundamental particles display both wave and particle properties and both must be taken into account to fully understand them. | • TOTEM 2<br>• ATLAS Data Express | 2<br>2 |
| 12. Particle physicists continuously check the performance of their instruments by performing calibration runs using particles with well-known characteristics. | • CMS Data Express | 2 |
| 13. Well-understood particle properties such as charge, mass, momentum and energy provide data to calibrate detectors. | • Calculate the Z Mass | 1 |
| 14. Particles that decay do so in a predictable way, but the time for any single particle to decay, and the identity of its decay products, are both probabilistic in nature. | • Mean Lifetime Part 1: Dice<br>• Mean Lifetime Part 3: MINERvA<br>• Mean Lifetime Part 2: Cosmic Muons | 1<br>2<br>2 |
| 15. Particle physicists must identify and subtract background events in order to identify the signal of interest. | • Signal and Noise: The Basics<br>• Signal and Noise: Cosmic Muons<br>• CMS Masterclass J/Psi | 0<br>1<br>2 |
| 16. Scientists must account for uncertainty in measurements when reporting results. | • What Heisenberg Knew<br>• Histograms: Uncertainty | 1<br>1 |

## Snapshot in Time

| In the Beginning (2017) | End of Grant (2022) | Now (2025) |
|---|---|---|
| 14 Activities | 38 Activities | 42 Activities |
| Variety of structures | Specific Structure | Specific Structure |
| No Protocol | Protocol Aligned with PD Criteria | Protocol Aligned with PD Criteria |
| Level 1-3 | Level 0 – 4 | Level 0-4 |
| No Teacher Answer Key | Teacher Answer Key in Teacher Notes | Teacher Answer Key in Teacher Notes |
| Assessment | Assessment with Answers | Assessment with Answers |
| No Coding Activities | Two Coding Activities | Six Coding Activities |
| No Spanish Language Versions | Five Spanish Language Activities | Nine Spanish Language Activities |

Exhibit D. Comparison of the Data Activities Portfolio from past to current grant. (Created by D. Roudebush, IIPOG Presentation May 2025 and used with permission.) Online activities, developed during COVID, are shown below in Exhibit E (for use for remote, online teaching or as homework assignments).

To give you a sense of the growth of these activities over time, in comparison during the 2012-2017 program grant years, there were 14 activities by the end of that grant period. (See Exhibit D.) Also shown in Exhibit E is a listing of DAP activities developed for online use, an effort that occurred during COVID to support these efforts during this turbulent period. Currently, seven coding activities have been added as well as nine DAP activities are now available in Spanish (as of May 2025). (A new activity has been added since the presentation of this slide.)

As already implied, each activity in the DAP is available through the QuarkNet website, https://quarknet.org/data-portfolio. These activities can be searched whether logged into the website or not; and instructions are provided as to how to search for desired examples. Activities can be searched by manually scrolling through the web pages (progressing from simple to complex); or, to facilitate searches these are organized by

| Activity | Level | Activity | Level | Activity | Level |
|---|---|---|---|---|---|
| Quark Workbench | 0 | Calculate the Z Mass | 1 | Mean Lifetime Part 2: Cosmic Muons | 2 |
| Shuffling the Particle Deck | 0 | Mean Lifetime Part 1: Dice | 1 | Atlas Data Express | 2 |
| Dice, Histograms, and Probability | 0 | What Heisenberg Knew | 1 | Making it 'Round the Bend -Quantitative | 2 |
| Histograms: the Basics | 0 | Histograms: Uncertainty | 1 | Mean Lifetime Part 3: MINERvA | 2 |
| Making it 'Round the Bend - Qualitative | 0 | Energy, Momentum, and Mass | 1 | Cosmic Racy e-Lab | 3 |
| Rolling with Rutherford | 1 | CMS Data Express | 2 | CMS e-Lab | 3 |

Note. Adapted from: https://quarknet.org/content/comments-adapting-data-activities-teaching-online.

Exhibit E. Listing of DAP activities developed for online use.

Data Strand (Cosmic Ray, LHC, and Neutrino); Level (0-4), Curriculum Topics, (e.g., Conservation Laws; Electricity; Quantum Mechanics; Half-Life/Mean Lifetime.); and NGSS Science Practices. An individual can search by one or all of these organizational categories. In support of these activities are Teacher Notes; Student Guide files (and at times other support materials); and information on technology requirements. Estimated class time to implement is also provided.

The word "activity/activities" is frequently used by QuarkNet staff and staff teachers as well as by participating QuarkNet teachers. We have adapted this language as well but note that when used we are referring to the full set of teacher and student resources and active learning opportunities that are associated with each.

Level 3 activities in the DAP are supported by masterclasses and e-Labs. Masterclass instructional materials are organized by three project maps (LHC Project Map, Neutrino Project Map, and World Wide Data Day), which offer a sequence of planning, orientation, and classroom preparation to help teachers get their students ready for this engagement. And e-Labs include resources to support a series of investigations into high-energy Cosmic Rays; and, to support a student research project using CMS authentic data and analytical tools. Links to MINERvA resources (MINERvA is the name of an experiment at Fermilab collecting data on how neutrinos interact with matter) including classroom information, data sets and the MINERvA web event display are also provided.

In addition, information about e-Labs is available in its own pull-down menu (https://quarknet.org/ content/about-e-labs) and offers overview and resource information links (http://www.i2u2.org/elab/) as well. As stated on the website, "e-Labs provide opportunities for students to: Organize and conduct authentic **research**; Experience the environment of scientific **collaborations**; and Analyze **authentic data** from large experiments." Students are able to explore data with other students and experts "to share results and publish **original work** to a world wide audience; discover and extend the research of other students, model the processes of modern, large-scale research projects; and access distributed computing techniques employed by **professional researchers**.

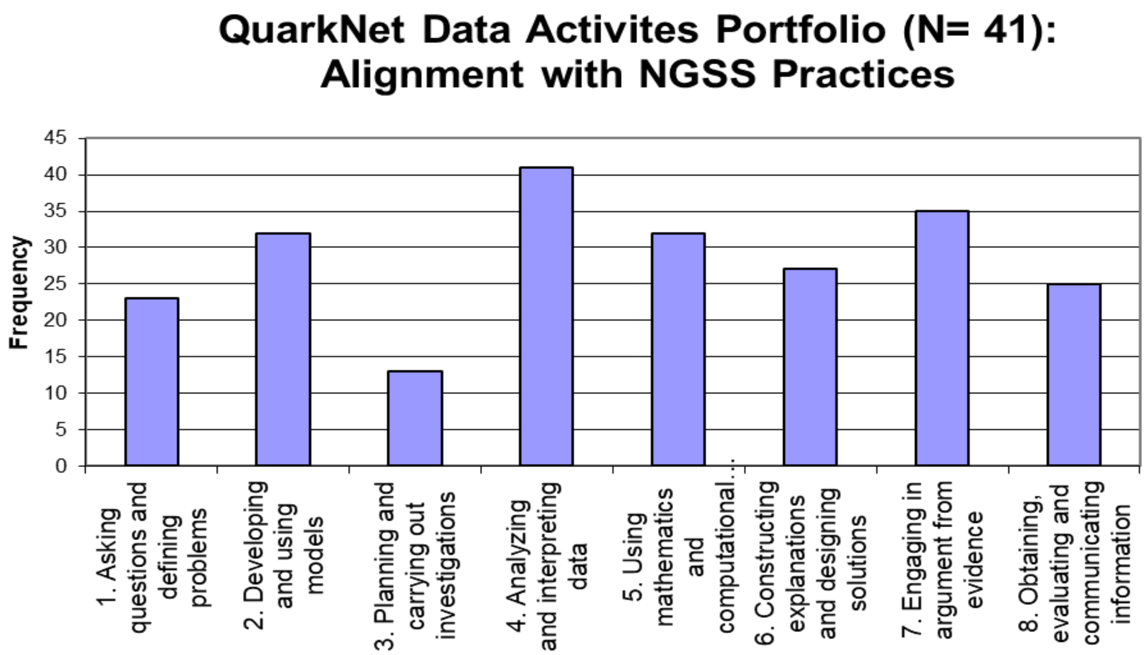



Figure 3. Alignment of Data Activities Portfolio activities with NGSS Science Practices. (Note: **Two** Step-Up activities are not included in this graph.) (As of 1/12/2026.)

Students may contribute to and access shared data which can come from professional research databases; and use common **analysis tools**, store their work and use metadata to discover, replicate and confirm the research of others." Through this collaboration students "correspond with other research groups, post comments and questions, prepare summary reports and participate in the part of scientific research that is often left out of classroom experiments" (https://quarknet.org/content/about-e-labs)

The criteria used to determine the alignment of DAP activities with the Next Generation Science Standards: Science Practices (Appendix F, NGSS April 2013) are shown in Table 2 (page 12).

Table 3 (page 13) provides a list of the current activities in the Data Activities Portfolio (DAP); 41 activities are listed in this table. This represents: 10 activities at Level 0; 14 activities at Level 1; 14 activities at Level 2; 2 activities at Level 3; and 1 activity at Level 4. (The two Step-Up activities are not included.)

As yet noted, there are two activities that are not included in Table 3. These activities were developed through a partnership with STEP UP focused on Broadening Participation. These activities are: QuarkNet: Changing the Culture (Level 0); QuarkNet STEP UP: and Careers in Physics (Level 1). These activities align with the NGSS All Standards, All Students" commitment to making NGSS accessible to all students (National Academies Press Appendix D, NGSS, April 2013).

**DAP Activities: Alignment with the Next Generation Science Standard Practices**

Figure 3 (previous page) shows the alignment of the activities from the Data Activities Portfolio (DAP) with the Next Generation Science Standards, Science and Engineering Practices and suggests the natural variability one would expect of a careful review of these materials. Two points seems evident from this distribution. First, at the program level a strength of these activities is how well these collectively align with these Practices. This is especially the case for Practices 2, 4, 5, and 7 (that is, 2. Developing and Using Models; 4. Analyzing and Interpreting Data; 5. Using Mathematics and Computational Thinking; and, 7. Engaging in Argument from Evidence). For example, all activities require analyzing and interpreting data (Practice #4). And, of importance, this engagement is based on authentic data, often using large data sets involving cutting-edge physics, especially for higher level activities (e.g., Level 2-4 activities).

Second, the less frequently noted first three practices (1. Asking questions and defining problems; 3. Planning and Carrying Out Investigations; 6. Constructing Explanations and Designing Solutions; and 8. Obtaining, evaluating and communicating information) suggest that these activities are largely guided-inquiry engagement (where the teacher provides the question) reflective of the complexity of the concepts covered in these activities.

Table 4 (page 14) shows the alignment of the DAP with the Enduring Understandings of Particle Physics that are an integral part of the PTM and the implemented program. As shown, typically one activity focuses on one Enduring Understanding as suggested by Wiggins and McTighe (2005) covering content in depth over breath. Masterclasses and e-Labs, along with a few other activities, are exceptions because these require prior preparation to be fully engaged. Also, it should be noted that when a given activity is embedded in a national-led or center-led program it is used to support the particle physics content contained within a workshop; thus, an Enduring Understanding(s) is sequenced into a workshop as well. Of importance, DAP activities provide a vehicle as to how this content may be incorporated into the classrooms of participating teachers.

The Enduring Understandings of Particle Physics were developed by Young, Bardeen, Roudebush, Smith and Wayne (originally in 2015 and revised in 2019). These were incorporated into the PTM because of their fundamental relevance to expected understandings of big ideas associated with participation in QuarkNet; and, because these are integral to the design and implementation of instructional materials contained in the Data Activities Portfolio.

Accordingly, these Enduring Understandings are in keeping with Wiggins and McTighe's (2005), *Understanding by Design,* who describe backward design as a three-stage process in which the teacher first identifies the desired results; then determines what would count as evidence to determine whether or not the students did or did not reach those results; and then designs the learning experience around these desired results and evidence. In this way, Wiggins and McTighe recommended four criteria, i.e., to what extent does the idea, topic or process:

1. Represent a "big idea" having enduring value beyond the classroom?
2. Reside at the heart of the discipline?
3. Require uncoverage?
4. Offer potential for engaging students?

Sample (2011) noted that uncoverage implies depth over breath; determining how much material to cover; how deep to go and how deeply to dig down into core principles or processes of a given discipline to gain a lasting understanding. Thus, *enduring understandings* are defined as "statements summarizing important ideas and core processed that are central to a discipline and have lasting value beyond the classroom. They synthesize what students should understand – not just know or do – as a result of studying a particular content area." (Wiggins and McTighe, 2003; http:/Enduring Understandings | iTeachU (uaf.edu)]

## 5. Program Implementation and Measuring Fidelity (*Designed* vs. *Implemented* Program)

Throughout the implementation of the current program, each center has been encouraged to apply for QuarkNet funds through a short RFP (Request for Proposal) process. The RFP requesting contact information (individual's name, email address, and center name); plans for workshops in the program year; expected number of days; anticipated dates; expected number of teachers; which nationally-led workshop if desired; and additional information as needed (see for example, https://quarknet.org/content/summer-2023-rfp). Staff teachers then have followed up with centers via emails and/or phone calls as a reminder and/or to help clarify any questions.

In the current program, centers can apply for a budgeted 30 teacher-days; for a merged or combined center (two or more) this budgeted amount is set at 45 teachers-days. There are various ways in which this budgeted 30 teacher-days commitment can be broken down. As explained in an annual email (January 18, 2019; February 3, 2020; March 1, 2021; January 24, 2022; January 19, 2023; January 25, 2024; and January 8, 2025), this could mean, for example, 6 teachers for 5 days or 15 teacher-days for 2 days. To help centers plan for a given program year (with most activities starting in the summer), centers are offered a list of national workshop opportunities along with sample agendas to aid in planning and implementation (https://quarknet.org/form/summer-2025-rfp) as well as a staff-member representative list (see for example, QuarkNet Center Staff Assignments as of January 2024 | QuarkNet).

As reported by QuarkNet staff teachers, typically these center-level workshop requests are initially confirmed; and finalized with an official follow-up funding letter that stipulates the maximum dollar amounts allocated for that center. Staff teachers also tracked requests for national workshop engagement and accommodate these requests to the extent to which their schedule permits (personal communication, email March 15, 2019).

This process was implemented in the 2018 program year and has been repeated for the 2019 through 2025 program years starting with an annual email blast distributed with a link to support information (as already described).

**Program Years 2019-2024**

Starting with the rollout of the 2019-2020 program year, QuarkNet staff provided mentors and workshop facilitators with examples of agendas for nationally-led workshops (as already described), which can and have been modified for workshops led by individual centers, if desired. During nationally-led workshops, these agendas often are modified in real time providing a straightforward way of documenting content and schedule changes. At times, this may include planned activities that were not implemented; when this happens the items are crossed out rather than deleted to help serve as an indicator as to what was planned and what was implemented, and to perhaps help in the planning of future workshop(s). Once a workshop is completed, the updated agenda serves to memorialize the scheduled events, including main topics of presentation and discussion, activities from the Data Activities Portfolio, and implementation plan development. Another benefit of this approach is that it may help centers complete their annual reports; with details regarding the workshop or meeting captured in one or both of these documents.

Nationally-led workshops are implemented within a standard template and reflect the program strategies articulated in the Program Theory Model. That said, each center has and does take advantage of locally-available resources. This is reflected in presentations by scientists related to, for example, computing in particle physics, understanding neutrinos, measuring Muon g-2; tutorials on using cosmic ray detectors; masterclass walkthroughs and access to large data sets; as well as presentations by students related to their research, for example, using cosmic ray detectors, or machine learning. A tour of local laboratories and research centers has often been an integral part of the workshop; or involve unique-opportunity research (e.g., building a cosmic ray detector and using it to collect data on the National Basilica of the Shrine of the Immaculate Conception in Washington, DC; or a presentation on cosmic ray detection and the 2017 Solar Eclipse).

The Neutrino Workshop, pilot tested during the 2018-2019 program year, was incorporated fully into the 2019-2020 QuarkNet program year. And STEP-UP was incorporated into designated workshops as well. (STEP UP is a national movement to provide high school physics teachers with resources to reduce barriers and inspire all students to consider a major in physics.) Coding Camp, added in the 2019-2020 program year, was pilot tested as a workshop in the 2020-2021 program year and expanded during the 2021-2022 and the 2002-2023 program years. An Introduction to Cosmic Watches was included as an option starting in the 2023-2024 program year. QuarkNet staff has also added many online-available resources, originally created in response to challenges due to the coronavirus starting in March 2020, which included program modifications made to help adapt QuarkNet to online teaching venues. These options remain available because of their usefulness. Additional teacher support for online resources were added including for example, remote online simulations and online lessons; and how to use Cosmic Ray detectors remotely for data collection and analyses.

A series of tables are presented in Appendix F, each summarizes QuarkNet Workshops held during a past program year. For 2018, there are two such tables where Table F-1 shows the national workshops run by QuarkNet staff; and Table F-2 lists the meetings and workshops held at QuarkNet Centers and led by individual centers. (Data Camp was implemented at Fermilab on July 16-20, 2018.) In subsequent program years, there is one table per program year where nationally-led workshops are highlighted in a bold-face font. (Workshops cancelled in 2020 and 2021 because of COVID are crossed out in these tables -- not deleted -- to reflect the impact of COVID on delivered programs at centers.)

**Program Year 2024-2025**

The implemented workshops during the 2024-2025 QuarkNet program year are shown in Table 5. The table focuses on highlighting workshops (and masterclasses) and in particular the DAP activities embedded in each as well as time allocated for their engagement, classroom implementation planning and the discussion of these. Other activities may be highlighted as well (such as, select talks on cutting edge topics in particle physics; or center tours on experiments/laboratory research).

Nationally-led workshop options were organized by the following categories: Large Hadron Collider Workshops (e.g., Higgs Boson, ATLAS Data, CMS Data); Neutrino Based Workshops (i.e., either MINERvA or NOvA Data); Cosmic Ray Workshops (e.g., Cosmic Watch Introductory Workshop); and Special Topics Based Workshops (e.g., Belle Data, Coding, Muon Study).

Over the course of the two most recent grant periods, there are four important points to note. First, there has been a noted increase in the number of workshops where DAP activities are incorporated (as well as introducing teachers to its webpage and search capabilities), coinciding with the rigor and robust increase in the number of activities included in the DAP (since 2017). By design, embedded DAP activities align with the workshop content, often at multiple student-skills levels (Levels 0-4). Teachers engaged in these activities as active learners – as students -- and, at times, can select from optional examples of activities to enhance this engagement. Experiencing these activities as active learners may give teachers insight as to how and in what ways their students may engage in these activities and subsequent comprehension. This aligns with effective teacher professional development practices outlined by Darling-Hammond, et al., (2017). Second, more frequently workshop agendas have been created and posted on center-level webpages which have improved the ability to capture these details (augmented by center-level annual reports). Third, during workshops teachers are given time to reflect on how they might use these activities (and other materials) in their classroom, a primary purpose of the DAP, and incorporate these into classroom implementation plans. The frequency in which workshops have included time for implementation reflection and planning has increased over this time period as well. And fourth, these implementation plans (or teacher content posters) are linked within these agendas as a means of documenting and memorializing these ideas; an activity that has increased over time as well.

Table 5

**2025** QuarkNet Workshops and Meetings: National- and Center-led (November 2024-August 2025)

| **Center** | **2025 Dates (All dates except where noted)** | **Workshop/Meeting** | **Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans] |
|---|---|---|---|
| Black Hills State University | July 9-11 | **Cosmic Ray Workshop** | Data Activities Portfolio: Participation in groups and then discussion<br>Shuffling the Particle Deck<br>Signal & Noise: The Basics<br>Signal & Noise: Cosmic Muons<br>How Speedy Are These Muons?<br>Mean Lifetime Part 1: Dice<br>Mean Lifetime Part 2: Cosmic Muons<br><br>Setting up cosmic ray detectors<br>Introduction to Cosmic Watches<br>Data collection<br>Share-a-thons<br>SURF underground tour<br>Create posters and follow-up discussion<br>Implementation plan development and discussion |
| | April 4 | **Neutrino Masterclass** | Neutrinos Dune Experiment (history and future) |
| Boston Area/Brown University/ Northeastern University[a,b] | November 25, 2024 | Fall Meeting (12 teachers) | Presentation and Video on Ferman's Least Time Principle. Then a Veritasium video "The Strange Physics Principle That Shapes Reality" |
| | March 29 | Particle Physic Masterclass (24 students 6 teachers) | Introduction to the standard model, particle accelerators, and cosmology connections. Overview of data analysis process for examining CMS collision data images. Students given a tour of a physic lab. Student pairs collected about 100 event records; able to compare data with other students from Maryland, Houston, and Stony Brook. |
| | June 16 | Spring Meeting | Presentation of least action<br>Participants reviewed and discussed Top Quark (DAP) activity |
| | August 6-7 | Summer Workshop Quantum!!! | Presentations on various particle physics topics<br>DAP Activity: TOTEM 2 |

Note. National-led QuarkNet workshops are in a bold-face font. Compiled from agendas and final reports posted on QuarkNet website by individual center. [a]Combined QuarkNet center. [b]Presented in chronological order (oldest to newest event) to reflect the sequencing of topics.

Table 5 (con't.)
**2025** QuarkNet Workshops and Meetings: National- and Center-led (November 2024-August 2025)

| Center | 2025 Dates (All dates except where noted) | Workshop/Meeting | Brief Summary of Activities and Data Activities Portfolio (Level) [and/or classroom use/implementation plans] |
|---|---|---|---|
| Brookhaven National Laboratory – Stony Brook University[a] | June 30-July 2 | Summer Coding Workshop | Intro to Coding<br>Probability<br>Position graphs<br>Exploring notebooks<br>CMS experiments<br>Teachers develop coding projects/implementation plans |
| Catholic University of America | April 21-22 | Cosmic Ray Detector | Installed detector at a local school, one QuarkNet teacher and several students participated |
| Colorado State University | No activity | | |
| Drew University | April 5 | **Masterclass** | Data Activities Portfolio:<br>Quark Workbench<br>Students in pairs conduct data analysis<br>Discussion of results |
| | February 22 | **Masterclass Orientation** | Data Activities Portfolio:<br>Shuffling the Particle Deck<br>Calculate the Z-Mass<br>Quark Workbench<br>Rolling with Rutherford<br>Intro to masterclass measurement |
| Fermilab/University of Chicago/College of DuPage[a] | July 29-31 | **CMS e-lab Workshop** (15 teachers) | CMS data activities<br>Data Activities Portfolio activities:<br>Histograms: the Basics<br>Histograms; Uncertainty<br>Calculate the Z-Mass<br>Implementation Plans and Discussion |

Note. National-led QuarkNet workshops are in a bold-face font. Compiled from agendas and final reports posted on QuarkNet website by individual center.
[a]Combined QuarkNet center

Table 5 (con't.)

**2025** QuarkNet Workshops and Meetings: National- and Center-led (November 2024-August 2025)

| **Center** | **2025 Dates (All dates except where noted)** | **Workshop/Meeting** | **Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans] |
|---|---|---|---|
| Florida International University | July 21-22 | Summer Workshop | Data Activities Portfolio:<br>Shuffling the Particle Deck<br>Rolling with Rutherford<br>Cosmic Watch Lab Suite<br>Making Tracks 1<br>Calculate the Mass of Z<br>Intro to World Wide Data Day measurement |
| Florida State University | July 24-25 | Summer Workshop | Data Activities Portfolio:<br>Cosmic Watches<br>Particle Transformation<br>How Speedy Are These Muons?<br>Develop and discuss Implementation Plans |
| Idaho State University | July 21-24 | Relativity and More Workshop | Data Activities Portfolio:<br>How Speedy Are These Muons?<br>Mean Lifetime Part 3: MINERvA<br>Energy, Momentum and Mass<br>MINERvA Masterclass<br>Implementation Plans<br>Cosmic Ray Detectors |
| Johns Hopkins University | July 22-26 | **JHU Workshop**<br>(14 teachers) | Morning Sessions: Talks and Presentations<br>Afternoon Sessions: Pathways and Lab Activities<br>DESMOS<br>Neutrinos<br>CMB Temperature/Rotation Curves<br>Raspberry Pi Muons<br>More new DAP activities<br>3D printing quarks<br>Lab activities (map torque, e/m, spec) |
| | March 29 | **LHC Masterclass**<br>(≈ 30 students) | |

Note. National-led QuarkNet workshops are in a bold-face font. Compiled from agendas and final reports posted on QuarkNet website by individual center.

Table 5 (con't.)
**2025** QuarkNet Workshops and Meetings: National- and Center-led (December 2024-August 2025)

| **Center** | **2025 Dates (All dates except where noted)** | **Workshop/Meeting** | **Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans] |
|---|---|---|---|
| Kansas State University | June 17-19 | **Cosmic Ray and NOvA Update Workshop** | Shuffling the Particle Deck<br>Signal & Noise: The Basics<br>Signal & Noise: Cosmic Muons<br>How Speedy are These Muons?<br>Mean Lifetime Part 1: Dice<br>Mean Lifetime Part 2: Cosmic Muons<br>Cosmic Watch Slides Physics Masterclasses in Africa and the World<br>Poster Session (created by teachers)<br>Develop and discuss implementation plans |
| | April 4 | **NOvA Masterclass** | NOvA Measurement Part 1 and Part 2<br>NovaPresentation_0.ppt<br>Nuclear Reactor tours |
| | February 22 | **Masterclass Orientation** | Preparation for NOvA masterclass |
| Lawrence Berkeley National Laboratory | June 16-20 | Physics in and Through Cosmology including 2-day Teacher Workshop (3 teachers plus 1 retired teacher and 43 students) | Data Activities Portfolio:<br>Shuffling the Particle Deck<br>Quark Workbench<br>Z Mass measurement prep<br>ATLAS or CMS event<br>How Speedy Are These Muons?<br>Muon Lifetime Part 2: Cosmic Muons<br>TOTEM Data Express<br>What Heinsberg Knew |
| Louisiana Tech University | March 14 | **ATLAS Masterclass** | Video conference with CERN<br>How to classify events<br>Classifying events<br>Video conference with Fermilab & other high schools |
| North Carolina A & T[c] | March 1 | **Intro to QuarkNet Workshop** | QuarkNet Basics<br>Data Activities Portfolio:<br>Shuffling the Particle Deck<br>Rolling with Rutherford<br>Calculate the Z Mass |

[c]Two teachers attended Data Camp. QuarkNet activities and information about center shared at the North Carolina Section of the AAPT 2025 Spring Meeting (March 29th).

Table 5 (con't.)
**2025** QuarkNet Workshops and Meetings: National- and Center-led (December 2024-August 2025)

| **Center** | **2025 Dates (All dates except where noted)** | **Workshop/Meeting** | **Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans] |
|---|---|---|---|
| Northern Illinois University | No activity | | |
| Oklahoma State University/University of Oklahoma<br>(combined QuarkNet center) | July 8-10 | **Summer Workshop** | Cosmic Ray experiment and data analysis<br>(Use detector, calibrate and analyze data)<br>Cosmic Ray e-Lab<br>Data Activities Portfolio:<br>Mean Lifetime Part 1: Dice<br>Mean Lifetime Part 2: Cosmic Muons<br>Careers in Physics (STEP-UP)<br>Implementation Plans |
| | No dates | **ATLAS Masterclasses** | Annual report indicated that 40 students participated |
| Purdue University | No activity | | |
| Purdue University Northwest | March 14 | **CMS Masterclass** | CMS particle identification<br>Data analysis by students<br>CMS Masterclass Presentation |
| Queensborough Community College | May-August | | Technical posters posted |
| Rice University/University of Houston<br>(conbined QuarkNet center) | June 11-13 | **Cosmic Watches/Quantum Data Workshop** | Intro to Cosmic Watches<br>Data Activities Portfolio:<br>Cosmic Watches<br>TOTEM 2<br>Heisenberg's Laser<br>Quantum Activity Concepts<br>Implementation Plans and Discussion |
| | June 9-10 | **Coding Workshop** | IRIS-HEP sponsored |
| | March 29 | **CMS Masterclass** | Detecting particles and analyzing CMS data<br>Data analysis and discussion |
| Rutgers University<br>(based on email from K. Cecire 9/8/2025) | July 7-11 | Student Workshop | Cosmic ray muon detector prep, collaboration and use during workshop |
| Southern Methodist University | July 15-17 | QuarkNet Workshop<br>(9 teachers) | Series of presentations and talks<br>Created cloud chambers and walked through 10 demonstrations appliable for classroom implementation. |

Note. National-led QuarkNet workshops are in a bold-face font. Compiled from agendas and final reports posted on QuarkNet website by individual center.

Table 5 (con't.)

**2025** QuarkNet Workshops and Meetings: National- and Center-led (December 2024-August 2025)

| **Center** | **2025 Dates (All dates except where noted)** | **Workshop/Meeting** | **Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans] |
|---|---|---|---|
| Syracuse University | August 11-13 | **QuarkNet Workshop** (6 teachers two of which were new) | Data Activities Portfolio:<br>Shuffling the Particle Deck<br>Rolling with Rutherford<br>Mean Lifetime Part 1: Dice<br>Mean Lifetime Part 2: Cosmic Muons<br>How Speedy Are These Muons?<br>Cosmic Watches<br>LHCb Masterclass<br>Posters created by teacher<br>Implementation Plans and Discussion |
| Texas Tech University | May 27-30 | Summer Experiences | Inside detector upgrades<br>Building the DREAM calorimeter<br>Exploring emergent properties in condensed matter |
| | June 4, 6 | Muon Detector | Relocation and setup at a local high school |
| University of Alabama | June 23-25 | **Coding Workshop** | Intro to Coding<br>Probability and Histograms using dice<br>Modeling Position vs. Time graphs – then with air resistance<br>Calculate the mass of a muon using CMS data<br>Time allocated to review/develop coding project from various notebooks<br>Implementation plan share-outs |
| University at Buffalo -SUNY | No activity | | |
| University of California Irvine | June 30-July 1 | **Workshop Cosmic Ray Muons** | Data Activities Portfolio:<br>Shuffling the Particle Deck<br>Signal & Noise: The Basics<br>Signal & Noise: Cosmic Muons<br>How Speedy Are These Muons?<br>Mean Lifetime Part 1: Dice<br>Mean Lifetime Part 2: Cosmic Muons<br>Intro to Cosmic Ray Muon Detector<br>Share-A-Thon<br>Implementation Plans and Discussion |

Table 5 (con't.)

**2025** QuarkNet Workshops and Meetings: National- and Center-led (December 2024-August 2025)

| **Center** | **2025 Dates (All dates except where noted)** | **Workshop/Meeting** | **Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans] |
|---|---|---|---|
| University of California – Santa Cruz[e] | March 15 | **Masterclass** (25 students) | Overview of data analysis techniques<br>Data analysis and particle detector demonstrations<br>Video conference with Fermilab |
| University of Cincinnati | July 28-30 | **LHCb Data Workshop** | Data Activities Portfolio<br>Quark Workbench<br>Mean Lifetime Part 1: Dice<br>Plotting a Consensus<br>Cloud Chambers<br>LHCb Masterclass<br>Implementation plans |
| University of Florida/Middle Florida | No activity | | |
| University of Hawai`i | March 17-19 | **Teacher Workshop** | Neutrino masses and oscillation<br>Intro to NOvA experiment<br>Cosmic ray physics and cosmic watches<br>Data Activities Portfolio<br>Shuffling the Particle Deck<br>Particle Transformations<br>NOvA Masterclass Measurement<br>Share out Cosmic Watch plans |
| University of Illinois at Chicago/Chicago State University[a]<br><br>(See 2025 Annual Report for listing of student presentations as well as summary of recent experiments and and findings.) | August 5-7 | **Summer Workshop** | Data Activities Portfolio:<br>Shuffling the Particle Deck<br>What are Neutrinos?<br>The Case of the Hidden Neutrinos<br>Intro to coding<br>Research using coding<br><br>CME work<br>Detector maintenance<br>Intro to Cosmic Ray Muon Detector<br>Implementation Planning |

Note. National-led QuarkNet workshops are in a bold-face font. Compiled from agendas and final reports posted on QuarkNet website by individual center.
[a]Combined QuarkNet center. [e]A local high school's physic class was visited where a small group led a BAMA activity in the classroom.

Table 5 (con't.)

**2025** QuarkNet Workshops and Meetings: National- and Center-led (December 2024-August 2025)

| **Center** | **2025 Dates (All dates except where noted)** | **Workshop/Meeting** | **Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans] |
|---|---|---|---|
| University of Iowa/Iowa State | No activity | | |
| University of Kansas | No activity | | |
| University of Maryland | August 11-12 | **Summer Workshop** | Introducing the Data Activities Portfolio<br>Calculate the Mass of Z<br>Intro to coding (Jypter, Python)<br>Select physics presentations<br>LHCb Masterclass<br>Lifetime measurement<br>Implementation plans |
| University of Minnesota | July 28-30 | **Summer Workshop** | Data Activities Portfolio<br>Shuffling the Particle Deck<br>Rolling with Rutherford<br>How Speedy Are These Muons?<br>Intro to Cosmic Watches and CRMDs<br>Mean Lifetime Part 1: Dice<br>Mean Lifetime Part 2: Cosmic Muons<br>Posters created by teachers<br>Implementation Plans and Discussion |
| | April 5 | **NOvA Masterclass** | NOvA Measurement Far Detector<br>Cloud Chamber<br>Liquid Nitrogen (Superconductors and Magnets(<br>NOvA Measurement Near Detector with Coding |
| University of Mississippi | July 25-26 | Summer Workshop | Several tours were scheduled. |
| University of New Mexico | July 14-15 | **Detector Workshop** | Data Activities Portfolio:<br>Shuffling the Particle Deck<br>Rolling with Rutherford<br>Cosmic Watch & Cloud Chambers<br>World Wide Data Day measurements<br>Share-A-Thon<br>Nuclear lab tours<br>Posters created by teachers |

Table 5 (con't.)
**2025** QuarkNet Workshops and Meetings: National- and Center-led (December 2024-August 2025)

| Center | 2025 Dates (All dates except where noted) | Workshop/Meeting | Brief Summary of Activities and Data Activities Portfolio (Level) [and/or classroom use/implementation plans] |
|---|---|---|---|
| University of Notre Dame | June-July | **Summer Research Projects** | Six week research program involving 16 students and 10 teachers |
| | September-May | **Weekly Meeting** | Each meeting focused on a combination of mutual support in teaching, planning for activities, and discussion of a wide variety of physics and non-physics topics. |
| | March 13 | **CMS Masterclass** | Intro to CMS Masterclass Measurement<br>CMS Masterclass Measurement |
| University of Oregon | June 20 | Summer Workshop (6 teachers) | Series of presentations<br>Roundtable on teacher projects, plans, advice. |
| University of Puerto Rico - Mayaguez | Participated in a series of coding workshops sponsored by IRIS-HEP | | |
| | March 22 | MINERvA Neutrino Masterclass | 15 teachers and 24 students participated |
| | March 1 | MINERvA Neutrino Masterclass Orientation | 19 teachers participated |
| ~~University of Rochester~~ | | | |
| University of South Dakota | April 4 | **NOvA Masterclass** | Data Activities Portfolio:<br>Shuffling the Particle Deck<br>Intro to Measurement<br>Measuring Far and Near Detectors |
| University of Washington | June 23-25 | **Cosmic Ray Workshop** | Intro to QuarkNet<br>Cosmic Ray e-Lab (mini-workshop or student research project support)<br>Mean Lifetime Part 1: Dice<br>Teacher Discussion<br>Implementation Plans |
| | March 29 | **ATLAS Z Path Masterclass** | Measurement and analysis by students |

Table 5 (con't.)

**2025** QuarkNet Workshops and Meetings: National- and Center-led (December 2024-August 2025)

| **Center** | **2025 Dates (All dates except where noted)** | **Workshop/Meeting** | **Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans] |
|---|---|---|---|
| Vanderbilt University | No activity | | |
| Virginia Center (Hampton University, the College of William and Mary, and the George Mason University)[a] | July 28-29 | **Summer Workshop** | Data Activities Portfolio:<br>Making Tracks I<br>Cosmic watch lab<br>Create and present implementation plans |
| Virginia Tech | July 30-August 1 | **Summer Workshop** | Intro to Cosmic Ray & Comic Watches<br>What is QuarkNet?<br>Data Activities Portfolio:<br>Cosmic Watch activities<br>MINERvA Masterclass measurement<br>Present implementation plans |
| Virtual Center | August 4-5 | **Summer Workshop** | Data Activities Portfolio:<br>How Speedy Are These Muons?<br>Mean Lifetime Part I: Dice<br>Mean Lifetime Part II: Cosmic Muons<br>Energy, Momentum and Mass<br>Z mass spreadsheet<br>Implementation Plans and Sum Up |
| | (9/22/24; 10/20/24; 12/8/24; 2/23/25; 3/23/25; 4/27/25; 6/24/25) | Series of Sunday Evening Meetings | Various topics relevant to group |
| Data Camp | July 14-18 | **Week long camp** | Introduction to the Standard Model<br>Introduction to coding<br>Particle physics note pads and coding notebooks<br>Various tours (virtual and in-person)<br>Data Activities Portfolio: Top Quark and others<br>Milestone 1-4 project preparation and posters<br>Share out of implementation |

Note. National-led QuarkNet workshops are in a bold-face font. Compiled from agendas and final reports posted on QuarkNet website by individual center.

[a]Combined QuarkNet center

# **Inform Outcomes Analyses** (Sections 6-9)

## 6. Linking Program Strategies to Outcomes

We begin this section by a recognition that fundamentally, evaluation efforts have focused on linking program engagement to measured outcomes. We have assessed program engagement through exposure to core strategies that occurs through various program events and implemented across centers. We do this in the spirit of congressional testimony given by Senta Raizen in 1991 where she noted that little, if anything, is gained if we don't know what has led to the outcomes we measure.

Appendix G provides in detail, as outlined in the PTM, how core strategies link to program outcomes. The first of the two tables in Appendix G reflect this alignment, first by showing the alignment of program anchors – that is, effective professional development, NGSS standards and guided inquiry – with core strategies. This table (based on the PTM) presents the grounding of these program strategies as suggested by the educational research literature.

The overarching strategy of the program is the recognition that QuarkNet is not static but evolves to reflect changes in particle physics and the education context in which it operates. Two big-picture strategies relate to opportunities for teachers to be exposed to instructional strategies that model active, that is, guided-inquiry learning, and big ideas in science and enduring understandings. Strategies directed toward teachers include: *Engage as active learners, as students;* and *Discuss the concept of uncertainty in particle physics.* There are two strategies that relate to local centers, these are: *Interact with other scientists and collaborate with each other*; and *Build a local (or regional) learning community*.

The next table in Appendix G shows the logical links between core strategies and program outcomes. As shown, these outcomes are organized by "target audience," including Teachers, their Students, and Local Centers. Of importance, teacher outcomes are directed toward how teachers translate their experiences into instructional strategies, which reflect guided inquiry and NGSS science and engineering practices and other science standards such as AP, as applicable and to the extent possible in their school setting. These outcomes include: *Discuss and explain concepts in particle physics;* and, *Use instructional practices that model scientific research.* Outcomes directed toward their students include: *Use, analyze and interpret authentic data; draw conclusions based on these data.* Long-term (teacher) outcomes: include use of resources, increased science proficiency, develop collegial relationships, and their students become more comfortable with inquiry-based science.

Exhibit F provides an overview of the program and evaluation outcomes data.

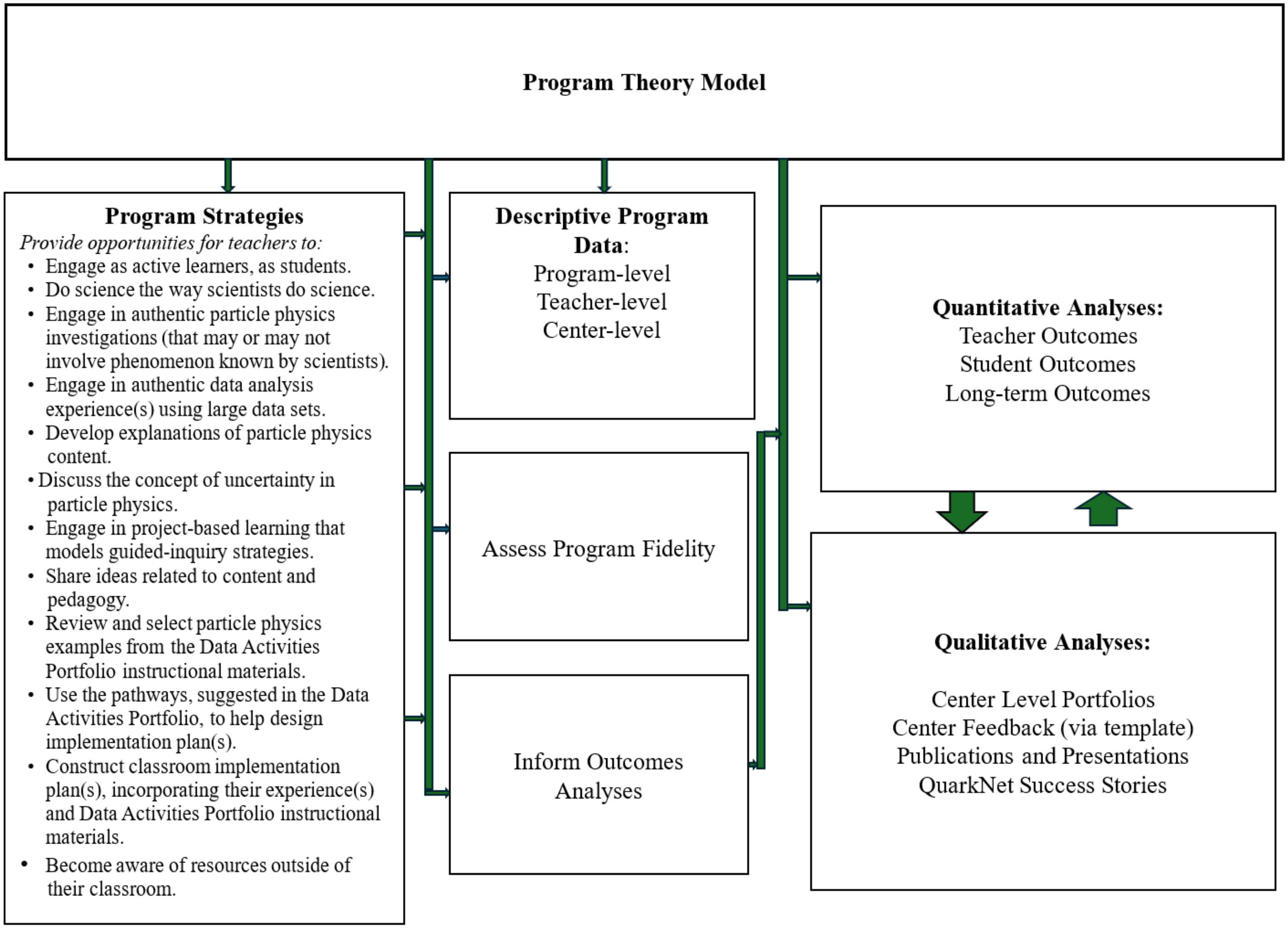



Exhibit F. Overview of Program and Outcomes Data

**Sources of Outcomes Data**

**Teacher Full Survey**
Primary Focus: Quantitative analyses of teacher, student, and long-term outcomes
**Update Survey**
Primary Focus: Qualitative analyses of QN content and material use in classrooms
**Center Feedback Process and Template**
Primary Focus: Comparing center-level and teacher-level responses
**Virtual Workshop Visits by Evaluator**
Primary Focus: Implementation plan discussions

**Multiple Sources of Information: Evidence of Program Engagement/ Alignment with PTM**

**Workshop Summary Table compiled from:**
Workshop Agendas
Annual Reports from Centers
**Data Activities Portfolio alignment with:**
NGSS Science Practices
Workshop Engagement
Enduring Understandings
**Acknowledge and Review other Information**
(e.g., cosmic ray studies, use of comic watches, professional presentations; masterclasses; student-collected data)

Exhibit G. Summary of Evaluation Measures and Program Engagement

Outcomes directed toward local centers include Teachers as Leaders, such as: *Act in leadership roles in local centers and in their school (and school districts) and within the science education community.* There are outcomes directed toward Mentors, such as: *Become the nexus of a community that can improve their teaching, enrich their research and provide broader impacts for their university*; and Teachers and Mentors such as: *Form lasting collegial relationships through interactions and collaborations at the local level and through engagement in the national program.*

Exhibit G provides an overview of the sources of outcomes data and the multiple sources of information in support of program engagement and alignment with the PTM. Collectively, this information is used to assess program fidelity (implementation vs. designed) and to help link exposure to core strategies to program outcomes. As will be seen in subsequent sections of this report, program outcomes directed toward teachers are measured by a Full Teacher Survey (followed by a short update) distributed on an annual basis. And program outcomes related to mentors and interactions between mentors and teachers have been captured in a Center Feedback Template (as well as sustainability outcomes). The Center Feedback Template serves a dual-role, to provide the context in which teachers receive the implemented program; and, to serve as a center-level outcome measure in its own right. These principal evaluation measures are supported, for example, by links to program operations data such as implemented workshop agendas and implementation plans developed by participating teachers (when available). In addition, the external evaluator conducts virtual visits of workshop discussions by teachers on proposed implementation plans and how QuarkNet content and materials may be used in their classrooms.

The sustainability framework is used to guide the assessment of the engagement of centers in the QuarkNet program and how factors related to this activity may help in the longevity of the center's broader impacts. It may also serve to better illuminate the context in which teachers engage in the QuarkNet program.

Finally, it is important to note that the designed and ultimately the implemented program are strategy-based in part because of the recognized need for flexibility in conducting workshops and events across 50+ centers (currently 57 centers). Program strategies offer guidelines and guard rails encouraging program versatility within these. There is not a prescriptive "recipe" of specific workshops/events and classroom activities but rather a family of workshop options and classroom-activities engagement (first by teachers and then their students through the Data Activities Portfolio) that can be implemented. Strategies increase the likelihood of providing teachers with professional development that reflects their individual -- as well as center -- needs and at the same time provide a framework that aligns with effective practices reflected in the educational research literature.

**Development of Evaluation Measures and Evaluation Plan**

Evaluation measures used to assess teacher-level, student-level and long-term outcomes were developed or adopted to align with the measurable outcomes listed in the PTM. Evaluation measures were supported by program operations data, annual reports submitted by participating centers, virtual site visits by the evaluator during implementation plan discussions at workshops, posted implementation plans, and examples of teacher and/or student work when available to help provide the context in which this assessment has occurred. (See Exhibit G.)

Details as to the content of each of these measures are provided in Appendix G. (The Full Survey is shown in Appendix H; the Update Survey is presented in Appendix I; and the Center Feedback Form, discussed later, is shown in Appendix J.) Statistics supporting the use of core strategies and outcomes scores are presented in Appendix K.

Over the course of these evaluation efforts during two grant periods, we have focused first on providing results from quantitative analyses that link program engagement (core strategies) to program outcomes. With time, we have added to these results through qualitative analyses that highlight survey responses by teachers as to how they have used or planned to use QuarkNet content and materials in their classrooms; examples of teacher work, student work, specific examples of implementation plans proposed by teachers; staff/teacher/student presentations at professional conferences; and success story scenarios by staff, teachers and students as to how QuarkNet engagement has influenced their academic and professional development.

Table 6
Summary of QuarkNet Teacher Enrollment and Survey Response Rate
by Program Year

| Program Year[h] | Number of Enrolled Teachers | Number of Completed Surveys | Total |
|---|---|---|---|
| 2025 | 306 | 239[g] | 78% |
| 2024 | 302 | 251[f] | 83% |
| 2023 | 330 | 257[e] | 78% |
| 2022 | 281 | 224[d] | 80% |
| 2021 | 242 | 192[c] | 79% |
| 2020 | 251 | 181[b] | 72% |
| 2019 | 311 | 242[a] | 78% |

[a]An additional 78 teachers who participated in QuarkNet in 2018 *but not* in 2019 were contacted via email and asked to participant in the survey. A total of 22 of these teachers completed the survey for a response rate of 28%. (These totals are not reflected in the above table.) Thus, a total of 264 teachers responded to the survey.
[b]In 2020, 91 teachers completed the full survey and 90 teachers completed the update survey.
[c]In 2021, 68 teachers completed the full survey and 124 teachers completed the update survey.
[d]In 2022, 76 teachers completed the full survey and 148 teachers completed the update survey.
eIn 2023, all teachers completed the full survey to coincide with the renewal grant award.
[f]In 2024, 135 teachers completed the full survey and 116 teachers completed the update survey.
[g]In 2025, 81 teachers completed the full survey and 158 completed the update survey.
[h]Program year numbers are unique for each program year.

## 7. Survey Implementation and Response Rates

A summary of enrollment numbers and survey response rates is shown in Table 6. For each year, participating teachers completed the survey at the time of the workshop program; or, after one email reminder. We believe the reason behind the high response rate for participating teachers is that the survey was administered face-to-face during 2019 workshops and programs; at the time of the workshop or program mostly in a virtual environment for 2020 and 2021; and, again in 2022 through 2025 during in-person workshops. (See for example footnote a in Table 6 for a comparison of response rates for 2018 vs. 2019 that supports this claim.) Thus, the credit for this high response rate is due to the commitment of the staff and facilitators of QuarkNet; we are thankful for it.

**Raw Data**

For each program year, raw data were downloaded from Survey Monkey via an Excel spreadsheet and exported to SPSS (Statistical Package for the Social Sciences, Version 28) for subsequent analyses. Although the survey is accessible to teachers by a link, raw data are only accessible via a specific Survey Monkey account.

Data were reviewed, cleaned, and new variables were created to facilitate data analysis, when necessary. (These data manipulations are described in the analysis sections of this report.) When a teacher self-identified and completed both surveys (full and update)

2019 through 2025 survey responses were linked so that year-to-year self-reports of QuarkNet content and materials used or planned to be used could be made.

A total of 782 QuarkNet teachers completed their full survey; this represents a unique count of teachers across the 2019-2025 program years. As this is a unique count, this does not represent the number of times teachers have completed a survey across multiple years. We estimate that we have gathered nearly 1,600 surveys over the course of this time period.

In addition to completed full surveys, 615 Update Surveys were completed across the 2020 through 2022 program years and in 2024 through 2025 program years. During the 2023 program year, a total of 257 teachers participated in QuarkNet and completed their survey. (All teachers were asked to complete the full survey in concert with the new grant period.) Of these 105 of these teachers were *new* to the survey process. In the 2024 program year, a total of 96 teachers were reported as new to the program (presenting about 32% of participants in that program year). Of these, 66 new teachers completed their full survey. In the 2025 program year, a total of 84 teachers were reported as new to the program (representing about 27% of participants in that program year). Of these, 81 new teachers completed their full survey.

## 8. Summary of QuarkNet Teachers: Demographics

### Gender of Teachers

The gender of participants is broken down in Table 7 using a unique count of the total number of QuarkNet teachers who participated during the 2019-2025 program years and who completed the full Teacher Survey. A total of 726 teachers responded to this question -- 56 teachers did not indicate their gender – for a total of 782 teachers. Of note, survey responses labeled as 2020 through 2025, reflect teachers who were *new* to QuarkNet survey (starting in 2019). These teachers may or may not be new to the QuarkNet program per se as will be discussed subsequently. Over the course of these program years, 49% of participating teachers are men (384); 44% are women (342) and 7% did not provide an answer to this question (based on survey responses). As evidence in Table 7 there has been an increase in the number of women who are engaged in QuarkNet as the program approaches gender parity, reflecting a statistically significant shift in these numbers over time.

Registration information from the 2024 and 2025 program years suggest similar percents; that is for the 2024 program year, 48% of teachers are men, 47% are women and 5% preferred not to answer this question. For the 2025 program year, 49.7% are men, 49.3% are women; and 1% prefer not to answer.

### Teachers *New* to QuarkNet

In Appendix L two tables represent a unique count of teachers who reported that they were new to the QuarkNet program, Table L-1 showing new teachers that participated in QuarkNet during the 2019-2022 program years by center. Table L-2 includes a similar

Table 7
Full Teacher Survey: Gender of QuarkNet Teachers

| Program Year: Unique Count | Gender | | | | | | Total | |
|---|---|---|---|---|---|---|---|---|
| | Men | | Women | | Not Specified | | | |
| *(new to survey)* 2025 | 34 | (42.0) | 36 | (44.5) | 11 | (13.5) | 81 | (100%) |
| *(new to survey)* 2024 | 32 | (35%) | 42 | (46%) | 17 | (19%) | 91 | (100%) |
| *(new to survey)* 2023 | 45 | (35%) | 60 | (47%) | 23 | (18%) | 128 | (100%) |
| *(new to survey)* 2022 | 42 | (55%) | 34 | (44%) | 1 | (1%) | 77 | (100%) |
| *(new to survey)* 2021 | 41 | (60.3%) | 24 | (35.3%) | 3 | (4.4%) | 68 | (100%) |
| *(new to survey)* 2020 | 33 | (42.5%) | 46 | (57.5%) | 0 | (0%) | 79 | (100%) |
| 2019 | 157 | (60.8%) | 100 | (38.7%) | 1 | (<.05%) | 258 | (100%) |
| Total | 384 | (49.1%) | 342 | (43.7%) | 56 | (7.2%) | 782 | (100%) |

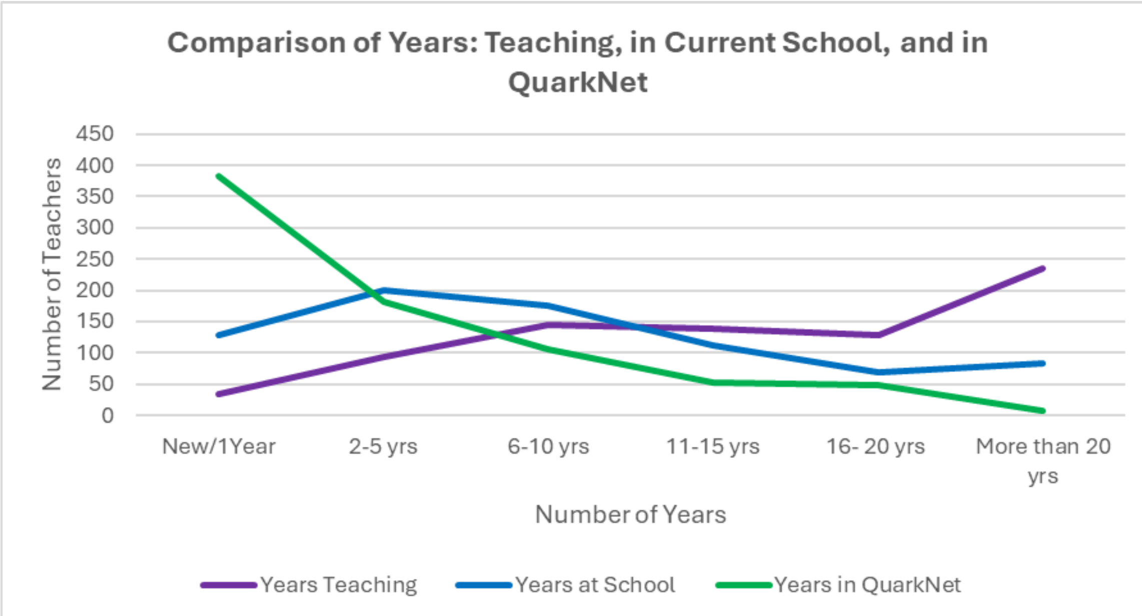
Note. Please note that this represents a unique count of teachers. Numbers for 2020-2025 do not represent the total number of teachers who participated in QuarkNet for each of these program years. *New* means new to the survey process not necessarily new to QuarkNet. A total of 56 survey respondents did not specify their gender. [$\chi^2_{(6,\ 726)} = 21.26$, $p < .01$ (comparing gender across program years).]

breakdown for the 2023-2025 program years. These counts are based on survey responses for a unique count total of 782 across the two tables. These data were based on a question, framed in an open-ended format, teachers were asked, *For how many years (approximately have you participated in QuarkNet (including today or your most recent participation)?*

Most often, new teachers either indicated that they were new; or had participated for one year or less in the program. When describing their participation as in and around one year, teachers frequently indicated that the workshop in question was their first. For this reason, the table includes both "new" and "1-year" responses as a representative number of new teachers. As indicated in Appendix L, counts are broken down by QuarkNet center.

A total of 36% of teachers who participated in QuarkNet during the 2019-2022 program were new/1-year in the program. In the 2023 program year, 33% of participants were new/1-year in the program. In the 2024 program year, the full survey was able to gather data on 66 of these teachers out of a total of 199 surveys – this also represents about 33% of participating teachers. In the 2025 program year, the full survey added 81 additional teachers to the survey data, of these 74% of participating teachers were new to QuarkNet – but as noted below survey responses likely overrepresented participating teachers for this year.

Starting in the 2024 program year, a more complete profile of teachers *new* to QuarkNet based on registration/stipend information was available. Using this information a total of 96 out of the 302 teachers participating in 2024 were new to the program (or 32%); very similar to results based on survey responses. In the 2025 program year, based on registration/stipend information, 84 out of 306 teachers (or 27%) of participating teachers were new to QuarkNet. For 2025 numbers, the registration information is more representative of the percent of teachers new to the program for that year.



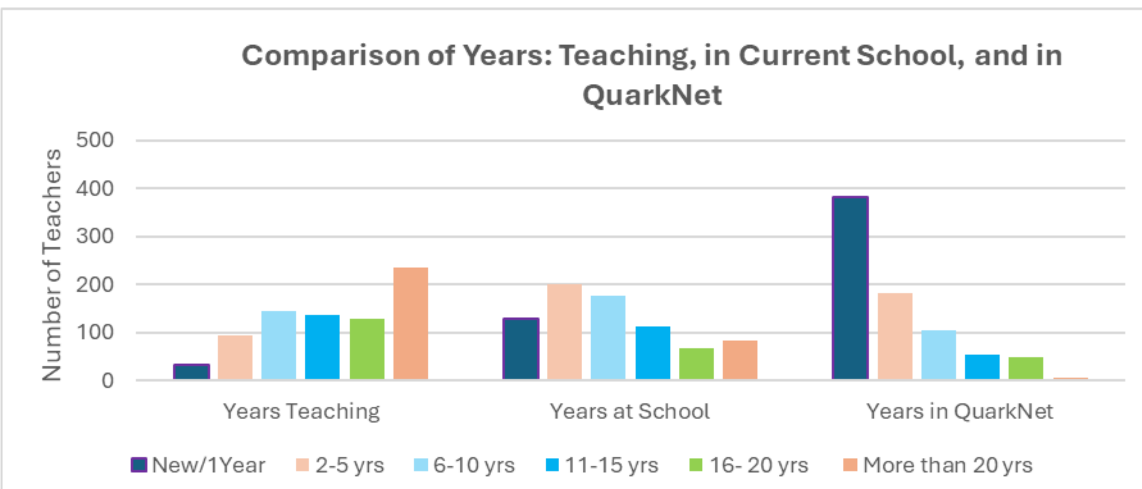




Figure Set 4. Comparison of the number of years: Teaching; at current school; and participating in QuarkNet (at the time the teacher completed his or her full survey).

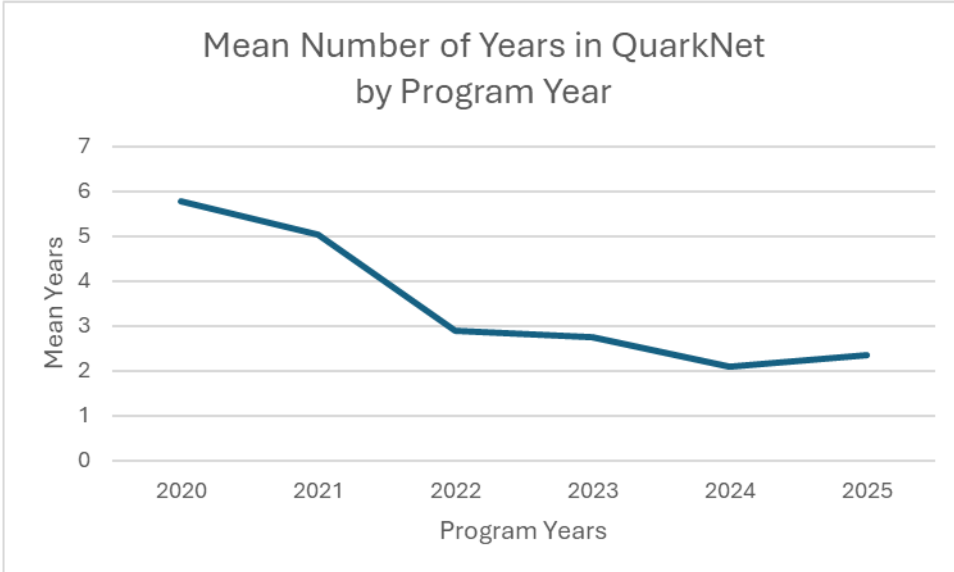



Figure 5. Over several program years, QuarkNet has been trending toward bringing in *new* teachers to the program (based on a unique count of teachers each year for a total of 782 teachers).

**Years in QuarkNet, Years Teaching and Years at Current School**

Figure Set 4 (previous page) displays the number of years teaching, years at current school compared to years in QuarkNet for participating teachers. The mean number of years in QuarkNet was 4.37 years (Standard Deviation, SD = 5.50), with a median of 2.0 years (50$^{th}$ percentile).

Collectively, these teachers had a mean number of years teaching of 16.07 years (SD= 10.11) (median 15.0 years); and a mean of 9.17 years at his/her school (SD = 8.02) (7.0 median years); with a few participating teachers who are retired.

The number of years a teacher has participated in QuarkNet is statistically related to teacher's gender and the program year in which a survey response is captured. In a 2 x 7 Analysis of Variance (ANOVA, Gender =2 and Program Year = 7), male teachers reported a higher mean number of years in QuarkNet (5.14; SD = 5.80) compared to female teachers (Mean = 3.46; SD =4.74) [$F_{(1, 710)} = 8.32$, $p < .01$]. Over the course of 2019 through 2025 program years, the number of years of QuarkNet participation is trending down from a high: (Mean = 6.23, SD=5.53) reported in program year 2019 to a low: (Mean 2.35, SD= 3.93) reported in program year 2025 [$F_{(6, 710)} = 12.49$, $p < .001$]. (See Figure 5 for this trend line.)

As one would expect, the number of years teaching and years at current school is positively correlated and notably high (r = .64); slightly lower but still high was the positive correlation between years teaching and QuarkNet experience (r = .43); and, years at current school and QuarkNet experience (r = .39).

Table 8
QuarkNet Teachers: School Location and Teaching Physics

| Demographic | Program Year: Unique Count | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | Total |
| **School Location** | | | | | | | | |
| Rural | 48 (19.0%)[a] | 15 (19.5%) | 16 (23.9%) | 12 (15.6%) | 23 (18.1%) | 19 (21.1%) | 12 (16.0%) | 145 (18.9%) |
| Suburban | 124 (49.0%) | 37 (48.0%) | 12 (17.9%) | 8 (10.4%) | 16 (12.6%) | 6 (6.7%) | 12 (16.0%) | 216 (28.2%) |
| Urban | 49 (19.4%) | 15 (19.5%) | 7 (10.4%) | 25 (32.5%) | 32 (25.2%) | 25 (27.8%) | 17 (22.7%) | 170 (22.1%) |
| Urban, Central City | 32 (12.6%) | 10 (13.0%) | 32 (47.8%) | 32 (41.5%) | 56 (44.1%) | 40 (44.4%) | 34 (45.3%) | 236 (30.8%) |
| Total | 253 (100%) | 77 (100%) | 67 (100%) | 77 (100%) | 127 (100%) | 90 (100%) | 75 (100%) | 766 (100%) |
| **Teach Physics?** | | | | | | | | |
| Yes | 223 (87.5%)[a] | 57 (73.1%) | 47 (69.1%) | 59 (77.6%) | 89 (70.1%) | 69 (76.7%) | 54 (73.0%) | 598 (78.4%) |
| No | 32 (12.5) | 21 (26.9%) | 21 (30.9%) | 17 (22.4%) | 38 (29.9%) | 21 (23.3%) | 20 (27.0%) | 170 (23.0%) |
| Total | 255 (100%) | 78 (100%) | 68 (100%) | 76 (100%) | 127 (100%) | 90 (100%) | 74 (100%) | 695 (100%) |

aColumn percent totals

Please note that this represents a unique count of teachers. Numbers in each year (2020 through 2025) **do not** represent the total number of teachers who participated in QuarkNet for each of these program years. *New* means new to the survey process not necessarily new to QuarkNet. Sixteen teachers did not indicate the location of their school. And fourteen teachers did not indicate whether or not they were teaching physics at the time they completed their survey.

## School Location

Teachers were asked the best descriptor for the location of the school they represented. As shown in Table 8, across the program years the location of the school represented by participating QuarkNet teachers have tended away from suburban locations to schools located in urban and urban, central city areas. In total, most participating QuarkNet teachers represent schools located in urban, central city areas (216 or 28.2%); followed by suburban locations (216 or 28.2%); while the percent of urban locations (170 or 22.1%) and rural locations (145 or 18.9%) tended to remain flat over this time period. This trend is statistically significant [$\chi^2_{(18, 766)} = 165.67$, $p$ <.001]. School location was not statistically related to the gender of participating teachers.

Table 8
QuarkNet Teachers: School Location and Teaching Physics

| Demographic | Program Year: Unique Count | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | Total |
| **School Location** | | | | | | | | |
| Rural | 48 (19.0%)[a] | 15 (19.5%) | 16 (23.9%) | 12 (15.6%) | 23 (18.1%) | 19 (21.1%) | 12 (16.0%) | 145 (18.9%) |
| Suburban | 124 (49.0%) | 37 (48.0%) | 12 (17.9%) | 8 (10.4%) | 16 (12.6%) | 6 (6.7%) | 12 (16.0%) | 216 (28.2%) |
| Urban | 49 (19.4%) | 15 (19.5%) | 7 (10.4%) | 25 (32.5%) | 32 (25.2%) | 25 (27.8%) | 17 (22.7%) | 170 (22.1%) |
| Urban, Central City | 32 (12.6%) | 10 (13.0%) | 32 (47.8%) | 32 (41.5%) | 56 (44.1%) | 40 (44.4%) | 34 (45.3%) | 236 (30.8%) |
| Total | 253 (100%) | 77 (100%) | 67 (100%) | 77 (100%) | 127 (100%) | 90 (100%) | 75 (100%) | 766 (100%) |
| **Teach Physics?** | | | | | | | | |
| Yes | 223 (87.5%)[a] | 57 (73.1%) | 47 (69.1%) | 59 (77.6%) | 89 (70.1%) | 69 (76.7%) | 54 (73.0%) | 598 (77.9%) |
| No | 32 (12.5) | 21 (26.9%) | 21 (30.9%) | 17 (22.4%) | 38 (29.9%) | 21 (23.3%) | 20 (27.0%) | 170 (22.1%) |
| Total | 255 (100%) | 78 (100%) | 68 (100%) | 76 (100%) | 127 (100%) | 90 (100%) | 74 (100%) | 768 (100%) |

aColumn percent totals

Please note that this represents a unique count of teachers. Numbers in each year (2020 through 2025) **do not** represent the total number of teachers who participated in QuarkNet for each of these program years. *New* means new to the survey process not necessarily new to QuarkNet. Sixteen teachers did not indicate the location of their school. And fourteen teachers did not indicate whether or not they were teaching physics at the time they completed their survey.

## Teaching Physics

As reflected in Table 8, across program years, a total of 78.4% of teachers reported that they teach physics. Over the course of program years, there was a tendency for more teachers to report that they are not teaching physics [$\chi^2_{(6, 768)} = 23.22$, $p < .001$] from a percent range of a high of 88% to a low of 69%. Slightly more female teachers do not teach physics as compared to male teachers [$\chi^2_{(1, 715)} = 23.88$, $p < .001$]. Other fields mentioned include Chemistry, Physical Science, Earth Sciences, Biology, Statistics, Math.

It is important to note that these survey results present a snapshot in time as to where and what a given teacher is teaching. Given that teachers often participate in QuarkNet frequently over the course of many program years, these data and results do not reflect this fluidity (e.g., scheduling changes for a given teacher at the same school over school years; or a change of schools during this time period). When changes occur, these are at times reflected in the open-ended comments made by teachers when they complete their shorter, update surveys; but even here these changes are likely under-reported and reflect a moment in time.

Table 9
Which Workshop or Program?

| Workshop/Program | Num. Teachers | Workshop/Program | Num. Teachers |
|---|---|---|---|
| Data Camp | 232 | Cosmic Ray e-Lab Advanced Topics | 38 |
| ATLAS | 60 | Neutrino Data Workshop | 137 |
| CMS Data Workshop | 121 | ATLAS Masterclass | 70 |
| CMS e-Lab Workshop | 103 | CMS Masterclass | 133 |
| Cosmic Ray e-Lab Intro | 222 | Neutrino Masterclass | 62 |
| **Other QuarkNet Events** | | | |
| International Muon Week | 41[a] | International Cosmic Day | 37[a] |
| CERN | 57 | World Wide Data Day | 29[a] |
| Greece Trip | 13 | | |
| Coding Workshops/Coding Camp 1 and Coding Camp 2[b] | | | 147[b] |

Note. Multiple responses were allowed.
[a]Since the main vehicle for gathering survey responses from teachers is through workshop participation, it is likely that some of these counts underestimate the actual number of teachers who participate in other programs, such as masterclasses or special events.
[b]Early exposure to coding was embedded in workshops that also included other physics content such as neutrino data and/or CMS updates (2020-2025). Portions of these events was sponsored by IRIS-HEP.

**QuarkNet Participation**

Teachers were asked to select the QuarkNet workshops or programs where they were participants. These responses are summarized in Table 9. Clearly, a workshop (workshops collectively) is the most frequently mentioned QuarkNet program. Given that multiple responses are allowed, summing these numbers would not provide a unique count of teachers (although each total is based on a unique count of teachers). As to specific programs, most often, teachers indicated that they had participated in Data Camp (232) and Cosmic Ray e-Lab introduction (222). Participation in (a variety of) workshops and masterclasses is noteworthy.

It is important to note that the value of Table 9 is in our ability to gauge the type and degree of QuarkNet engagement by teachers as this relates to their perceived assessment of exposure to strategies core to the program. Another way to say this is, at the time that they evaluated their exposure to core program strategies what had their past (and immediately present) engagement in QuarkNet looked like. Table 9 *is not* a program operations data table indicating participation totals for a particular program year or across this grant period.

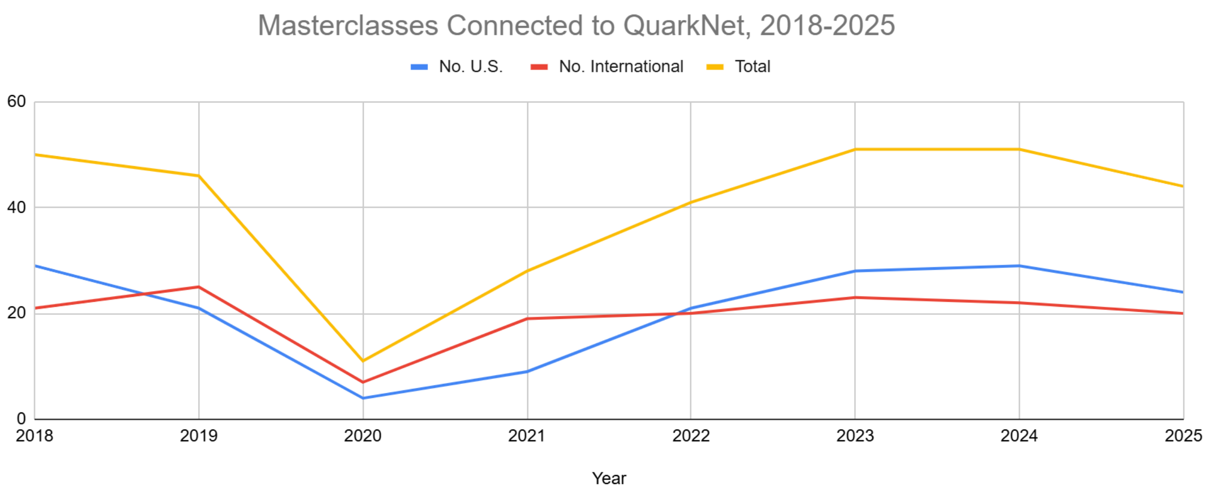



Figure 6A. QuarkNet Masterclasses by program year (data from K. Cecire, 2025).

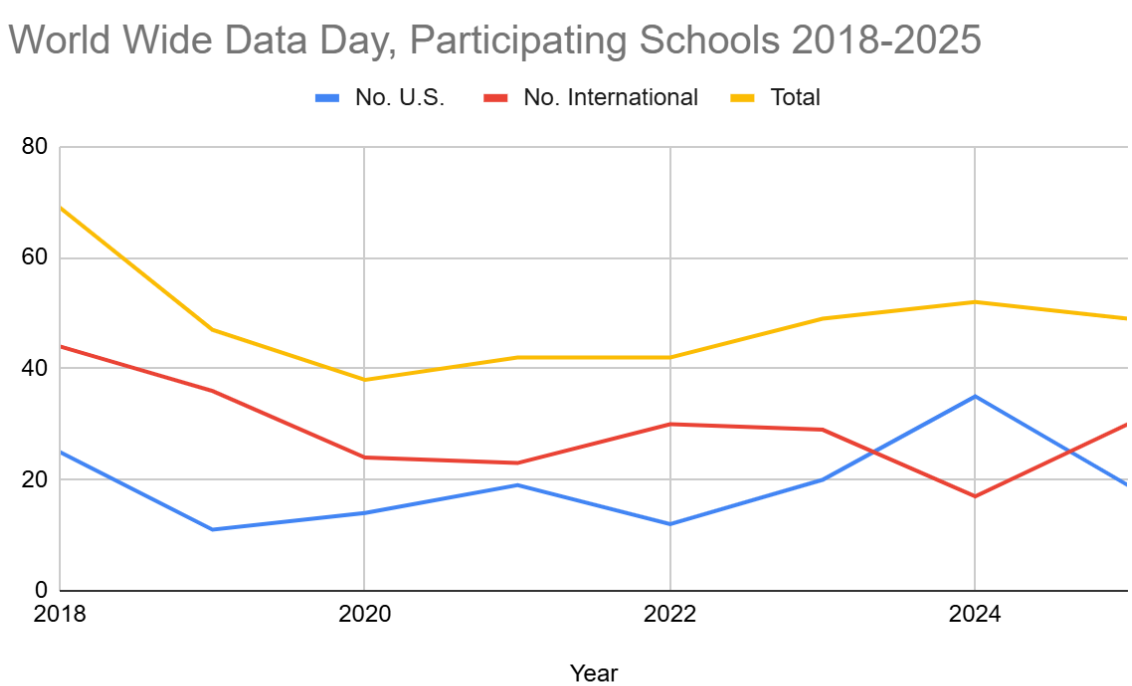



Figure 6B. QuarkNet Word Wide Data Day by program year (data from K. Cecire, 2026).

<u>QuarkNet Participation Beyond the Survey: Masterclasses and e-Labs.</u> It is noteworthy that workshops are the principal vehicle in which professional development is provided to participating QuarkNet teachers (supported by other opportunities as well); it is also the principal means by which survey responses are collected. Thus, these data may overrepresent workshop participation and undercount engagement in other types of QuarkNet events.

Table 10A
High School Long-term Collaboration Using
High Energy Physics Model

| Time Period | DAQs (Data Acquisitions) [a] | Uploads | Analyses Run[c] |
|---|---|---|---|
| Apr-Oct 2019 | 66 | 2,173 | -- |
| Apr-Oct 2020[b] | 27 | 2,733 | 2,182 (from 26 DAQs) |
| Apr-Oct 2021 | 42 | 2,871 | 4,300 (from 30 DAQs) |
| Apr-Oct 2022 | 55 | 3,513 | 5,055 (from 34 DAQs) |

Note. Data compiled by M. Adams used with permission (email Adams 1/31/23)
[a]DAQ measurement/experiments using Cosmic Ray Muon Detectors.
[b]These reporting periods were used because of COVID and remained consistent over a 3-year period.

Table 10B
High School Long-term Collaboration Using
High Energy Physics Model

| Time Period | DAQs (Data Acquisitions) [a] | Uploads | Analyses Run |
|---|---|---|---|
| Nov 2021-Oct 2022 | 68 | 6,667 | 85,943 (not reported) |
| Nov 2022 -Oct 2023 | 59 | 6,577 | 38,997 (from 96 DAQs) |
| Nov 2023-Oct 2024 | 69 | 6,339 | 36,940 (from 92 DAQs) |
| Nov 2024-Oct 2025 | 47 | 3,812 | 29,496 (from 87 DAQs) |

Note. Data compiled by M. Adams used with permission (email 2/18/26). The definition of the analysis metric changed in 2022 to be (analyses)*(files in each analysis). It cannot be directly compared to the analysis in the previous 3-year period (email Adams 3/4/25).
[a]DAQ measurement/experiments using Cosmic Ray Muon Detectors.

To offer a sense of the wider implementation of QuarkNet programs and materials we present the following. As to likely undercounts, survey responses on coding program engagement were not representative of actual participation levels. Thus, as noted, we report the participant level as reflected in a number reported by Adam LaMee in the renewal proposal to NSF. In addition, two graphs created by Cecire show the level of participation in masterclass and world wide data day across program years.

Figure 6A (displayed here with permission, Cecire email 11/4/2025) shows the number of QuarkNet masterclasses held over the course of the current grant. Although the number of events and not teachers are provided, this graph offers a representative picture of the possible opportunities for QuarkNet teachers to engage in QuarkNet masterclasses across two current grant periods. In a similar manner, the graph on World Wide Data Days (see Figure 6B (see previous page) again displayed with permission, Cercire email 1/12/2026 of participating schools across program years. (See page 44 for each graph.)

As to e-Lab activities, QuarkNet teacher engagement is measured in various ways. For example, information compiled by Adams (and used here with permission) suggests that there are over 2,000 teacher accounts. These teachers support approximately 1,400 student accounts (with a single student account representing one to many students).

Table 10A shows the number of uploads during 2019 through 2022; and the number of analyses run during 2020 through 2022. A total of 382 e-Lab plots were saved in 2022. It should be noted that these time periods were used because of schedule disruption caused by COVID.

Table 10B reflects the collection time periods that are currently used; reflecting an important change in how these runs are computed that is, (the number of analyses) times (files in each analysis) submitted during 2021 through 2024. Additional metrics were added in 2022 that also report the number of DAQs used in analyses. As reported by Adams: A total of 189, 308, and 351e-Lab plots were saved in 2025, 2024, and 2023, respectively. (Historic totals for plots and file uploads are 27,128 and 139,073, respectively.) As noted by Adams, e-Lab uploads were unavailable from May to October 2025 after a server update, leading to a drop in uploads, with a return to previous usage levels expected (Adams email 1/18/2026.)

**QuarkNet Participation and Program Year**

Returning to QuarkNet participation as gauged by the Teacher Survey, please keep in mind that teachers were asked about their current and past QuarkNet participation. When doing so, engagement in QuarkNet by type of opportunity was found to be related to the program year in which they responded to the full survey (see Table 11). These program year differences are likely due to the manner in which our survey data are collected and not necessarily on actual program event participation differences.

Participation by program year differences was likely linked to the onset of COVID as well, which altered the implementation of QuarkNet especially during 2020-2021. For example, Data Camp (fundamentally an in-person event) was implemented only in 2019; returned again in 2022 and 2023. Teachers who indicated that they had participated in Data Camp, as reflected in program years 2020 and 2021, were reporting past engagement in QuarkNet; not the program year when their survey responses were gathered. That said, analysis suggests that more than expected teachers reported having participated in Data Camp in 2019 as compared to 2020-2025 program years. This was also the case of the variety of prior workshop engagement during 2019 (more teachers than expected reported engaging in prior workshops) as compared to 2020-2025 program years. The number of masterclasses was more than expected engaging in 2019, although the data presented in Figure Set 6A suggest that the number of masterclass events has returned to post COVID numbers during the 2022-2025 program years. In subsequent sections of this report, program-year participation will be reported only if found to be statistically related to exposure to core strategies and/or program outcomes.

Table 11
QuarkNet Participation by Program Year (Responses from Full Surveys)

| QuarkNet Program | Program Year | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|
| | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | |
| **Data Camp**[a] | | | | | | | | |
| Yes | 112 | 33 | 14 | 24 | 22 | 12 | 15 | 232 |
| No | 146 | 46 | 54 | 53 | 106 | 79 | 66 | 550 |
| Total | 258 | 79 | 68 | 77 | 128 | 91 | 81 | 715 |
| **Variety of Prior Workshops**[b] | | | | | | | | |
| None | 79 | 37 | 35 | 46 | 88 | 63 | 0 | 348 |
| One workshop | 79 | 19 | 20 | 18 | 29 | 19 | 0 | 184 |
| Two or more | 100 | 23 | 13 | 13 | 11 | 9 | 81 | 250 |
| Total | 258 | 79 | 68 | 77 | 128 | 91 | 81 | 782 |
| **Masterclasses**[c] | | | | | | | | |
| None | 147 | 56 | 52 | 69 | 105 | 80 | 72 | 581 |
| One or more | 111 | 23 | 16 | 8 | 23 | 11 | 9 | 201 |
| Total | 258 | 79 | 68 | 77 | 128 | 91 | 81 | 782 |

[a][$\chi^2_{(6, 782)} = 57.90$, $p < .001$]; [b][$\chi^2_{(12, 782)} = 273.32$, $p < .001$]; [c][$\chi^2_{(6, 782)} = 72.51$, $p < .001$]

## 9. School Characteristics and Student Demographics

To take a deeper dive into the schools represented by QuarkNet participating teachers a large-scale case study was undertaken to explore the student demographics represented by these schools. This was a one-time effort and was based on teachers registered for the 2022 QuarkNet program year – the results from 21 Centers (27 combined) and approximately 250 teachers from about 120 schools. Some teachers represented the same school but please keep in mind that QuarkNet program engages individual teachers and does not represent a school-wide or science-department level of professional development outreach. This section is repeated from a past evaluation report.

Organized by center, the summary shows the name and city, state location of the school, school-level student demographics including school enrollment size; gender breakdown of students (by percents); ethnicity of students (by percents); and percent of students who are eligible for free or reduced lunch programs. The summary is based on publicly available information, and we have accepted information at face value. (In a separate report.)

What have we learned from this review? That the schools represented by QuarkNet teachers are varied; representing mostly public schools both large and small; and, to a lesser extent, private schools. Some centers show evidence that students represented by schools are diverse in ethnicity and represent notable percents of low-income students (e.g., free or reduced lunch eligibility). Other centers less so. As mentioned, we have organized this information by center in the hope that this would help facilitate its usefulness. It is likely most helpful if used by and for the local centers, especially in discussions as to how to draw new teachers into QuarkNet to improve representation by teachers who teach at schools with under-represented student populations, as needed.

# **Quantitative Analyses** (Sections 10-12)

## 10. Overview of Analyses: Teacher (and their Students) and Long-term Outcomes

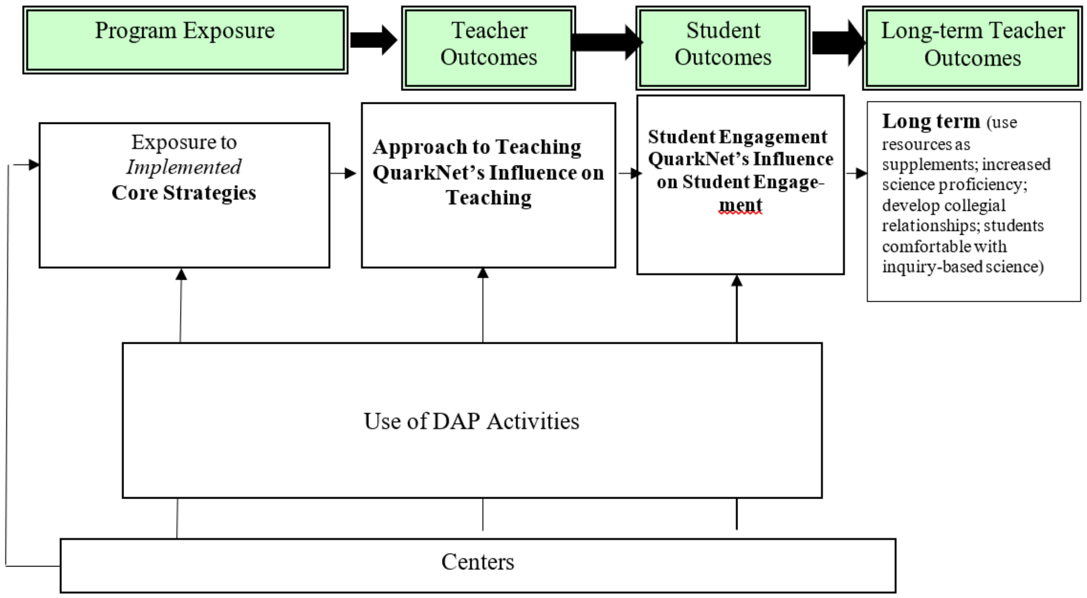



Figure 7. Teacher (and their Students) and Long-term Outcomes: Overview of Analyses

Quantitative analyses of outcomes began by exploring the relationship between engagement in QuarkNet and exposure to core program strategies; and subsequently the potential impact this involvement may have on teacher outcomes, student engagement outcomes, and long-term outcomes. We have analyzed responses from the 2019 through 2025 Full Teacher Surveys and have conducted a descriptive look at responses from the 2020 through 2022 program years, and then again in 2024 through 2025 program years, based on Update Teacher Surveys (the latter of which will be discussed in subsequent sections).

At times, a given measure serves as the dependent measure in a set of analyses; and in turn, a given measure may be used as a "predictor" variable as we build models toward understanding teachers' approach to teaching (both teacher and student-level outcomes) and use of activities in the Data Activities Portfolio. Because of this complexity, Figure 7 provides an overview of these analyses as a means of offering a road map to their logic. Each analysis is presented and discussed separately in the next several sections. To help simplify these analyses and to use data with measured reliability (internal consistency), several scale scores were created (which will be explained shortly).

Please be mindful that these analyses explore the association of exposure to core strategies through QuarkNet programs and outcomes; and are not intended to imply causality. Multiple models are proffered as a means of helping us understand these relationships. *The weight of the evidence suggests a strong association between program participation and exposure to core strategies. In turn, exposure to core strategies and measured outcomes are positively and statistically related.* Although we treat these analyses as preliminary, results have been stable over the course of these program years. As the number of teachers in this data set grew, we have been able to test the role that centers play in these analyses, to reflect that teachers tend to be nested within a center. The inclusion of center-level effects (i.e., nested teachers) in these analyses has strengthened our confidence in the interpretation of these results of these models.

To tell the story behind the data, we used qualitative analyses to describe how teachers have incorporated QuarkNet content and materials in their classrooms based on answers to open-ended survey questions. These responses have been organized by center, in portfolios to reflect center-level program engagement. Additional examples are included in these portfolios, which will be described in more detail later in this report.

**Scale Score Development to Measure Exposure to Program and Teacher (and their Students) and Long-term Outcomes**

The following scale scores were developed in support of these analyses: Core Strategies (assess program exposure); Approach to Teaching; QuarkNet's Influence on Teaching; Student Engagement; and QuarkNet's Influence on Student Engagement. An additional scale score has been added, that is, Long-term Outcomes: Teachers. All scale scores are based on teacher self-reported responses to the Full Teacher Survey.

To help understand the content of these scales, the individual survey items, included in each of these scale scores, are shown in detail in Appendix K. In all cases, the responses to a given item set (scale) are summed with the *higher* the score, the more positive response, based on individual 5-point Likert-like response categories. Descriptive statistics and the reliability coefficient for each scale are also shown in Appendix K. Scale-building results have been stable throughout survey years. We provide more descriptive details about these scales in Appendix K as well.

## 11. Unique Contributions of QuarkNet Program Components

At the suggestion of a project and proposal review by NSF, we have conducted a series of statistical analyses where each of the following QuarkNet program components, that is, Data Camp participation, Variety of Workshop engagement, and MasterClass participation, are analyzed simultaneously. In these analyses, each comprised of a 2x3x2 Analysis of Variance (ANOVA), the contribution of each QuarkNet component is simulatenoutsly assessed using the following as a dependent measure: Core Strategies (level of exposure to key instructional strategies), reported Approach to Teaching, the perceived influence QuarkNet has had on teaching in the classroom, reported Student

Table 12
Analyses Comparing Individual QuarkNet Components:
Unique Contributions of Each

| QuarkNet Program Component | Statistical Results | Other Relationships | Long-term Teachers: Outcomes |
|---|---|---|---|
| **Data Camp** | Data Camp experience was shown to be statistically significantly related to higher **Approach to Teaching** scores and **Student Engagement** scores (on average) by participating teachers. | Workshop experience was also statistically significantly related to higher **Approach to Teaching** scores (on average). | All QuarkNet components Data Camp, Variety of Workshops, and Masterclass participation were statistically significantly related to higher **Long-term Teacher Outcomes**[a] scores (on average). |
| **Variety of Workshops** | Participation in workshops (two or more) as reported by teachers was statistically significantly related to higher scores (on average) for **Core Strategies,**[a] **Approach to Teaching**, **QN's Influence on** Teaching,[a] and **Student Engagement.** | Higher **Student Engagement** scores (on average) were also statistically significantly related to teachers' participation in Data Camp and Masterclass. | |
| **Masterclass** | Participation in Masterclasses (one or more) as reported by teachers was statistically significantly related to **Core Strategies, Student Engagement**, and **QN's Influence on Student Engagement** scores. | Higher **Student Engagement** scores were also statistically significantly related to reported workshop participation and Data Camp participation. | |

Note: This table summarizes the results of a series of ANOVA analyses where each of the listed QuarkNet program components are treated simultaneously as independent variables, and where in separate analyses Core Strategies, Approach to Teaching; QN's Influence on Teaching, Student Engagement, QN's Influence on Student Engagement, and Long-term Teacher Outcomes scores each is treated as the dependent variable. Long-term outcomes include survey items that address: 1. Use resources as supplements. 2. Increased science proficiency; 3. Develop collegial relationships; and 4. Students are more comfortable with inquiry-based sciences. [a]Unequal variance was noted as well.
Based on scale scores created from survey responses from 2019 through 2025 program years.

Engagement of their students (as assessed by teachers), the influence of QuarkNet on this reported Student Engagement, and Long-term Outcomes.

The results of these analyses are summarized in Table 12 (previous page). Statistical details including means, standard deviations, number of teachers included in each analysis and reported statistical significance levels are shown in Appendix L.) These analyses suggest that engagement in Data Camp contribute to Approach to Teaching and Student Engagement as measured. Engagement through a Variety of Workshops is associated with increased exposure to Core Strategies, Approach to Teaching, QuarkNet's Influence on Teaching, and Student Engagement. Masterclasses engagement is associated with Core Strategies, Student Engagement and QuarkNet's Influence on Student Engagement. All program components, that is, Data Camp, Variety of Workshops, and Masterclasses were associated with Long-term Teacher Outcomes. In summary, these analyses suggest that each of the major components of QuarkNet contribute uniquely to one or more of the outcomes as measured.

Although encouraging, these analyses are limited in that each *does not* consider that teachers are nested within their individual QuarkNet center (i.e., statistically insufficient sample size numbers to include center data). To be shown shortly, centers contribute significantly to QuarkNet's reported impact and should not be ignored. To include individual major QuarkNet components in analyses that take the role of the centers into account is beyond our capabilities as statistically this would require a much larger number of teachers that we currently have (perhaps as many as 30-50 teachers per center). Thus, we use core strategy scores as a surrogate measure of the type and level of program engagement.

## 12. How QuarkNet Engagement is Related to Outcomes: QuarkNet Centers *Matter*

In the main, and already stated, teachers participate in QuarkNet through their local center. Thus, statistically it is plausible and likely that center-related variance is systematic and not random (that is, not independent as required in a simple multiple regression analysis or in the ANOVA analyses just highlighted). Or said in another way, it is likely that teachers within a given center are more like other teachers within that center than compared to other QuarkNet teachers who participate in the program at other centers; at least in terms of how we measure their exposure to the program and outcomes.

In these analyses and as just stated, Core Strategies scores are used as a surrogate measure for the type and level of QuarkNet program engagement. The relationship between participation in individual QuarkNet components and the measurement of Core Strategies is shown in Figure 8.

Several statistical steps were necessary before we could explore the influence that individual centers contribute to teacher-level, student-level and long-term outcomes and specifically teacher-level outcomes which are discussed in this section. First, to meet analysis requirements, only centers where at least 10 teachers (who engaged in QuarkNet

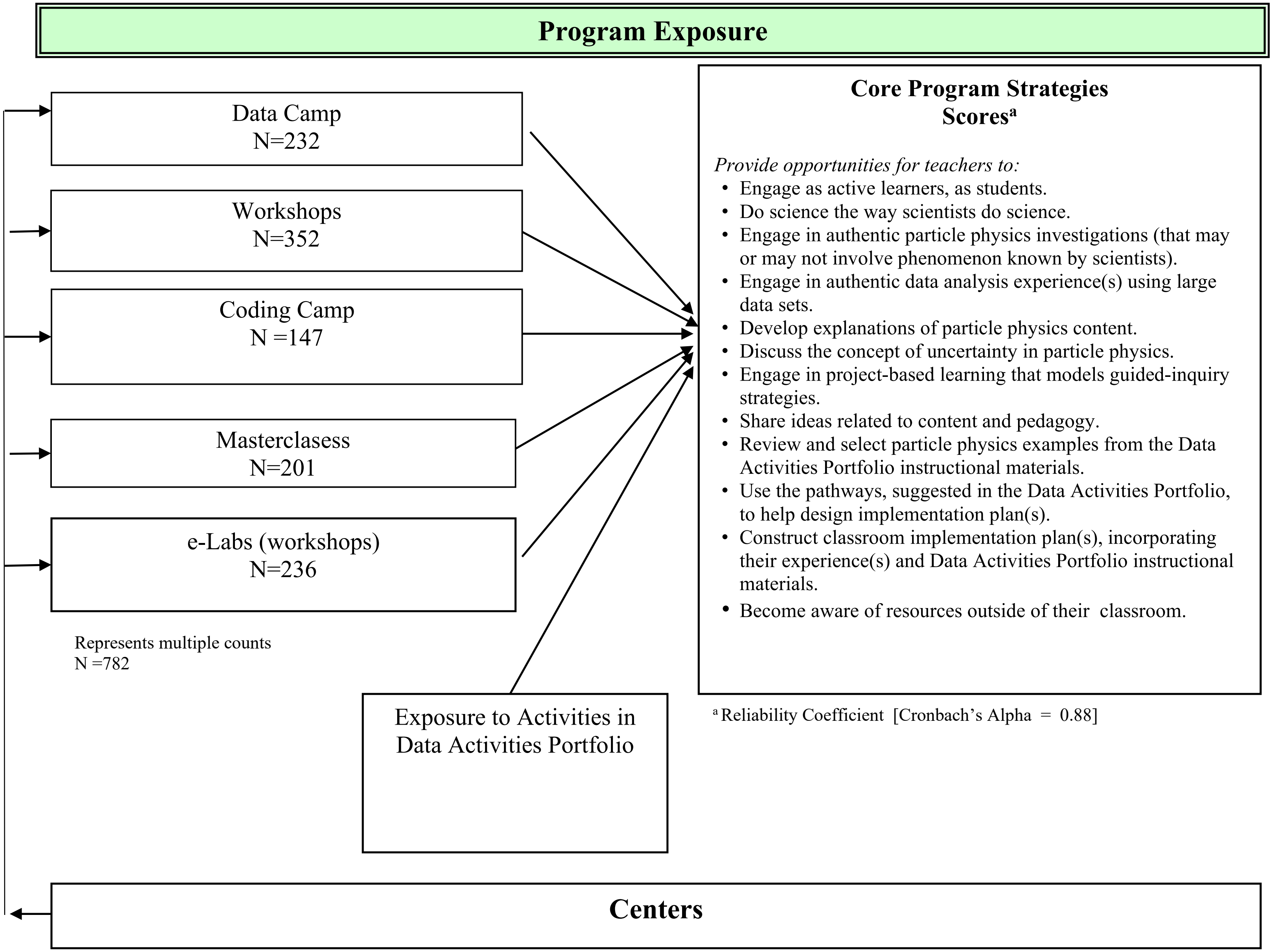
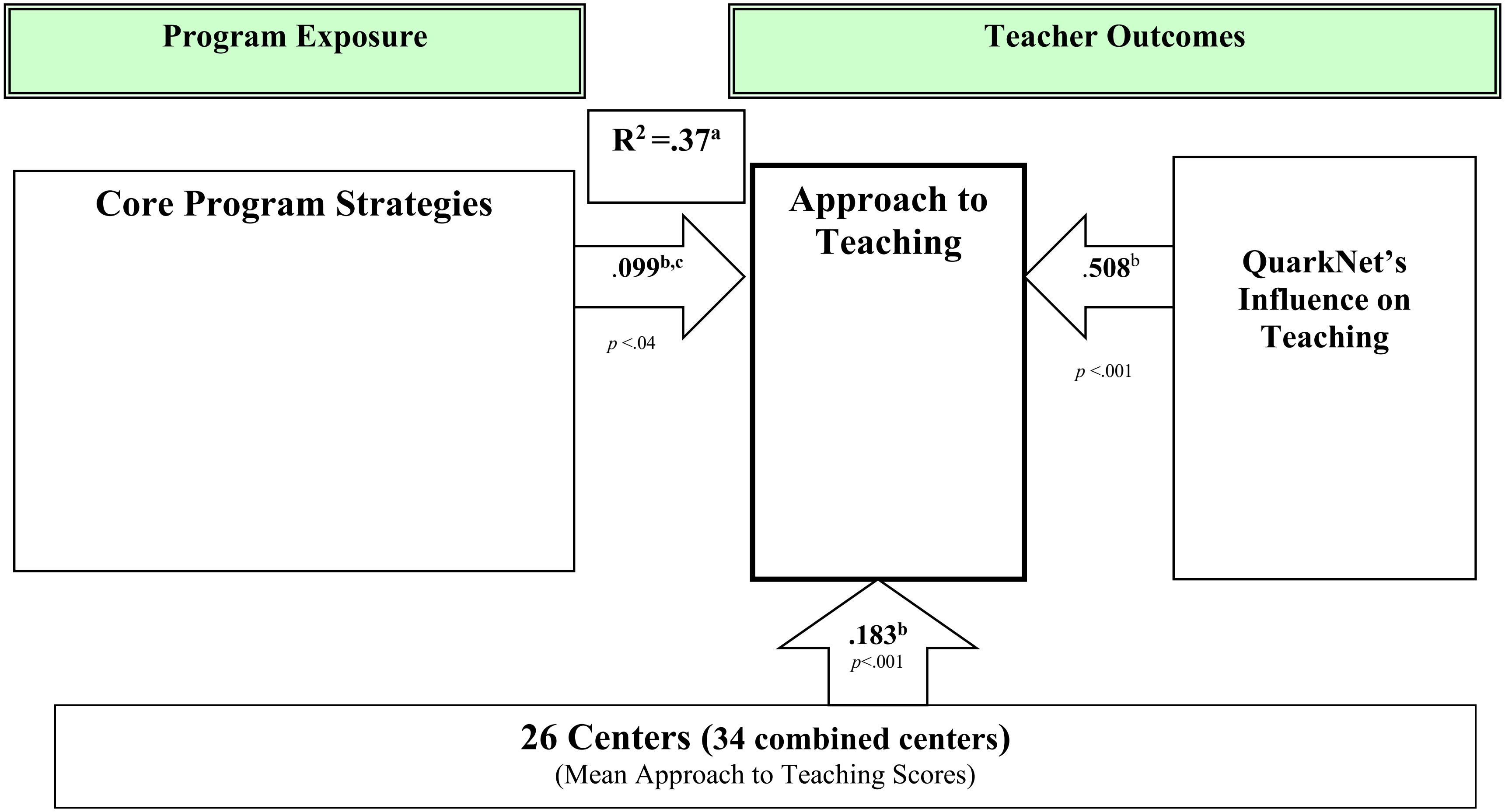



Figure 8. The relationship between engagement in QuarkNet program components and the measure of Core Strategies.




Reliability Coefficients:

| | |
|---|---|
| Core Program Strategies | 0.88 |
| Approach to Teaching | 0.87 |
| QN's Influence on Teaching | 0.95 |

$F_{(3, 427)} = 85.34$, $p < .001$

[a]Percent variance explained

[b]Standardized beta weights

[c]Beta weight reduced to .062 in final analysis

Figure 9. The statistically positive relationship between exposure to Core Program Strategies, QuarkNet's Influence on Teacher, and Approach to Teaching as assessed using a hierarchical linear model.

## Program Exposure

### Core Program Strategies

*Provide opportunities for teachers to:*

- Engage as active learners, as students.
- Do science the way scientists do science.
- Engage in authentic particle physics investigations (that may or may not involve phenomenon known by scientists).
- Engage in authentic data analysis experience(s) using large data sets.
- Develop explanations of particle physics content.
- Discuss the concept of uncertainty in particle physics.
- Engage in project-based learning that models guided-inquiry strategies.
- Share ideas related to content and pedagogy.
- Review and select particle physics examples from the Data Activities Portfolio instructional materials.
- Use the pathways, suggested in the Data Activities Portfolio, to help design implementation plan(s).
- Construct classroom implementation plan(s), incorporating their experience(s) and Data Activities Portfolio instructional materials.
- Become aware of resources outside of their classroom.

## Teacher Outcomes

### Approach to Teaching/QuarkNet's Influence

- Discuss and explain concepts in particle physics.
- Engage in scientific practices and discourse.
- Use physics examples including authentic data when teaching subjects such as momentum and energy.
- Review and use instructional materials from the Data Activities Portfolio.
- Selecting these lessons guided by the suggested pathways.
- Facilitate student investigations that incorporate scientific practices.
- Use active guided-inquiry instructional practices that align with science practices standards (NGSS and other standards).
- Use instructional practices that model scientific research.
- Illustrate how scientists make discoveries.
- Demonstrate how to use, analyze and interpret authentic data.
- Demonstrate how to draw conclusions based on these data.
- Become more comfortable teaching inquiry-based science.

**Approach to Teaching**

**QuarkNet's Influence on Teaching**

## Centers

Figure 10. Survey items included in the measurement of Core Program Strategies scores, and Approach Teaching scores and perceived QuarkNet's Influence on Teaching scores.

and who responded to the full Teacher Survey) were included in the analysis. This sampling requirement resulted in the inclusion of 26 centers (34 combined centers).

Thus, a hierarchical linear regression analysis explored the relationship between core program strategies, perceived influence QuarkNet has had on classroom teaching practices and implemented instructional practices (Approach to Teaching). The results of this analysis are modeled in Figure 9 (page 54) where QuarkNet's Influence on Teaching, Core Strategies and Centers (as measured by mean Approach to Teaching Scores) are shown to be positively related to teacher use of content and instructional practices in their classrooms (i.e., Approach to Teaching). As indicated, these results are statistically significant [$F_{(3, 427)} = 85.34$, $p < .001$]. Figure 10 shows details of the survey items that comprise each of these scale scores (see page 55).

To summarize these results, the weight of the evidence suggests that each QuarkNet component (i.e., Data Camp, Workshops and Masterclasses) contributes uniquely to one or more of the following: exposure to core strategies (program engagement), teacher outcomes, student outcomes, and long-term outcomes, where on average the more engagement by teachers (within each component) the higher the score of the outcome measure. (As described in Section 11.)

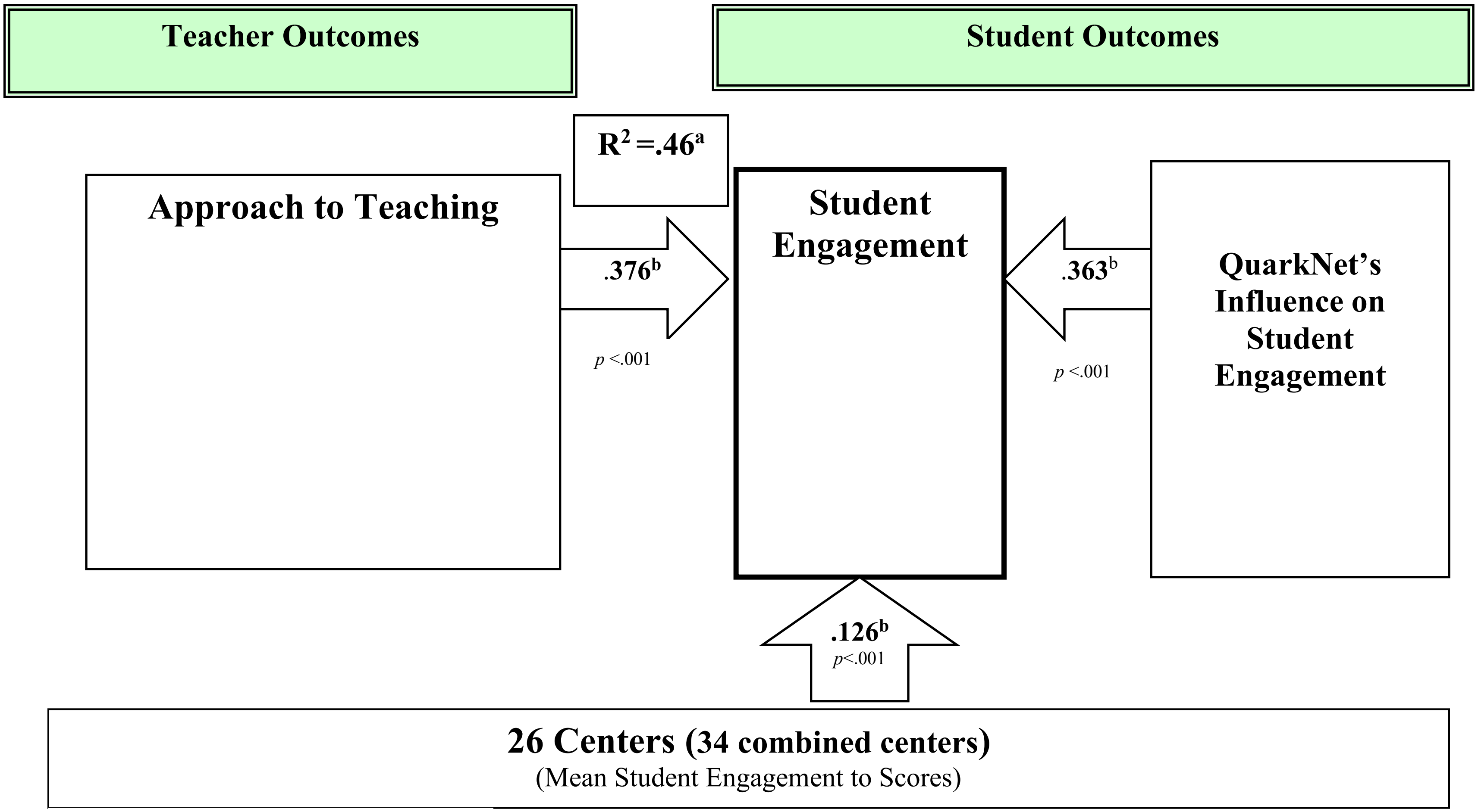
In turn, and of importance, exposure to core program strategies, which serves as a surrogate to program engagement, and the perceived influence QuarkNet has on teaching are positively and statistically related to teacher outcomes (Approach to Teaching scores). Accounting for the nesting of teachers by QuarkNet centers, these relationships are *systematically tied* to the Center in which the QuarkNet teachers engage in the program. These results of the hierarchical analysis on QuarkNet's engagement and Approach to Teaching have been relatively stable over these analyses that have been repeated over time (that is, as data are added each year). This consistency has held to our confidence in using and interpreting these results to support the assessment of QuarkNet's outcomes.

## Student Engagement

*How is QuarkNet Related to Perceived Student Engagement?*

In a similar vein, we looked at the relationship between the teachers' perceptions of student engagement in the context of exposure to the program (Core Strategies), classroom implementation (Approach to Teaching scores) and the perceived influence of QuarkNet on Student Engagement. And again, we have used a hierarchical linear regression model to account for the nesting of teachers within QuarkNet Centers.

This hierarchical linear regression analysis was based on 26 centers (34 centers) as done in the previous analysis. Analysis results are modeled in Figure 11 where QuarkNet's Influence on Student Engagement, Approach to Teaching and Centers (as measured by mean Student Engagement scores) have on this Student Engagement. As indicated, these results are statistically significant [$F_{(3, 357)} = 103.95$, $p < .001$]. Figure 12 shows this relationship detailing the survey items that comprise each of these scale scores. These analyses suggest a positive relationship that QuarkNet participation by teachers has on engagement of their students.




Reliability Coefficients:

| | |
|---|---|
| Approach to Teaching | 0.87 |
| Student Engagement (SE) | 0.83 |
| QN's Influence on SE | 0.95 |

$F_{(3, 357)} = 103.95$, $p < .001$
[a]Percent variance explained
[b]Standardized beta weights

Figure 11. The statistically positive relationship between Approach to Teaching, QuarkNet's Influence on Student Engagement and Student Engagement as assessed using a hierarchical linear model.

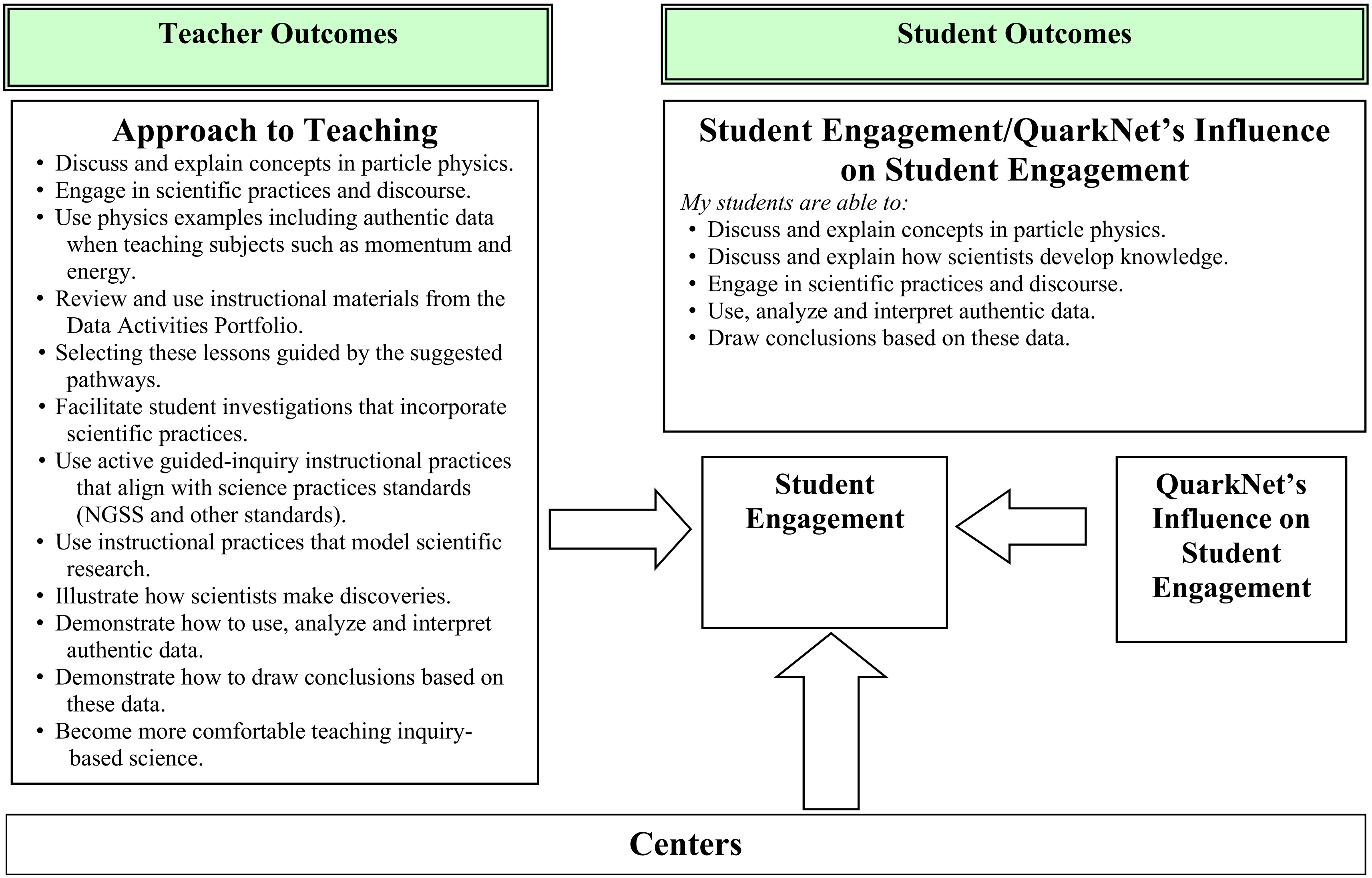



Figure 12. Survey items included in the measurement of Approach to Teaching scores, QuarkNet's Influence on Student Engagement scores and Student Engagement scores as assessed using a hierarchical linear model.

## Long-term Outcomes: Teachers

Newer to these analyses is the measurement of long-term outcomes by participating QuarkNet teachers. The positive relationship between QuarkNet and long-term outcomes of teachers is shown in Figure 13. That is, perceived QuarkNet's Influence on Teaching, Student Engagement and Center-level mean scores are positively and statistically related to Long-term Outcomes: Teachers [$F_{(3, 430)} = 87.13$, $p < .001$]. These results have remained consistent over the past several program years.

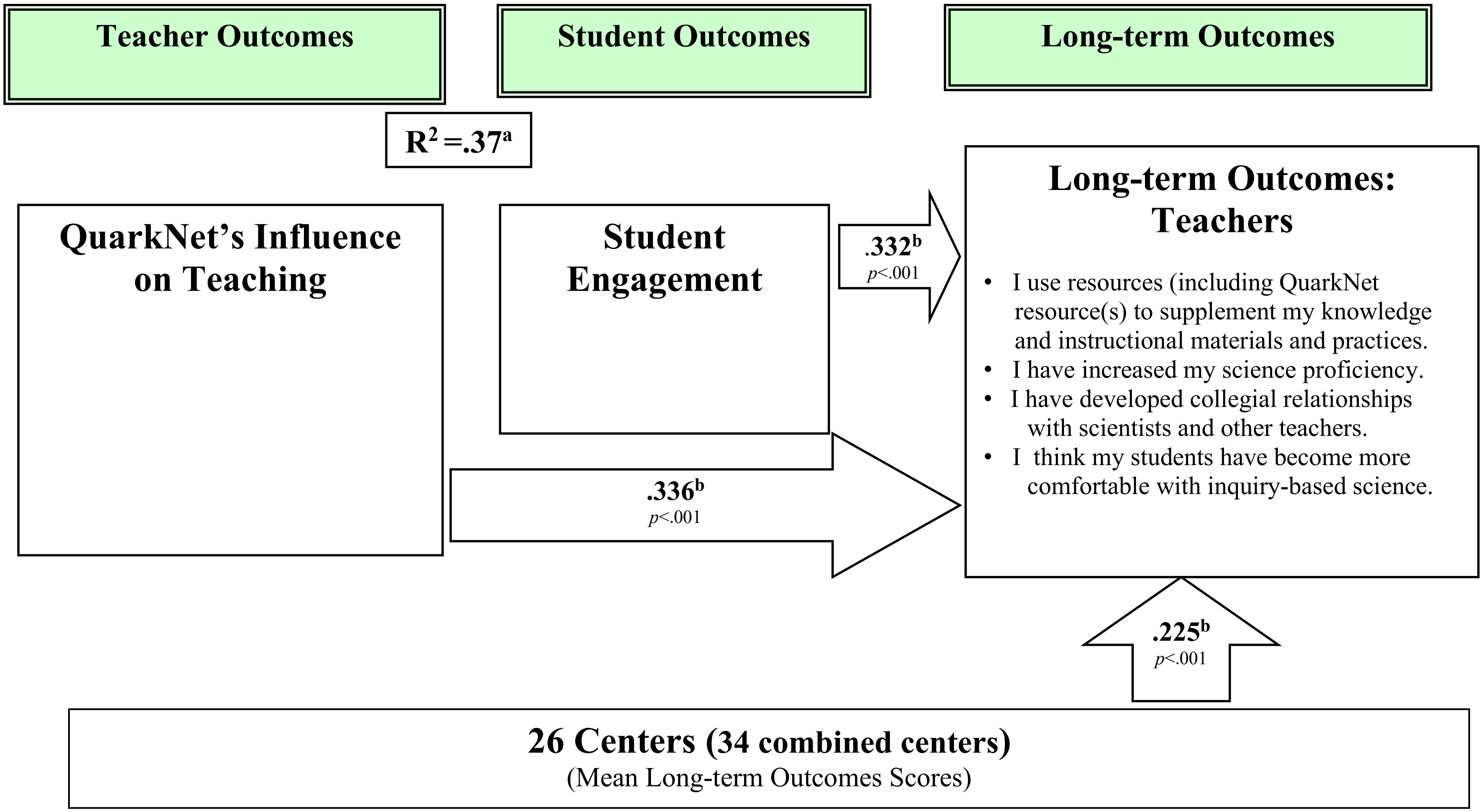
**Summarizing Results from Quantitative Analyses**

In quantitative analyses, we have used sets of survey item responses to form scale scores that measure exposure to QuarkNet, as well as teacher-, student- and long-term outcomes. Statistical analyses support the reliability (i.e., internal consistency) and use of these scales where the higher the score the more positive the assessment. These scales are: Core Strategies, Approach to Teaching, QuarkNet's Influence on Teaching, Student Engagement ment, QuarkNet's Influence on Student Engagement, and Long-term Outcomes: Teachers.

At the behest of NSF, we have conducted a series of simultaneous analyses (i.e., 2x3x2 ANOVA analyses) where the effects of engagement in Data Camp, (Variety of) Workshops and MasterClass are assessed independently by exposure to Core Strategies, Approach to Teaching, QuarkNet's Influence of Teaching, Student Engagement, QuarkNet's Influence on Student Engagement, and Long-term Outcomes: Teachers (each a dependent measure).

To summarize these results, the weight of the evidence suggests that each QuarkNet component (i.e., Data Camp, Workshops and Masterclasses) contributes *uniquely* to one or more of the following: exposure to core strategies (program engagement), teacher outcomes, student outcomes, and long-term outcomes, where on average the more engagement by teachers (within each component) the higher the score of the outcome measure. These analyses *do not* take into consideration that teachers are nested within their individual QuarkNet center and additional analyses underscore this importance.

A series of hierarchical linear regression analyses were conducted to account for this nesting. To meet statistical requirements, data from 26 (34 combined) centers were included in these analyses and program engagement was captured by using Core Strategies scores as a surrogate measure. Results suggest that exposure to core program strategies and the perceived influence of QuarkNet on teaching are positively and statistically related to teacher outcomes (Approach to Teaching scores). And these relationships are *systematically tied* to the Center in which the QuarkNet teachers engaged in the program. Student engagement was positively and statistically related to QuarkNet's Influence on Student Engagement, Approach to Teaching and Centers (as measured by mean Student Engagement scores). Long-term outcomes were positively and statistically related to perceived QuarkNet's Influence on Teaching, Student Engagement and Center-level means. Of importance, the Center in which the teachers engage in QuarkNet *matters.*




Reliability Coefficients:

| | |
|---|---|
| QN's Influence on Teaching | 0.95 |
| Student Engagement (SE) | 0.88 |
| Long-term Outcomes | 0.81 |

$F_{(3, 430)} = 87.13$, $p < .001$
[a]Percent variance explained
[b]Standardized beta weights

Figure 13. The statistically positive relationship between QuarkNet's Influence on Approach to Teaching, Student Engagement and Long-term Outcomes as assessed using a hierarchical linear model.

# **Qualitative Analyses** (Section 13-16)

## 13. Qualitative Analyses: Center-level Portfolios
## A Narrative Picture of QuarkNet's Influence

To support quantitative analyses, we have conducted qualitative analyses highlighting information from the same 26 (34 combined) centers included in the hierarchical regression analyses just described. To this end, we have used three sources of information; these are:

- Reponses to open-ended questions from the full and update teacher surveys (summarized in a table)
- Implementation plans posted by QuarkNet teachers and examples of teacher work (when available, taken from workshop agendas and/or annual reports)
- Examples of student work including posters and presentations (when available, taken from workshop agendas and/or annual reports)

Information from each of these sources is highlighted in what we refer to as center-level portfolios. This evaluation approach is consistent with the use of *authentic assessment* to evaluate performance, "teaching for understanding and application rather than for rote recall" (Darling-Hammond & Snyder, 2000, p. 523).

Given that these portfolios are intended to be stand-alone documents, each center-level portfolio starts with a brief explanation of what is contained in it. This is followed by a table that summarizes teacher responses regarding examples of ways in which QuarkNet content and materials have been (or planned to be) used in their classrooms. Each row in the table represents the responses to open-ended questions from the same teacher over time. Thus, we start with the original responses to the first time a teacher completes his/her full survey and then track their responses from subsequent update surveys. We focus on answers to the three open-ended questions in the update survey; these questions are:

- *Briefly describe how you intend to incorporate (or have incorporated) your QuarkNet experiences into your classroom (e.g., Cosmic Ray, LHC, neutrinos, e-labs; masterclass) when teaching, for example, conservation laws, uncertainty, the standard model or something else.*
- *Which activities from the Data Activities Portfolio have you used (or will use) in your classroom? (Please list up to three activities. If you don't plan or haven't used these activities, please provide a short explanation as to why not.)*
- *What else would you like to tell us about your QuarkNet experience as you reflect on applications in your classroom?*

Because these are responses to open-ended questions, teachers are free (and encouraged) to provide information that he or she thinks most relevant. These are presented anonymously in these summary tables to protect the identity of the teacher.

In keeping with Darling-Hammond, Hyler and Gardner (2017), a characteristic of effective professional development is a program of sustained duration, providing "multiple opportunities for teachers to engage in learning around a single set of concepts or practices; that is rigorous and cumulative" (Darling-Hammond, et al., 2017, p. 15). As such, the table summarizes responses by teachers over the course of several program years and likely several QuarkNet programs and/or events in support professional development of a sustained duration.

In the table, if a particular box is blank, it likely means that a teacher did not participate in an event for that program year or skipped the question (or the center may not have had a major event that year). The table provides the essence of these responses; a given response, as presented, may be a direct quote, a paraphrase, or lightly edited; the intent is to convey the overall idea or its essence from that particular teacher.

When this information is available, each table is followed by examples of work by teachers, such as a group of teachers working on an exercise in a QuarkNet workshop, proposed implementation plans incorporating QuarkNet content and materials in classrooms, examples of presentations by teachers either during a QuarkNet workshop and/or during a presentation at a professional conference (e.g., AAPT). Student work, again when available, includes presentations by students at science fairs, presentations at a QuarkNet workshop, data gathered by students during a Masterclass as well as presentations at professional conferences.

Each of these portfolios is posted on the center-specific QuarkNet's website. We propose that the usefulness of these qualitative examples of classroom implementation is likely to be in its review by the center represented in each.

That said it is worth noting a few general themes evident within and across centers. We do this in two ways, first with a summary of this engagement across a three-year period (see Exhibit H). There is a corresponding center-level portfolio for each of the centers, except for one new center, included in this exhibit. Second, in a bit we will highlight examples of implementation in more detail.

Over the course of several years, there has been a concerted effort by centers, with support from QN staff, to incorporate DAP activities into QuarkNet workshops. Concomitant with this, the number of activities in this portfolio has grown (as already noted) increasing the likely these activities are relevant to the content and materials covered in workshops. During workshops, often teachers are given time to experience these activities first as active learners (i.e., as students). Of importance later in the workshop, teachers are given time to create implementation plans (which may include DAP activities, other QuarkNet content and materials, and/or other resources) and share their ideas, through implementation plan discussions and/or share-a-thons. Digital agendas, posted on center's webpages, have increased over time as well and provide a place where posted implementation plans can be housed. These digital postings of implementation plans help to memorize these efforts for future use and review.

Exhibit I suggests how the progression of these program elements have helped facilitate classroom implementation of QuarkNet content and materials by participating teachers.

Exhibit H. QuarkNet's Influence on Teachers' Implementation: Summary of Select Examples

| Centers | Years | | |
|---|---|---|---|
| | 2023 | 2024 | 2025 |
| Black Hills State University | Teachers share ideas of how coding might be used in their classrooms | No workshop held | Posters created and presented by teachers |
| Boston Area/Brown University/ Northeastern University | Teachers developed, posted and discussed implementation plans<br><br>Students analyze and poster Masterclass data | | Teachers developed coding projects/ implementation plans |
| Brookhaven National Laboratory-Stony Brook University | Teachers prepared and shared implementation plans | Teachers develop and post implementation plans | Teachers worked on coding projects for implementation consideration |
| Catholic University of America | Teachers developed, posted and discussed implementation plans | Teachers selected DAP activity(ies) to kick off classes; then reported to group | No workshop held |
| Colorado State of America | American Association of Physics Teachers Colorado Wyoming Section Meeting November 2023 | Teachers worked on implementation plans | No workshop held |
| Fermilab/University of Chicago/ College of DuPage | ALTAS Published Mass Plots generated from data analyzed by teachers Northern Illinois Science Educators Conference, November 2023 | Teachers developed plans for continued improvement of the integration of physics research data into their classrooms. | Teachers developed, posted and discussed implementation plans |
| Florida State University | | Teachers created and shared implementa-tion plans | Teachers developed, posted and discussed implementation plans |
| Idaho State University | Students present posters at local science fair April 2023 | Teachers developed, posted and discussed implementation plans | Teachers developed, posted and discussed implementation plans |
| Johns Hopkins University | Teachers developed, posted and discussed implementation plans | Student cosmic ray experiments | Teachers worked on a variety of lab activities directed by their interests |
| Kansas State University | Multiple teachers and students engaged in a research project correlating muon rates with atmospheric temperature and pressure changes | Share-a-ton postings; teachers developed and shared implementation plans | Poster session (created by teachers)<br><br>Teachers developed, posted and discussed implementation plans |
| Lawrence Berkeley National Laboratory | Student presentation during QuarkNet workshop | Prep for Z mass measurement | Teachers worked through various DAP activities |

Exhibit H. QuarkNet's Influence on Teachers' Implementation: Summary of Select Examples (con't.)

| Centers | Years | | |
|---|---|---|---|
| | 2023 | 2024 | 2025 |
| Rice University/University of Houston | Teachers developed, posted and discussed coding projects | Teachers developed, posted and discussed implementation plans | Teachers in group presented a poster describing their Cosmic Watch study, data collected and the group learned<br><br>Implementation plans created and discussed |
| Southern Methodist University | One SMU teacher participated in Coding Camp 2 (2023) and created a coding project that began during the 2023 SMU workshop, that is, Eclipse Colab Notebook Project, planned as a weeklong eclipse unit: Download data; Collect individual data; Upload collected data;<br>Display as graphs; and Write conclusion. | | Discussed how to use online teaching (physics) resources |
| Syracuse University | During workshop, teachers drew Feynman diagrams for weak decays of heavy quarks. | As a group, teachers worked on and created coding notebooks including a project developed individual that could be used in their classroom. | Teachers created and presented posters based on specific questions about muons. |
| University of Cincinnati | Teachers developed, posted and discussed implementation plans | Teachers developed, posted and discussed implementation plans | Teachers developed, posted and discussed implementation plans |
| University of Illinois at Chicago/Chicago State University | Students (of QN teacher) present (posters and talks) at APPT Winter Meeting January 2023 in New Orleans Louisiana. | Teachers select ten Coronal Mass Ejection events to analyze further. Subsequent workshop led to results that are better understood and much improved. | At January 2025 AAPT conference in St. Louise students presented three posters.<br><br>Results of the Moon Shadow project was completed and a poster was created.<br><br>The 2024 total eclipse results were finalized in June 2025.<br><br>Paper submitted to JURPA4 in August |
| University of Iowa/Iowa State University | Teachers developed, posted and discussed implementation plans | No workshop held | No workshop held |

Exhibit H. QuarkNet's Influence on Teachers' Implementation: Summary of Select Examples (con't.)

| Centers | Years | | |
|---|---|---|---|
| | 2023 | 2024 | 2025 |
| University of Maryland[1] | | | Teachers developed, posted and discussed implementation plans |
| University of Minnesota | Teachers developed, posted and discussed implementation plans | Teachers created and presented posters | Teachers created and presented posters |
| University of New Mexico | Student classroom work engaged in two QuarkNet DAP activities (Shuffling the Particle Deck and Rolling with Rutherford).<br><br>Implementation plan posted by participating teacher | Teachers created and posted their coding projects | Teachers created, posted and shared their posters |
| University of Notre Dame | Masterclass data presented and posted | Teachers participated in several experiments and lab activities | |
| University of Oklahoma/ Oklahoma State University | Teachers developed, posted and discussed implementation plans | Teachers developed, posted and discussed implementation plans | Teachers developed, posted and discussed implementation plans |
| University of Puerto Rico – Mayaguez | Teachers developed, posted, and discussed coding projects and implementation plans | | Participated in a series of coding workshops |
| Virginia Center (Hampton University, the College of William and May, and the George Mason University | CMS data analyzed by 20 students (Virginia and Maryland high schools) who participated in a masterclass held in March 2023 | Teachers developed, and discussed implementation plans | Teachers developed, posted and discussed implementation plans |
| Virgina Tech University | Workshop time allotted for implementation plan development | Teachers developed, posted and discussed implementation plans | Teachers developed, posted and discussed implementation plans |
| Virtual Center | Workshop time allotted for implementation plan development | Teachers developed, posted and discussed implementation plans | Teachers created implementation plan links and then discussed plans |

[1]The University of Maryland QuarkNet center is new – starting in 2025.

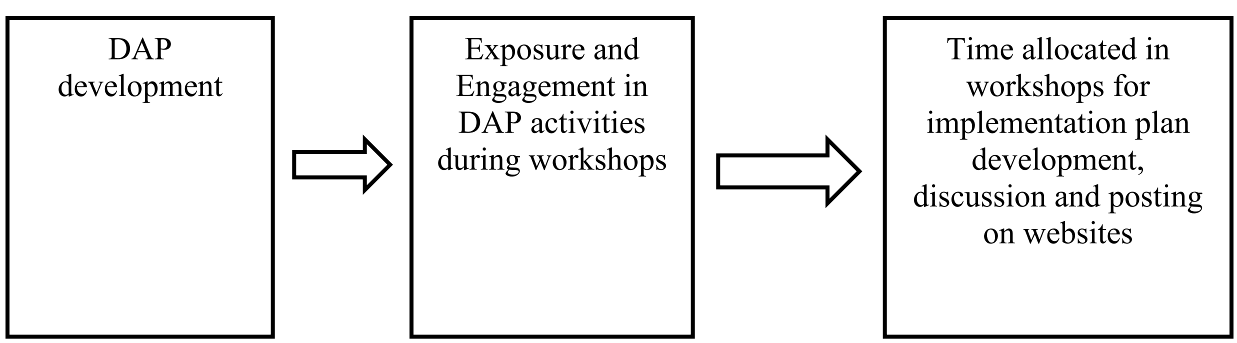



Exhibit I. The progression of QuarkNet program elements that facilitate classroom implementation.

**Highlighting Examples: From Tables, Implementation Plans and Teacher/Student Work**

Survey Response Tables. The responses to open-ended survey questions suggest a variety of ways in which QuarkNet content and materials are planned or are implemented in teachers' classrooms. As a caveat, there is danger in over characterizing general themes across responses to these open-ended survey questions. That said, in line with the questions that were asked there are four general areas that teachers typically focused on: 1. Identifying a specific event(s) (e.g., workshop, masterclass) that was viewed as most helpful; 2. Use/planned use of DAP activities. 3. Whether they would (or would not) recommend the DAP activities to others. and 4. Connections or community development with others. Even so, I think assessing these responses are best served by reviewing responses within each of the individual centers as this will tend to point to the important role played by QuarkNet centers as suggested by quantitative analyses.

In reference to item 1., many teachers provide specific events/components of QuarkNet such as CERN, Data Camp, a specific workshop or masterclass. Often, teachers indicate that they thought that each/all of the QN programs that they participated in were helpful. Specific examples of DAP activities (item 2) are frequently mentioned such as Rolling with Rutherford, Top Quark, Mass of U.S. Pennies. Teachers often mention why he or she is using these activities such as for a specific unit (e.g., conservation and momentum) and/or used in specific physics classes, (e.g., General Physics, AP Physics, Honors Physics). Use in physics classes is mentioned, as expected, but so are examples of use of materials and/or content in astronomy, chemistry, biology (genetics), math, statistics and other classes (e.g., creating histograms, analyses of data) as well as other school-related environments such as physics or science clubs, and/or student-led presentations for science fairs. Regarding item 3, many teachers indicated they would recommend the DAP to others. Some with caveats (e.g., teachers may need support or guidance to do this). Others indicated that they have not yet used activities in the DAP — or in some cases not sure what the DAP is (the frequency of this response is declining) for the reasons they would not recommend /have not yet recommended the DAP to others. As to item 4, responses were based on an open-ended general question. The opportunity to engage with other teachers/mentors/scientists was frequently mentioned. And, overall comments about the value, appreciation for QN as a professional development program.

Given that responses were available for many teachers (the same teacher over time) there was an opportunity to explore implementation examples for teachers who were not initially aware of the DAP activities, followed by examples of how these activities were used in subsequent school years.  And, for other teachers to provide examples of implementation over time.

Please keep in mind that over two grant periods and as we have noted several times in this report, national-led QuarkNet workshops have intentionally focused on the array of QuarkNet DAP activities that are available, presenting how to access these on the QuarkNet website and ways in which these activities can be searched to help maximize their relevance to classroom application. Very frequently, relevant DAP activities are embedded in the agenda of a workshop with teachers having an opportunity to actively engage as students as a hands-on walk through of the purpose and intent of the activity.

Table 1 (con't.)

Self-reported Use of Data Activities Portfolio Activities: Based on Responses from the Full Survey and then Responses from the Update Survey in Subsequent Years **Johns Hopkins University**

| Center | Program Year (Year of Full Survey) | Subsequent Program Year | Subsequent Program Year | Subsequent Program Year | Subsequent Program Year | Subsequent Program Year |
|---|---|---|---|---|---|---|
| Johns Hopkins University | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 |
| | I think Rolling for Rutherford is an easy way for them to understand the experiment through experience and inquiry. I would adapt it to more than just rolling a marble at dice. I would also have them roll a marble at a mystery shape underneath a piece of cardboard and predict what the shape was. | This year, we did more related to online learning because of the circumstances related the pandemic. Having content that can be used virtually, like the QuarkNet e-Labs, will be super useful. Examples: Rolling with Rutherford; The one where you use the detector information. | Next year I will be teaching astronomy in addition to physics, so the cosmology topics and activities that we just happen to focus on this year will be particularly helpful. The new ones I will incorporate are: Mapping the Poles and Particle Transformation. | I was doing Coding Camp 1. The obvious thing from this experience is that I would incorporate is the coding in Python. I will have some introductory coding activities, but ultimately I envision it as a tool that they will be using to help them with labs, homework or projects. I would love to do the muon decays or the leptonic mass coding activities if we get that deep into particle physics. | | (1.) Rolling for Rutherford (2.) Dice, Histograms, and Probability (3.) Histogram: The Basics (4.) All the coding notebooks.<br><br>I would recommend the Data Activities Portfolio and Quarknet to everyone because it is free, and it has changed my content and pedagogical knowledge better than any other PD. |
| | I have not had the opportunity to really share with other teachers and, unfortunately, in today's test happy society, it is difficult to fit these topics into class and to convince others to fit them into class. | | I plan on using the spectral analysis activities we were working on this past week into my ninth-grade physics course. Examples: Mass of the pennies; What Heisenberg knew; CMS masterclass. | When teaching forces, I have a unit on the fundamental forces of nature where I present and the students explore the standard model and the reason why we have Fermilab and the LHC. The first lab is based on the Millikan experiment using histograms and searching for patterns. | Millikan experiment developing histograms. The projects based leaning with an inquiry approach drives my classroom instruction. | Great resources. I always refer to my inquiry approach as "guided inquiry." |
| | The I2U2 site examples, specifically modern physics puzzle | 1. Use of the materials in classroom is great: The subparticle puzzle to start modern physics 2. Masterclass involvement and implementation 3. Standard model discussions, etc. Examples: 1. Quark puzzle/map involving learning color charge, bosons, etc. 2. Penny/coin activity | I have used a significant number of resources involving the QuarkNet workbench, some investigations and more. Overall, my last 10+ years at QuarkNet have really increased my knowledge of certain areas. Examples: The quark workbench, masterclass, J psi (occasionally) | I intend to use my QuarkNet experiences in my own modern physics unit with all physics classes as well as having my Science National Honor Society students to listen to some of the speakers who come to our high school. Examples: The Quark Puzzle, Z mass activities, missing momentum, etc. | Quark puzzle workbench and the mass of the top quark | Workbench. It (DAP) has some really good things for students and teachers |

Exhibit J. An example of a segment of the response summary table of survey questions on how teachers plan or have used QuarkNet content and materials in their classrooms.

Teacher(s):

Class: Physics

| When to present: | Description |
| --- | --- |
| Kinematics Unit | How Speedy are these Muons<br>Jupyter Notebooks and PhyPhox Data Collection |
| Momentum | Calculate the Z Mass<br>Cloud Chamber |
| Energy | Event Display from 2025 UC Quarknet<br>D0 Lifetime<br>Jupyter Notebook |

Exhibit K. An example of an implementation plan posted by a participating teacher from the University of Cincinnati QuarkNet Center (2025).

Finally, although these are short answers to larger questions these responses do provide some insight into the how/what/where/why of QuarkNet content and materials are used in the classroom by participating program teachers. In that vein, a section of one of these tables is shown in Exhibit J reflecting responses from several participating teachers from the Johns Hopkins University QuarkNet Center. That said and as already suggested, a review of several QuarkNet Center-level portfolios will give the reader a much better sense of these implementation examples.

Implementation Plans. In more detail, implementation plans proposed by teachers are included in these center-level portfolios when such has been posted and/or shared by teachers during workshop sessions. Posted implementation plans vary in their level of detail but these offer an opportunity to glean more of what teachers are thinking of when asked how they intend to use QuarkNet content and/or materials. Implementation plans are presented in the center portfolios of, for example, the Boston Area, the Catholic University, Johns Hopkins University, the University of Iowa/Iowa State University, the University of Cincinnati and Vanderbilt University offer such details. The Rice University/University of Houston Center Portfolio and the University of Puerto Rico Mayagüez provide examples of proposed coding projects offered by participating teachers (See also Exhibit H for a summary.) Exhibit K shows a specific example of an implementation plan.

Examples of Teacher Work. Examples of work by teachers include teachers drawing Feynman diagrams during a workshop (University of Syracuse Center), conducting a center-level experiment (Kansas State University), analyzing data from a Coronal Mass Ejection event (University of Illinois at Chicago/Chicago State University), presentations at a professional conference (Colorado State University), and masterclass data analyses by teachers at the Northern Illinois Science Educators Conference (i.e.,

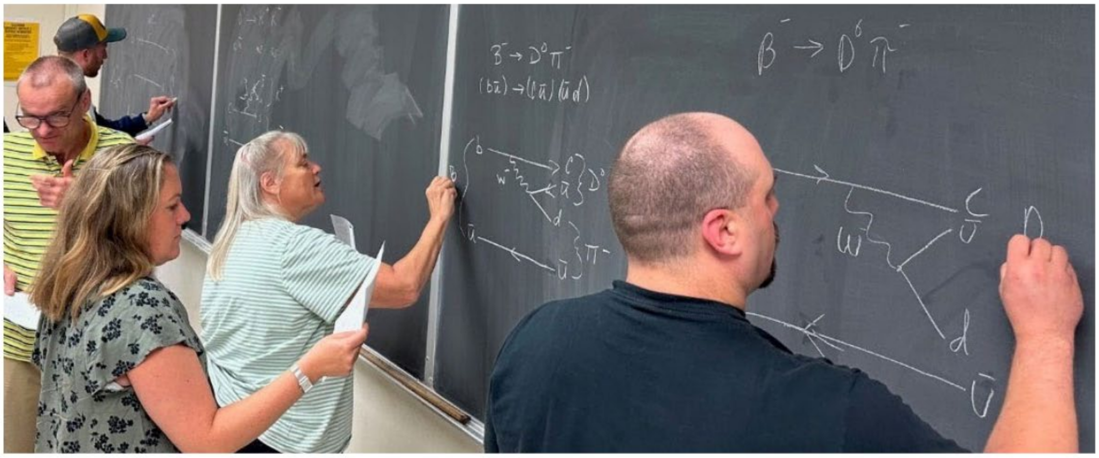


Exhibit L. Teachers drawing Feynman diagrams for weak decays of heavy quarks
Source: Photo and description extracted from the Syracuse University Center's Annual Report Summer 2023 QuarkNet Workshop hosted by Syracuse University group from Aug 14-16, 2023.

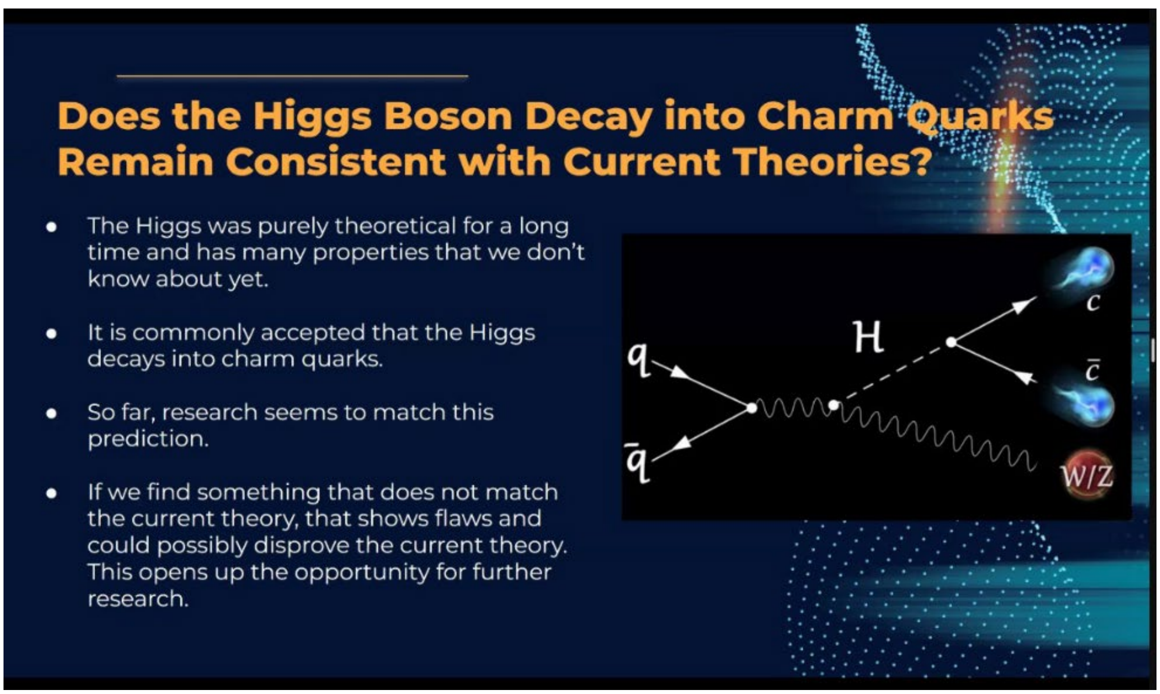



Exhibit M. Slide presentation by student given during QuarkNet workshop. (Source: Excerpt from Lawrence Berkeley National Laboratory Annual Report July 20, 2023)

Fermilab/University of Chicago combined center). Exhibit L shows an example of teacher participating in an activity during a QuarkNet workshop.

Examples of Student Work. Examples of student work include students in classroom working on a Shuffling the Particle Deck activity (school of a participating teacher at the University of New Mexico Center), masterclass data analysis based on students working in groups of two (Boston Area Center), science fair presentations by students (Idaho State University), a student presentation during QuarkNet workshop (Lawrence Berkeley

National Laboratory Center) and student presentations at national conferences (AAPT) (University of Illinois at Chicago/Chicago State University combined center.) (See Exhibit M for a poster presented by a student during a QuarkNet workshop.)

## 14. Center-level Outcomes and Effective Practices

The involvement of center-level engagement in QuarkNet was measured through the Center Feedback Template starting during the previous grant period. We added this to the mix of the individual-teacher analyses to provide the context in which teachers participate in QuarkNet at the center level. This information had been used to corroborate (or not) teacher-level responses and to gauge center-level outcomes in their own right. Further, results of quantitative analyses have suggested the importance role that centers play in QuarkNet implementation and engagement by teachers. New QuarkNet centers will be added into the mix of this process once each has matured enough to be seen as eligible to gain from this participation.

The timetable of this evaluation effort and brief description of the method used are shown in Appendix J. In this report, Table 13 is a summary table of selected results where individual-teacher and center-level responses are compared. The appendix provides a series of tables that provide the details behind this summary.

**Engagement by QuarkNet Teachers as Active Learners/Opportunities to Building Relationships/Networking**

On this basis, we conclude:

- There is good agreement between individual teacher responses and center-level reports of opportunities for teachers to engage as active learners as students during their engagement in QuarkNet programs and events. The perceived influence QuarkNet has on this behavior (at the center level) is reported as *Very High/High.*

- Similarly, individual teachers and centers tend to agree on opportunities to engage with mentors and other teachers during QuarkNet program engagement. QuarkNet's influence again is reported as *Very High/High* (at the center level).

- And both individual teachers and centers tend to report that QuarkNet program engagement facilitates forming lasting collegial relationships with QuarkNet's influence on relationship building as *Very High/High*.

**Alignment of the Implemented QuarkNet Program with NGSS Science Practices**

A**s** previously discussed, QuarkNet predates the articulation of Next Generation Science Standards (NGSS). From the start, QuarkNet fundamentally embraced a claims/ evidence/reasoning approach (McNeill & Krajcik, 2008) to professional development which lent well to its embrace of NGSS science and engineering practices. These practices as well as inquiry (which was operationally defined in the PTM) and

Table 13
Comparison of Center-level[a] and Individual Teacher[b] Responses

| Program Engagement Opportunities | Center: Engage Teachers as Active Learners, as Students[a] | Teachers: QuarkNet provides opportunities for teachers to engage as an active learner, as a student[b] | Center: QuarkNet's Influence on Teachers (on this behavior)[a] |
|---|---|---|---|
| Teachers engage as active learners, as students | *Almost all* Teachers 20/25 centers | 79% of teachers reported opportunities as *Excellent* | Rated as 14/25 centers *High* 11/25 *Very High* |
| Teachers interact with Mentor(s) and/or | *Almost all* Teachers 18/25 centers | 81% of teachers reported opportunities as *Excellent* | Rated as 16/25 centers *Very High* 6/25 centers *High* 22/25 *Very High/High* |
| Other teachers | 22/25 centers | | 12/25 centers *Very High* 9/25 centers *High* 21/25 center *Very High/High* |
| Form lasting collegial relationships | *Almost all* Teachers 12/25 centers *Most* Teachers 7/25 centers<br><br>*Almost all/Most* Teachers 19/25 | 62% of teachers reported opportunities to form collegial relationships with scientists/teachers as *Excellent*<br><br>71% of teachers reported opportunities to building a local learning environment as *Excellent* | Rated as 12/24 centers *Very High* 9/24 centers *High* 19/24 centers *Very High/High* |

[a]Based on 25 (33 combined) centers.
[b]Based on teacher survey data from 2019-2024 program years (for teachers who answered this question).

characteristics of professional development ala Darling Hammond (et. al., 2017) are anchors of QuarkNet's PTM.

We have reviewed the alignment of the *implemented* QuarkNet program with NGSS Science Practices across centers (rather than by individual center). In Figure Set 14, the graph in the upper left-hand corner reflects the potential exposure to NGSS practices based on all DAP activities *as designed* and is repeated here (previously Figure 3) for ease of comparison to QuarkNet DAP activities as *implemented*.

The graph in the upper right-hand corner shows the exposure to NGSS practices based on *implemented* QuarkNet workshops held during the 2019 through 2025 program years (based on review of workshop agendas for each of these program years) where DAP activities embedded in the workshop were counted and then aligned with NGSS practices.

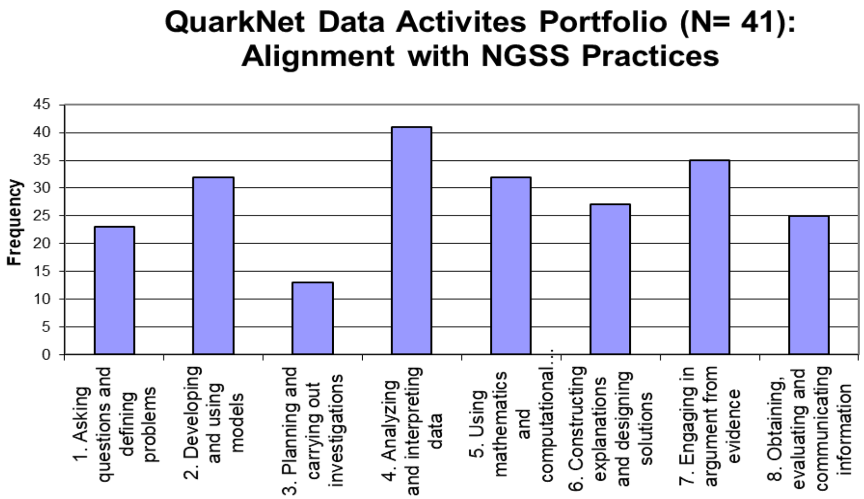
Taken together data in these two graphs suggest the alignment of NGSS science practices evident in DAP activities at the program level as *designed;* and as *implemented* --- via workshops held across the program years during this (and previous) grant periods.

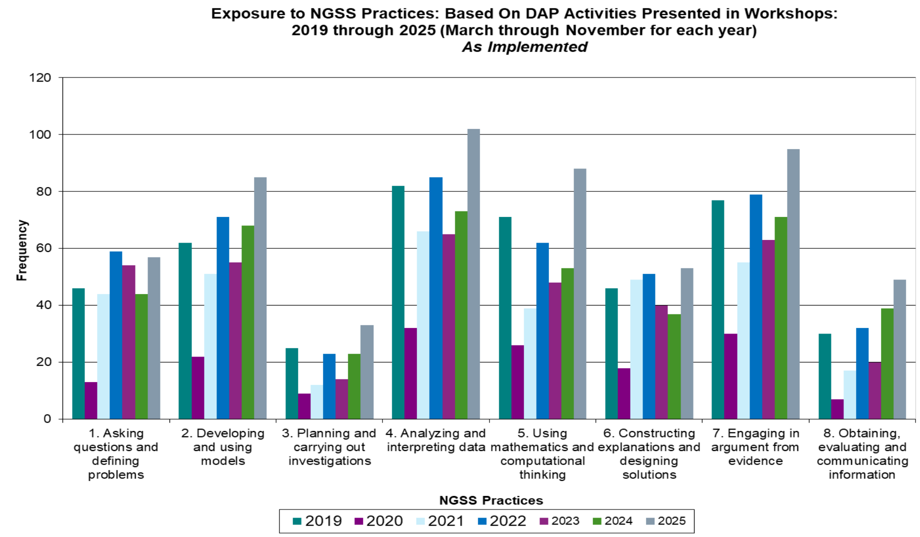
(Also evident, the graph in the upper right-hand corner suggests that the implementation level of embedded DAP activities returned to pre-COVID levels, comparing data from 2019, 2022-2025 program years.)

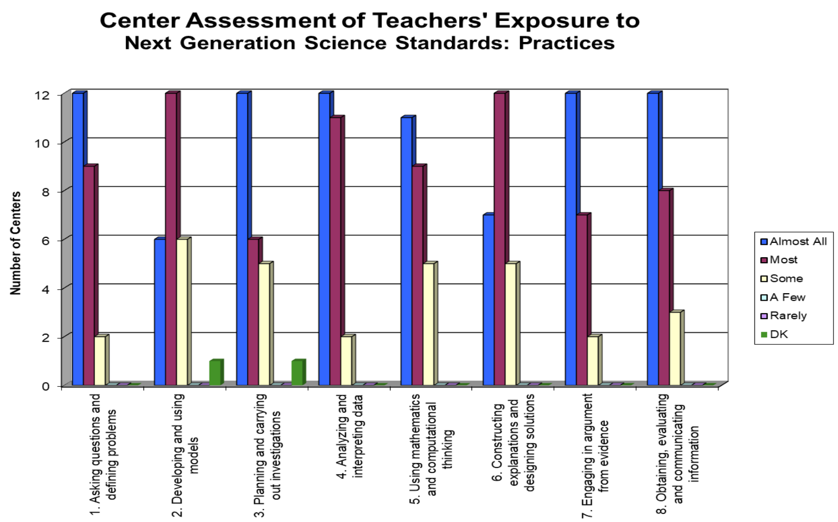
The next graph in the lower left-hand corner presents the perceived engagement in NGSS practices by teachers based on center-level assessment of their *implemented* program. This reflects an assessment of engagement at the individual teacher level. (Based on responses from Center Feedback Templates.) As shown, data in this graph suggest that the individual-teacher engagement at the center aligned with these NGSS practices, as "*Most*" or "*Almost All*" teachers engaged in endeavors that align with each of these science practices during their participation in QuarkNet.

The graph in the lower right-hand corner presents the centers' assessment of QuarkNet perceived influence of this alignment. (Again, based on responses from Center Feedback Templates.) This graph suggests that these centers judged QuarkNet's influence on participating teachers relative to these practices as "*High*" or "*Very High*."

Together these graphs suggest that, at the overall program level, participating QuarkNet teachers are engaged in scientific endeavors during the *implemented* program that align with NGSS science practices; and this engagement mirrors the pattern of alignment with the DAP activities as *designed.* Of importance, this engagement occurred at a high and frequent level as measured by the count of DAP activities embedded in workshops during multiple program years (at the overall program level) and as measured by center-level assessments based on center that participated in the Center Feedback Template process (at the individual teacher level).



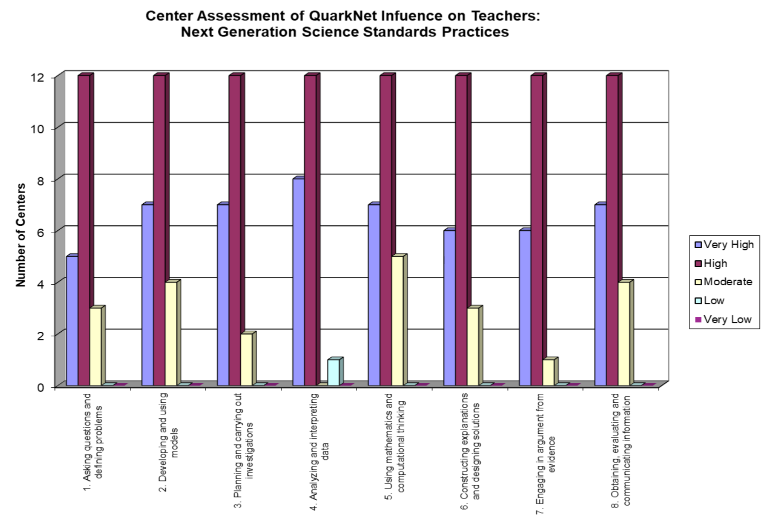




Figure Set 14. Alignment of Next Generation Science Standards (NSS) science practices and activities from the Data Activities Portfolio as designed (upper left-hand corner). Then, the exposure to NGSS practices based on *implemented* QuarkNet workshops held during the 2019 through 2022 program years (upper right-hand corner); and finally based on QuarkNet program content and DAP activities as assessed by

## Effective Practices: QuarkNet Centers

The importance of the partnership between QuarkNet and participating centers have already been noted. To help review these centers through the lens of effective practices, Young and Associates (2017) created a matrix of interrelated factors and in turn, we embedded the assessment of these factors by centers within the Center Feedback Template. A summary of these center-level assessments is shown in Appendix J (for centers that completed their template). Because of the individual characteristics of each center, we would expect some variability across these assessments and indeed variability is evident. The more telling profile, however, is that individually and collectively these centers tend to report that they have met the standards proposed by these factors.

That said, there were two areas where centers most often cited a challenge. We begin with Factor 3. *Participants meet regularly.* (QuarkNet model is for a summer session with follow-up during the academic year or sessions during the academic year. Follow up includes working with the national staff and collaboration within and across centers. Mentors and teachers have flexibility to set the annual program locally.)

For example, these challenges/comments were noted:

- (Yes, but) Strong seasonal involvement; could increase overall frequency and depth.
- (Yes, but) We often fail to follow up during the school year; probably need to try harder to make this happen.
- (Yes, but) We usually only meet as a QuarkNet group during the summer. An in-person meeting during the academic year is not feasible and there are no follow up sessions during the year.
- (Yes, but) No group meetings generally during the academic year – think that would be helpful even if informal. Mentor does visit schools and teachers, often working with small student groups.
- (Yes, but) Currently we meet about twice a year. 3-4 days in the summer, 1 day in Jan/Feb for Masterclass orientation, and 1 day in March/April for Masterclass. it

Perhaps the most frequently mentioned challenge for these centers is reflected in responses to Factor 7. *Money for additional activities or additional grants.* (Seeking additional funding to fulfill the mission/objective of the center; providing supplemental or complementary support for QuarkNet e.g., providing transportation, lodging, buying equipment, providing food.)

- (Yes, but) Money for stipends to attend meetings has been generally available. Also, QuarkNet has provided four teachers with cosmic ray detectors. We have not asked for more.
- (Yes) Preparing a NSF proposal.
- (Yes) QuarkNet helped with paying mileage to teachers who have to travel quite far for our summer workshop and also paid for a shared set of equipment for a specific lab experiment.
- (Yes, but) Lately funding has shrunk, so teacher stipends shrunk or we capped the participant number.

Table 14
Examples of Presentations and Posters Presented in 2024- 2025 by QuarkNet Staff, Teachers, and Students

| **Author (Last, First)** | **Role (staff, fellow, etc.)** | **Center (if applicable)** | **Date** | **Title** | **Format (Publication, Presentation or Poster)** | **Name of conference, publication, etc.** |
|---|---|---|---|---|---|---|
| Anderson, Schroeder, & Wood, | Teacher, fellow, and staff | Minnesota, Kansas | 08/02/2025 | QuarkNet | Presentation | 2025 PhysTEC Workshop (Washington, DC) |
| Cecire, Kenneth | Staff | | 01/20/2025 | Heisenberg's Laser | Interactive Presentation | AAPT Winter Meeting 2025 |
| Stapleton, Sydney, Afrdeen, Chong, Harzandi, Halwax, & Hecht* | Students | UIC | 01/18/2025 | Total Solar Eclipse Effects on Cosmic Ray Showers | Poster | AAPT Winter Meeting 2025 |
| Pasero, S. | Staff | | 05/14/25 | Hands-on with the MINERvA masterclass | Presentation | 29th IPPOG meeting |
| Borgelt, D., Bilow, U., Hatxifotiadou, D. Cecire, K. & Klein-Bösing, C. | Staff | | 12/17/2024 | International Masterclasses in Particles Physics - expanding geographically and broadening in scope | Proceedings paper<br>Proceedings of Science | 42nd International Conference on High Energy Physics (ICHEP2024) |

Excerpt from information compiled by K. Cecire, S. Wood, et al.
*Several groups of QuarkNet Students presented at the AAPT Winter Meeting 2025, this is just one example.

- (No) We can do more with funding. We have had a very successful center but have had budget cut after budget cut.
- (Yes) Extra food and opportunities to discuss in an informal setting are really appreciated

Funding is of course fundamental to the sustainability of any program but through the assessment of these factors we have hoped to address the question, *What is sustained via this implemented program?* (relative to program fidelity and measured benefits).

## 15. Getting the Word Out

There are various means in which QuarkNet staff, teachers and students have worked to get the word out about particle physics and the QuarkNet program. Publications, presentations and posters are organized into two categories; those presented during the

2019-2023 program years Publications, Presentations, and Posters 2019-2023 | QuarkNet and presentations from June 2023 to the present Publications, Presentations, and Posters June 2023-Present | QuarkNet (as of January 2025).

During the previous grant period (2019-2023) a total of 72 presentations, posters, or keynote talks at professional conferences such as the American Association of Physics Teachers (AAPT) (as of January 2025) (information compiled by K. Cecire and S. Wood). An excerpt from the list of presentations posters conducted in 2023 included on this website is shown in Table 14.

Since this time period, (June 2023 to present) an additional 57 publications, presentations, posters, and key note talks were given at national and regional profession conferences.

## 16. QuarkNet Success Stories: Case Studies

In further detail as to the nature of how QuarkNet has influenced teachers, students as well as its staff, a series of two supplemental reports were created in support of these quantitative and qualitative analyses. We began this search by starting with participant testimonials from QuarkNet teachers and students QuarkNet Stories from the Classroom | QuarkNet but as this effort grew it quickly gathered steam as QuarkNet staff shared information (e.g., such as emails) from QuarkNet teachers and students as to their perceptions as to the role QuarkNet played in shaping their teaching, academic and professional paths. Our intent was to begin with these examples and then explore the role that the level of QuarkNet engagement and/or exposure may have played in these outcomes. (Race, 2024b; Race, 2024c)

Each vignette is organized by the QuarkNet Center represented for that individual. Each individual was actively engaged in the effort to create his/her vignette. The first supplement provides examples that cut across four centers and the second report encompasses one center (i.e., QuarkNet Center HU-WM-GMU also known as the Virginia Center). Each report contains several examples of how QuarkNet engagement has benefited the classroom teaching and instructional practices of QuarkNet teachers and in turn, how these teachers, fellows and staff have influenced QuarkNet. First-hand accounts of how QuarkNet has influenced the academic plans and career choices of former high school students who have engaged in QuarkNet directly and/or through the instructional support of their teachers have been included as well.

The accomplishments of QuarkNet teachers are noteworthy including presentations at regional and/or national conferences, as well as exploring the impact of QuarkNet's masterclass in partial fulfillment of a doctorate in education. Teachers are often cited as playing an important role in notable accomplishments of former QuarkNet students. These former students include, for example, Fulbright awardees, pursuing and obtaining a PhD in physics or related field, co-authors of published articles, and working in the field as researchers or as a physics high school teacher.

As implied by its name, these documents are best viewed as a supplement to the final evaluation report in support of the other sources of data that support QuarkNet's influence viewed in the context of engagement level in the program through workshops, masterclasses, and other program events implemented by these centers. Evaluation Team | QuarkNet

## 17. Program and Evaluation Recommendations

Program and evaluation recommendations start on page 86 of this report, contained in the evaluation summary and are not repeated here.

## QuarkNet Evaluation Summary

Since the start of the 2019 QuarkNet program year, the evaluation themes are: (1) (Develop and) Use a Program Theory Model (PTM); (2) Measure Outcomes (teacher, student and long-term); and (3) Measure Center-level Program Outcomes. During the previous grant period, new evaluation measures based on the PTM were created; these were combined with select previously used evaluation measures. We seek to link program engagement, as articulated through program strategies, to measurable program outcomes (see Figure 1 repeated here).

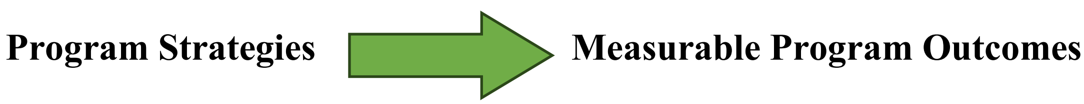



Figure 1. Throughout the evaluation, program engagement (i.e., specifically exposure to core program strategies) provides the context in which assessment has occurred.

### Program Theory Model (PTM): What's New and What's Kept

QuarkNet's PTM was reviewed and revised (in small but important ways) to coincide with the current renewal grant. To this end, a new partner (i.e., the Institute for Research and Innovation in Software for High Energy Physics, IRIS-HEP) was added; we added new program components; and, reviewed, updated and revised descriptions of other programs, as needed. The programmatic anchors of the PTM focus on: characteristics of effective professional development (Darling-Hammond, Hyler and Gardner, 2017); NGSS Science and Engineering Practices (NGSS, April 2013); and an operational definition of inquiry (Herron, 1971 as modified by Jan-Marie Kellow, 2007). Also, the PTM details the major partners, program goals, program components of QuarkNet, articulating program strategies and their linkage to expected outcomes as well.

### Evaluation Measures and Sources of Information

Exhibit F provides an overview of the program and evaluation outcomes data. The evaluation measures and sources of information used to inform the evaluation is shown in Exhibit G (both are repeated here). These measures align with the PTM.

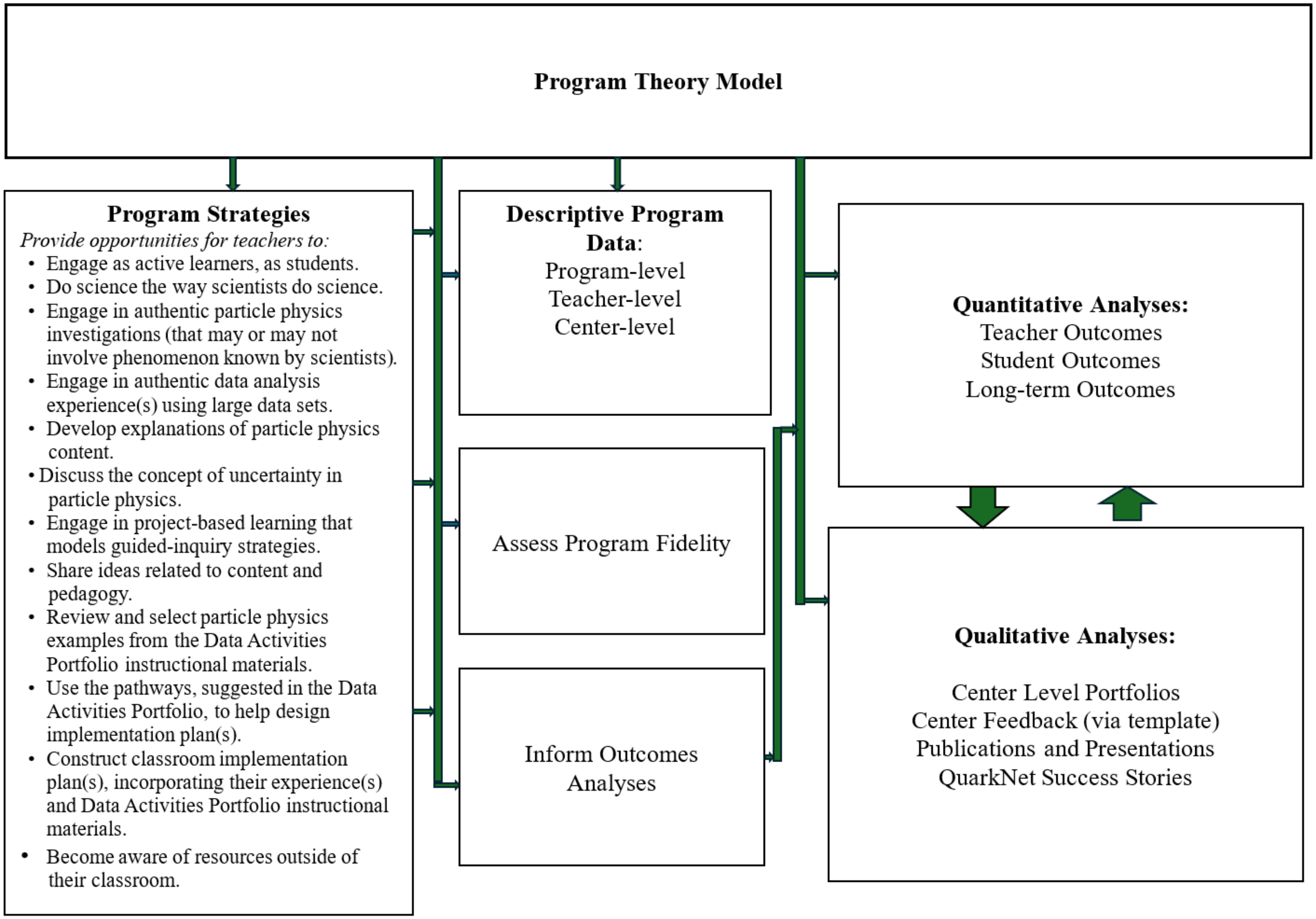



Exhibit F. Overview of Program and Outcomes Data

**Sources of Outcomes Data**

**Teacher Full Survey**
Primary Focus: Quantitative analyses of teacher, student, and long-term outcomes
**Update Survey**
Primary Focus: Qualitative analyses of QN content and material use in classrooms
**Center Feedback Process and Template**
Primary Focus: Comparing center-level and teacher-level responses
**Virtual Workshop Visits by Evaluator**
Primary Focus: Implementation plan discussions

**Multiple Sources of Information: Evidence of Program Engagement/ Alignment with PTM**

**Workshop Summary Table compiled from:**
Workshop Agendas
Annual Reports from Centers
**Data Activities Portfolio alignment with:**
NGSS Science Practices
Workshop Engagement
Enduring Understandings
**Acknowledge and Review other Information**
(e.g., cosmic ray studies, use of comic watches, professional presentations; masterclasses; student-collected data)

Exhibit G. Summary and Overview of Evaluation Measures and Program Engagement

## Summary of Evaluation Results

Using the outline below (the same organization that was used throughout the evaluation report), Table 15 summarizes evaluation results, highlighting conclusions for each:

**Program Design** (Sections 1-2)
1. QuarkNet: Professional Development for HS Teachers
2. (Develop and) Use a Program Theory Model

**Program Fidelity (*as Implemented*)** (Sections 3-5)
3. Program Organization
4. Data Activities Portfolio: Brief History and Development
5. Program Implementation and Measuring Fidelity (*Designed vs. Implemented Program)*

**Inform Outcomes Analyses** (Sections 6-9)
6. Linking Program Strategies to Outcomes
7. Survey Implementation and Responses Rates
8. Summary of QuarkNet Teachers: Demographics (e.g., new teachers, gender parity)
9. School Characteristics and Student Demographics

**Quantitative Analyses** (Sections 10-12)
10. Overview of Analyses: Teacher (and their Students) and Long-term Outcomes
11. Unique Contribution of Major QN Program Components
12. How QuarkNet Engagement is Related to Outcomes: QuarkNet Centers *Matters*

**Qualitative Analyses** (Section 13-16) The Story behind the Data
13. Center-level Portfolios A Narrative Picture of QuarkNet's Influence
14. Center-level Outcomes and Effective Practices
15. Getting the Word Out (Presentations and Publications)
16. QuarkNet Success Stories: Case Studies

**Recommendations** (Section 17)
17. Program and Evaluation Recommendations

Table 15
QuarkNet Evaluation: Summary of Major Efforts and Results

| Evaluation Effort | Source(s) of Information | Highlighted Major Results |
|---|---|---|
| **Program Design** (Sections 1-2) | | |
| **1. QuarkNet: Professional Development for HS Teachers**<br><br>Appendix A highlights program history. | • Review of previous program and evaluation documents<br>• QuarkNet staff expertise | • Brief program history presented.<br>• Importance of centers noted.<br>• Four Program Goals presented.<br>• Approach to evaluation provided (three themes). |
| **2. (Develop and) Use a Program Theory Model**<br><br>Appendix B summarizes the protocol used to develop this model.<br>Appendix C presents the full model (PTM). | Created by working groups based on:<br>• Structured interviews with key QuarkNet staff<br>• Relevant literature<br>• QuarkNet staff expertise<br><br>PTM is intended to reflect that *context matters* in the implementation of the program providing a representative picture of how *change* is expected to happen. | • In detail (7 pages) PTM outlines the links between core program strategies, program structure and major program outcomes. (See Appendix C.)<br>• Offers a Theory of Change:<br>*By immersing teachers in doing authentic particle physics research and by engaging them in professional development that supports guided-inquiry and standards-aligned instructional practices and materials designed for the classroom, teachers become empowered to teach particle physics to their students in ways that model the actual practices of scientists and support instructional best practices suggested by the educational research literature.* |
| **Program Fidelity (*as Implemented*)** (Sections 3-5) | | |
| **3. Program Organization**<br><br>(See Figure 2 for chart.)<br>(See Table 1 for list of QuarkNet centers.) | • Organization and Implementation Chart (developed by QuarkNet staff)<br>• Program's website https://quarknet.org/ | • Overviews the administration and implementation of the program.<br>• Key role of centers noted (presently 57 centers).<br>• Importance of QuarkNet's website presented. |
| **4. Data Activities Portfolio: Brief History and Development**<br><br>Appendix D overviews protocol.<br>Appendix E presents a brief history of Data Activities Portfolio (DAP) growth.<br><br>(See Tables 2-4.) | • *The Data Portfolio is a compendium of particle physics classroom activities organized by Data Strand, Level of student engagement, Curriculum Topics and NGSS Standards*. (Data Activities Portfolio QuarkNet)<br>• Organized by key search options<br>• Pathway and Template documents created to support development of activities<br>• Supported with resources (e.g., teacher/student notes) | • Organized by required student skills sets (Levels 0-4) (developed by QuarkNet staff).<br>• Criteria used to determine the alignment of DAP with Next Generation Science Standards (NGSS) defined by QuarkNet staff. (See Table 2 in full report.)<br>• DAP *as designed* aligns well with Next Generation Science Standards (NGSS), (see Table 3) and<br>• QuarkNet's defined Enduring Understandings (see Table 4).<br>• Grown to include 40 plus activities, designed to be implemented in the classroom. Several can be implemented online and several are in Spanish. |

Table 15 (con't.)
QuarkNet Evaluation: Summary of Major Efforts and Results

| Evaluation Effort | Source(s) of Information | Highlighted Major Results |
|---|---|---|
| **Program Fidelity (*as Implemented*)** (Sections 3-5) (continued) | | |
| **5. Program Implementation and Measuring Fidelity (*Designed* vs. *Implemented* Program)**<br><br>Previous program years are highlighted in a series of tables in Appendix F.<br><br>(See Table 5 in evaluation report for 2025 program year summary.) | • Program Theory Model<br>• Workshop Agendas<br>• Center Annual Reports<br>• Virtual site visits by the evaluator | • Workshop summary table highlights the *implemented* QuarkNet program. (See Table 5.)<br>• Workshop agendas incorporate DAP activities offering opportunities for teachers to engage in these as active learners.<br>• *Implemented* activities align well with NGSS Science Practices (see Figure Set 14).<br>• Creates predicate to compare program engagement to program outcomes (presented here shortly). |
| **Inform Outcomes Analyses** (Sections 6-9) | | |
| **6. Linking Program Strategies to Outcomes**<br><br>Appendix G presents a series of tables that link core program strategies to relevant education literature, followed by linking core strategies to program outcomes.<br>Appendix H presents Full Teacher Survey.<br>Appendix I presents Update Survey.<br>Appendix J presents Center-level Feedback Template. | • Program Theory Model<br>• Linking Program Engagement to Outcomes (evidence of program engagement)<br>• Sources of Outcomes Data delineated<br>• Appendix K shows statistical support for use of scale scores | • Overview outcomes data sources:<br>• Teacher Full Survey<br>• Update Survey (Spanish language version also)<br>• Center Feedback Process and Template<br>• Virtual Workshop Visits by Evaluator |
| **7. Survey Implemented and Reponses Rates**<br><br>(See Table 6.) | • Teacher surveys (full/update) were conducted during 2019-2025 program yrs<br>• Survey implemented during workshop participation with follow-up email as necessary<br>• Raw data from the full teacher survey and the update survey<br>• Data retrieved from Survey Monkey<br>• Raw data cleaned and multiple data calculations and all analyses conducted using IBM SPSS version 28 | • Annual survey responses (including combined full and update versions for years when relevant) range from a low of 72% (during COVID) to 80% during the 2019-2023 program years.<br>• 83% response rate for the 2024 program year.<br>• 78% for the 2025 program year. |

Table 15 (con't.)
QuarkNet Evaluation: Summary of Major Efforts and Results

| Evaluation Effort | Source(s) of Information | Highlighted Major Results |
|---|---|---|
| **Inform Outcomes Analyses** (Sections 6-9) | | |
| **8. Summary of QuarkNet Teachers: Demographics** | | |
| **a. Gender of Teachers** (not statistically related to outcomes) (See Table 7.) | Full Teacher Survey | • The number and percent of women who participate in QuarkNet has increased over recent program years.<br>• Over the 2019-2025 program years program engagement is close to parity: 49% for men; 44% for women; and 7% not specified (based on survey data).<br>• From 2024 program registration information, 48% are men, 47% are women and 5% preferred not to answer. And for the 2025 program year, 49.7% are men, and 49.3% are women, and 1% prefer not to answer, based on registration information. |
| **b. Teachers *New* to QuarkNet** Appendix L presents these data by QuarkNet center and program years. | • Full Teacher Survey<br>• Operations Data (teachers receiving stipends) | • For 2019-2022 program years, 36% of teachers were new/1-year in program.<br>• For the 2023 program year, this percent was 33%.<br>• In the 2024 program year, 33% of teachers were new/1-year in program (information from attendance/stipend records and survey responses).<br>• In the 2025 program year, 27% of teachers were new to QuarkNet (based on attendance/stipend records). |
| **c. Years in QuarkNet, Years Teaching and Years at Current School** (See Figure Set 4.) | • Full Teacher Survey (at the time teachers completed their survey) | • Based on teacher reports, the mean number of years in QuarkNet is 4.37 years (median 2.0 years).<br>• Mean number of years teaching is 16.07 years (median 15 years).<br>• Mean number of years at current school is 9.17 years (median 7 years). |
| **d. School Location** (See Table 8.) | • Full Teacher Survey | • 30.8% of schools are in urban central city locations (where participating teachers teach).<br>• 22.1% of schools are in urban locations.<br>• 28.2% of schools are in suburban locations.<br>• 18.9% of schools are in rural locations.<br>• Over time (2019-2025) there has been a shift to a balanced distribution of school locations. |
| **e. Teaching Physics** (See Table 8.) | • Full Teacher Survey (at the time teachers completed their survey) | • A total of 78.4% of teachers reported teaching physics.<br>• Over time, there has been a tendency for more teachers to report that they are not teaching physics.<br>• Other fields mentioned include Chemistry, Physical Science, Earth Sciences, Biology, Statistics, Math.<br>• Slightly more women report that they do not teach physics as compared to men. |

Table 15 (con't.)
QuarkNet Evaluation: Summary of Major Efforts and Results

| Evaluation Effort | Source(s) of Information | Highlighted Major Results |
|---|---|---|
| **Inform Outcomes Analyses** (Sections 6-9) (continued) | | |
| **8. Summary of QuarkNet Teachers: Demographics** (con't.) | | |
| **f. QuarkNet Participation**<br>(See Tables 9-10.)<br>(See Figure 6.) | Full Teacher Survey | • Any and all programs (as reported) teachers participated in at the time when they completed their full survey.<br>• Program engagement linked to exposure to core program strategies. |
| **g. QuarkNet Participation and Program Year**<br>(See Table 11.) | Full Teacher Survey | • Outcomes do not vary by year that a teacher participates in QuarkNet. |
| **9. School Characteristics and Student Demographics**<br>(based on publicly available school-level information)<br>**a. Location**<br>**b. Enrollment size**<br>**c. Student: Gender (%), Ethnicity/Race (%); Free or Reduced Lunch (%)** | • Large scale case study<br>• Either www.publicschoolreview.com or www.privateschoolreview.com<br>• Information accepted at face value.<br>• Based on teachers enrolled in QuarkNet during the 2022 program year.<br>• ~ 250 teachers from ~120 schools. | • Organized by center.<br>• Schools represented by QuarkNet teachers are varied; representing mostly public schools both large and small; and, to a lesser extent, private schools. Some centers show evidence that students represented by schools are diverse in ethnicity and represent notable percents of low-income students (e.g., free or reduced lunch eligibility). Other centers less so. |
| **Quantitative Analyses** (Sections 10-12) | | |
| **10. Overview of Analyses: Teacher (and their Students) and Long-term Outcomes**<br>(See Figure 7.) | • Full Teacher Survey: Quantitative Data Analyses<br>• Appendix K shows statistical support for use of scale scores | • Maps out key outcomes analyses<br>• Statistical analyses support the use of scale scores as program exposure/outcome measures.<br>• Outcomes measures are:<br>Core Strategies (exposure),<br>Approach to Teaching,<br>QuarkNet's Influence on Teaching,<br>Student Engagement (as perceived by teachers),<br>QuarkNet's Influence on Student Engagement and<br>Long-term Outcomes. |

Table 15 (con't.)
QuarkNet Evaluation: Summary of Major Efforts and Results

| Evaluation Effort | Source(s) of Information | Highlighted Major Results |
|---|---|---|
| **Quantitative Analyses** (Sections 10-12) (continued) | | |
| **11. Unique Contributions of QuarkNet Program Components**<br>**a. Data Camp**<br>**b. (Variety of) Workshops**<br>**c. Masterclasses**<br>(See Table 12 in full report.)<br>Appendix L presents summary of results and analysis details. | • Full Teacher Survey (Program Exposure and Outcome Scale Scores: Core Strategies, Approach to Teaching, QuarkNet's Influence on Teaching, Student Engagement, QuarkNet's Influence on Student Engagement, and Long-term Outcomes: Teachers.)<br>• Requested by NSF. In response, conducted a series of simultaneous Analysis of Variance (ANOVA) analyses | • Analyses suggest that Data Camp and Variety of Workshops each contribute to teachers' reported engagement in Core Strategies, and that<br>• Each major program component of QuarkNet contributes uniquely to at least one or more outcome measures: Approach to Teaching; QuarkNet's Influence on Teaching, Student Engagement (as reported by teachers), QuarkNet's Influence on Student Engagement; and Long-term Teacher Outcomes. (See Table 12 in full report.)<br>• Thus, analyses suggest that each of the major components of QuarkNet contribute *uniquely* to outcomes as measured.<br>• Analyses do not take into consideration the role that centers play in engagement and outcomes (do not meet statistical requirements for such analyses). |
| **12. How QuarkNet Engagement is Related to Outcomes: QuarkNet Centers *Matter*** | • Full Teacher Survey<br>• Hierarchical linear regression analyses that account for teachers nested in QuarkNet Centers.<br>• Using scale scores to measure outcomes. | • See Figure 8 for a schematic on the relationship between engagement in major program components and exposure to core program strategies.<br>• QuarkNet Centers *matter* when assessing teacher, student, and long-term outcomes. (See below for short summary of each.) |
| **a. Approach to Teaching**<br>(See Figure 9-10.) | • Scale Scores: Core Strategies, Approach to Teaching, QuarkNet's Influence on Teaching and Center-level Mean Scores (Approach to Teaching) | A hierarchical linear regression analysis based on 26 centers (34 combined) explored the relationship between QuarkNet program engagement and Approach to Teaching. The results of this analysis suggest that QuarkNet's Influence on Teaching, Core Strategies and Centers (as measured by mean Approach to Teaching Scores) are shown to be positively related to teachers' reported use of content and instructional practices in their classrooms (i.e., Approach to Teaching). These results are statistically significant [$F_{(3, 427)} = 85.34$, $p < .001$]. See Figures 9-10. |

Table 15 (con't.)
QuarkNet Evaluation: Summary of Major Efforts and Results

| Evaluation Effort | Source(s) of Information | Highlighted Major Results |
|---|---|---|
| **Quantitative Analyses** (Sections 10-12) (continued) | | |
| **12. How QuarkNet Engagement is Related to Outcomes: QuarkNet Centers *Matter*** (con't.) | • Full Teacher Survey<br>• Hierarchical linear regression analyses that account for teachers nested in QuarkNet Centers.<br>• Using scale scores to measure outcomes. | |
| **b. Student Engagement**<br><br>(See Figure 11-12.) | • Scale Scores: Student Engagement, QuarkNet's Influence on Student Engagement, Approach to Teaching and Center-level Student Engagement Mean. | This hierarchical linear regression analysis was based on 26 (34 combined) centers. The results of this analysis suggest QuarkNet's Influence on Student Engagement, Approach to Teaching and Centers (as measured by mean Student Engagement scores) have a positive relationship on this Student Engagement. These results are statistically significant [$F_{(3, 357)} = 103.95$, $p < .001$]. |
| **c. Long-Term Outcomes**<br><br>(See Figure 13.) | • Scale Scores: QuarkNet's Influence on Teaching, Student Engagement and Long-term Outcomes | Again, using a hierarchical linear regression analysis, perceived QuarkNet's Influence on Teaching, Student Engagement and Center-level Means (Long-term Outcomes) are positively and statistically related to Long-term Outcomes: Teachers [$F_{(3, 430)} = 87.13$, $p < .001$]. |
| **Qualitative Analyses** (Section 13-16) The Story behind the Data | | |
| **13. Qualitative Analyses: Center-level Portfolios A Narrative Picture of QuarkNet's Influence**<br><br>Compiled for 26 (34 combined) centers that were included in the quantitative analyses. | • Full Teacher Survey (open-ended questions)<br>• Update Survey (open-ended questions)<br>• Virtual workshop site visits by evaluator<br>• Teacher Implementations Plans (workshop agendas/center annual report)<br>• Examples of teachers<br>• Examples of student work | Organized by center, portfolios are comprised of:<br>• Teachers reported planned or actual use of QuarkNet content and materials in their classroom over time (based on responses to open-ended survey questions).<br>When available (may be in a supplemental report):<br>• Implementation plans prepared by teachers or groups of teachers and posted on QuarkNet website are included.<br>• Examples of teacher work (during workshops, science fairs, presentations at workshops/ professional conferences) are included.<br>• Examples of student work are included. |

Table 15 (con't.)
QuarkNet Evaluation: Summary of Major Efforts and Results

| Evaluation Effort | Source(s) of Information | Highlighted Major Results |
|---|---|---|
| **Qualitative Analyses** (Section 13-16) The Story behind the Data (continued) | | |
| **14. Center-level Outcomes and Effective Practices**<br><br>(See Figure Set 14 for comparisons of designed vs. implemented and teacher-level and center-level responses.) | • Center Feedback Template<br>• Effective Practices [M.J. Young & Associates (2017, September). *QuarkNet: Matrix of Effective Practices.]* | • Center-level responses from Center Feedback Templates indicate that QuarkNet teachers engaged in NGSS Science Practices as part of their work-shop engagement; and this experience has a noted influence on teachers related to these practices.<br>• Comparisons suggest good agreement on select responses by individual QuarkNet teachers and QuarkNet centers [26 (34 combined) centers].<br>• Results suggest good alignment of centers to meet the criterion of each of 10 effective practices.<br>• Offers a suggestion of program sustainability (i.e., what is being sustained). |
| **15. Getting the Word Out**<br><br>Compiled by K. Cecire and S. Wood | • https://quarknet.org/content/publications-presentations-and-posters-sept-2018-sept-2023<br>• Publications, Presentations, and Posters June 2023-Present \| QuarkNet | • As of the 2023 program year (Sept), QuarkNet has posted a total of 72 presentations, posters, and publications by staff, teachers and/or students.<br>• From June 2023 to present, an additional 57 presentations, posters, and publications by staff, teachers and/or students have been posted. |
| **16. QuarkNet Success Stories: Case Studies**<br><br>**Supplement I Final \| QuarkNet**<br><br>**Supplement II Final \| QuarkNet** | • Testimonials<br>• Interviews with select staff, teachers and former students<br>• Emails from staff about former students<br>• Evaluation Team \| QuarkNet | • In more detail as to how QuarkNet has influenced teachers, students as well as its staff, a series of two supplemental reports were created in support of these quantitative and qualitative analyses<br>• Each vignette prepared with the active participation of the individual highlighted.<br>• The first report highlights individuals from four QuarkNet centers. The second report highlights individuals from one QuarkNet center.<br>• Staff, teacher and student work examples are proffered including publications, and presentations. |
| **17. Program and Evaluation Recommendations (Section 17)** | • Culmination of information sources contained in this evaluation | • A total of 10 program recommendations and<br>• 10 evaluation recommendations are proffered. |

## In Conclusion

Using various sources of information, the evaluation attempts to provide a cohesive look, based on quantitative and qualitative analyses, at the impact QuarkNet (exposure to core strategies that run throughout the major components of the program) has on teacher, student and long-term outcomes. Results suggest that QuarkNet engagement is statistically associated with each of these outcomes and that QuarkNet Centers play a key role in program delivery and impact. Teacher-level and center-level data tend to agree on fundamental metrics (e.g., active engagement, science practices). Qualitative analyses attempt to tell the story behind these data and include examples of implementation plans, teacher work, and student work including presentations at national and/or regional professional meetings as well as vignettes of individual success stories.

## Program Summary and Recommendations

The following program summary and recommendations are proffered:

P1.The program has had a long-standing practice of holding regularly-scheduled staff meetings. One is staff-wide; one is specific to IT concerns; and one is specific to program content and development. The evaluator has regularly attended the staff-wide meeting. These weekly staff-wide meetings provide a convenient and frequent means for staff and the evaluator to exchange ideas, such as opportunities to highlight evaluation results and for the evaluator to learn and respond to program needs when possible. This meeting structure was essential during COVID for the evaluator (and likely QuarkNet staff as well). The evaluator has attended weekly staff-wide meetings as her schedule has permitted; this open invitation is greatly appreciated.

Recommendation P1: The frequent opportunity to exchange ideas among staff members as well as the evaluator is important and should be continued.

P2. Over the course of the grant period, the collection of program operations data has improved substantially including, for example, simple counts, e.g., number of participating teachers during a given program year. QuarkNet staff have the responsibility of managing workshop RFP’s and the award of monies to conduct these efforts as well as tracking teachers to award stipends. These efforts are managed well as are attempts to gather a complete list of registered teachers, although these responsibilities are shared across QuarkNet staff rather than the responsibility of one individual.

Recommendation P2: Continue to improve the collection of program operations data to help facilitate both program and evaluation efforts. In keeping with these efforts, improved program operations data has helped with a running count of *new* teachers in QuarkNet each year across participating centers. It also may help to provide insight into the outreach to additional teachers who are not directly engaged in QuarkNet who nevertheless benefit from the program in other ways.

P3. Starting in 2019, and continuing during the 2020 through 2024 program years, there has been a concerted effort by QuarkNet staff to help nationally- and center-led workshops document the content of their workshops through the development and use of agenda templates. These agenda examples are readily available and offer a simple and pragmatic step that is very valuable; these agendas can and have been modified and used by QuarkNet centers. In many cases, agendas are modified during the event which memorializes the program in a just-in-time fashion. These documented agendas can help centers prepare their annual reports, which each participating center is asked to do.

Recommendation P3: Continue to support these efforts.

P4. Documenting workshop agendas and center annual reports – and posting these online -- have been extremely helpful in gathering information useful to the evaluation. Specifically, the workshop agendas improved the ability to identify which (and how) activities from the Data Activities Portfolio (DAP) have been incorporated into workshops, especially nationally-led workshops and a growing number of center-led workshops. Other information gathered from these sources helps to summarize program year QuarkNet engagement by centers in general, and specifically in helping centers to complete the Center Feedback Template. We have also used this information for comparisons of the *designed* and *implemented* program; and in comparing individual teacher- and center-level response similarities/differences.

Recommendation P4: For these reasons (plus benefits noted in 3) continue to encourage centers to use the agenda template options to create their own and to post these on the QuarkNet website.

P5. As evident in the narrative of this report, the Data Activities Portfolio has grown substantially during this past grant period and into this new grant period. Of importance, collectively DAP activities have been shown to align well with Next Generation Science Standards Science and Engineering Practices. To this end, QuarkNet staff have provided operational definitions to support how this alignment is determined. The DAP activities have also been aligned with the Enduring Understandings of Particle Physics. Noteworthy, these activities are a bridge for teachers to implement QuarkNet content and materials into their classrooms. Many of these activities were modified for online uses expanding implementation options for teachers (with COVID the impetus for this effort). These options can now be used to support in-person instruction. Early efforts have translated several of these activities (and supportive resources) into Spanish. Teacher and student resources have been added; and older activities have been updated, modified, or even removed as scientific knowledge has advanced.

Recommendation P5: The dynamic effort that underlies the DAP is acknowledged and program support to maintain this effort is encouraged. The DAP may be the legacy of the QuarkNet program.

P6. The number (and the quality) of activities in the DAP has increased dramatically from 2017. This has included applying the review and restructuring of previously developed activities, offering activities by graduated student skill sets, and separating activities by data strand and curriculum topics. As the number of these activities has grown, so has the workload for their development and eventual use.

Recommendation P6: Consider adding a select group of lead teachers or fellows to help in this process in the future. These individuals could help the education specialist with DAP activity development as well as have other responsibilities related to updating and augmenting resource information related to these activities.

P7. During the past and present grant period, QuarkNet staff have demonstrated to teachers how to access DAP activities on the website; demonstrated search options and the availability of supportive resources such as teacher notes and student notes. Participating teachers often have had the opportunity to engage in these activities as active learners (as students) and to reflect on their possible use during implementation plan development and discussion that is part of the agendas of the workshops.

Recommendation P7: Continue program efforts to maximize the use of Data Portfolio Activities by teachers at center-led and nationally-led QuarkNet workshops and meetings; and to encourage teachers to implement these activities in their classrooms.

P.8 Starting with the 2020-2021 program year, staff created an implementation plan template to help teachers reflect on and develop implementation plans that can be incorporated into teachers' classrooms using QuarkNet content and instructional materials. Staff members have mandated this discussion in nationally-led workshops and they have strongly encouraged this inclusion in center-run workshops. Many of these implementation plans are posted on the QuarkNet website. Early results suggest that this structured approach, that is, time for planning and discussion as well as the implementation templates or a variation of it, has helped teachers frame their classroom plans in meaningful ways. It is likely that these program efforts have made it easier for teachers to respond to implementation questions asked in the Update Survey(s). These efforts are valuable for the teachers and are very valuable for the evaluation. Because of these efforts, many implementation plans created by teachers have been incorporated into center-level portfolios that include other qualitative data as well.

Recommendation P8: Continue to incorporate the use of these templates (or a variation of it) and encourage teachers to post these on the QuarkNet website. Documenting these implementation plans will substantially help in providing the narrative as to the *how/what/why* QuarkNet content and materials are used in their classroom. In keeping with this, "coding camps" and workshops use a protocol of "share-out spreadsheets" where implementation plan coding projects are regularly posted by participating teachers. Adopting something similar to this protocol may aid in the consistent documentation of these proposed efforts across all QuarkNet workshops and programs. Regularly posting implementation plans may encourage teachers to post other examples of how QuarkNet content and materials are incorporated into their classrooms.

P9. Sustained duration is among the characteristics of effective professional development identified by Darling-Hammond et al (2017).

Recommendation P9: QuarkNet has been a long-standing program. To support the sustained duration of the program for participating teachers throughout the year, encourage centers to meet during the school year in support of and to augment summer-led events. Although there are other issues such as time commitments and scheduling within a school year, the familiarity and necessity of online remote meetings during the 2020-2023 program years may help centers move in this direction.

P.10. The Program Theory Model offers an approximate fit of QuarkNet as designed and provides a road map as to how change is expected to occur.

Recommendation P10: Reflect on ways in which the Program Theory Model may be used to inform others in the program, those participating in the program (including centers), and those external to the program.

Although not recommendations per se a few additional thoughts are warranted.

Credit goes to QuarkNet staff for a roll-out of a series of mini-workshops for lead teachers at QuarkNet centers (started in the 2021 program year and again in the 2023 program year). Given that nearly all QuarkNet centers are mature (except for a few new centers), staff have taken this opportunity to clarify and expand the roles and responsibilities of lead teachers and to give these teachers a platform to exchange ideas on these possibilities.

QuarkNet staff have proposed during this grant period to hold a series of needs assessment workshops across participating centers. Each such workshop was named *Physics Education Forum* and sub-titled as *Helping Share the Future of Physics Education in Our Schools*. The first was held at Rice University/University of Houston QuarkNet Center on December 16, 2023 (Rice QuarkNet Physics Education Forum - December 16, 2023 | QuarkNet). The second was held at the University of Minnesota QuarkNet Center on February 1, 2025 QuarkNet - U of M Physics Education Forum - February 1, 2025 | QuarkNet. The purpose of these forums was to help broaden participation to reach more teachers and students in STEM, to learn about the program needs and interests of teachers who are not yet engaged in the QuarkNet program and to help inform the program as to possible options to help expand the program's outreach.

Finally, QuarkNet staff has done outstanding work to support evaluation efforts and to help embed evaluation efforts and requirements within the structure and delivery of the program. This is reflected in a standing invitation for the evaluator to attend staff-wide weekly meetings, setting aside time during the workshop for the completion of Teacher

Surveys (either the full or shorter update versions), as well as coordinating with centers for the Center Feedback process and the virtual workshop site visits by the evaluator during teachers' discussions of implementation plans. The success of the evaluation's implementation is due to this cooperation by QuarkNet staff and is greatly appreciated. As is, the participating teachers' willingness to complete the survey (both full and update versions) in a timely and frank manner.

**Evaluation Recommendations**

The following evaluation summary and recommendations are proffered:

E1. The response rates for the Full Teacher Survey and the Update Survey remain high over the 2019 through 2025 program years (ranging between 72% to 83%). Survey links have been embedded in the agendas of workshops to help facilitate a high response rate. This success is due to the commitment of QuarkNet staff teachers, fellows, and center mentors in allocating time during their workshops and meetings for this purpose. We acknowledge and are grateful for this commitment; and to participating teachers who complete their surveys.

Recommendation E1: Continue to work with QuarkNet staff in their support of evaluation efforts.

E2. The Update Teacher Survey dovetails well with the in-workshop discussions by teachers about implementation plans. These discussions have served the evaluation well (and likely the program) as it provides teachers with a quick means to capture their thoughts in describing how and in what ways teachers plan to or have used QuarkNet program content and materials in their classrooms when completing the Update Survey. During the 2023-2025 program years, there has been an important uptick of teachers posting implementation plans. This is very important to help qualitatively describe implementation in-roads of QuarkNet content and materials in the classroom.

Recommendation E2: With QuarkNet staff help, increase the number of teachers who post their implementation plans or ideas on the QuarkNet website.

E3. The use of the Update Teacher Survey has allowed a more in-depth descriptive analysis of the *how/what/why* of the use of QuarkNet content and materials by teachers in the classroom (and reduces the ask of teachers to supply evaluation information) over time. The linking of these surveys (both full and updates) by individual teachers has provided a valuable picture of how these plans and QuarkNet content/material use may have changed over time as participation in QuarkNet continues. Both the review of posted implementation plans and responses from the Update Teacher Survey have helped to provide the story or narrative behind the results of the quantitative analyses; this information is now captured in center-level portfolios along with examples of teacher/student work, when available. In some cases, examples of teacher and student work are highlighted in a supplemental document to specific center-level portfolios. (These portfolios are consistent with the use of *authentic assessment* as a means to evaluate performance, “teaching for understanding and application rather than for rote recall.” Darling-Hammond & Snyder, 2000, p. 523.)

Recommendation E3: These qualitative analyses have been expanded during this grant period to provide a more in-depth descriptive look at classroom implementation of QuarkNet content and materials across centers and the program overall. This effort should be continued as these qualitative analyses help to provide a narrative of what classroom implementation of QuarkNet content and materials looks like. Add examples of teacher work, student work, and presentations/posters given at professional conferences when available.

E4. The Center Feedback Template process continues to provide valuable information to compare individual teacher- and center-level views on teacher engagement and on center-level outcomes. For the near future this effort may be put on the back burner and revisions to this process may be explored. This is the case, in part, because the most active centers and those most likely to align their center-level efforts with the national program as well as the Program Theory Model have completed the process.

Recommendation E4. Although not an active part of the current evaluation efforts, going forward, we will explore two ends; first, a quick and easy method to assess centers so that individual and center level responses can be compared. Second, it is expected that this revised process will be designed to help jump start or re-ignite centers to help increase their engagement in QuarkNet and/or to document these efforts.

E5. Per a recommendation by NSF, we revamped the preliminary quantitative analyses to investigation the unique contribution major QuarkNet components play in the measurement of program engagement and outcomes. These analyses suggest that Data Camp and Variety of Workshops each contribute to teachers’ reported engagement in Core Strategies, and that each major program component of QuarkNet contributes uniquely to at least one or more outcome measures: Approach to Teaching; QuarkNet’s Influence on Teaching, Student Engagement (as reported by teachers), QuarkNet’s Influence on Student Engagement; and Long-term Teacher Outcomes. Thus, these analyses suggest that each of the major components of QuarkNet contribute uniquely to outcomes as measured.

Recommendation E5: The unique contribution of major QuarkNet program components has been noted but these analyses do not take into consideration the center in which teachers engage in the program (because of sample size limitations). Thus, these analyses will not be explored further unless recommended by NSF.

E6. *Centers Matter.* Teachers principally participate in QuarkNet through centers suggesting the statistical need to account for this nesting of teachers within these centers. Thus, a hierarchical linear regression analysis based on 26 centers (34 combined) explored the relationship between core program strategies, perceived influence QuarkNet has had on classroom teaching practices and implemented instructional practices (Approach to Teaching). The results of this analysis show that QuarkNet's Influence on Teaching, Core Strategies and Centers (as measured by mean Approach to Teaching Scores) are shown to be positively related to teacher use of content and instructional practices in their classrooms (i.e., Approach to Teaching). These results are statistically significant.

Recommendation E6: Continue to analyze teacher-level outcomes based on nested centers and increase the inclusion of as many teachers and centers in these analyses as is feasible and that meets analysis criteria.

E7. Similarly for Student Engagement, the center in which the teacher participates in QuarkNet *matters*. Thus, a hierarchical linear regression analysis [based on 26 (34 combined) centers] was conducted where QuarkNet's Influence on Student Engagement, Approach to Teaching and Centers (as measured by mean Student Engagement scores) were shown to be positively related to Student Engagement.

Recommendation E7: Modelling student-level outcomes through analyses continue to be challenged where a wide variety of possible relationships may exist but recent data suggest that this model may be becoming a more stable, reliable model. That said, continue to explore student level outcomes analyses based on nested centers with the hope that additional data will help to stabilize these results. And continue to supplement these quantitative results with qualitative examples of student work as well as former QuarkNet student achievement through success story vignettes.

E8. Long-term outcomes by participating QuarkNet teachers were measured quantitatively as well. That is, perceived QuarkNet's Influence on Teaching, Student Engagement and Center-level means scores are positively and statistically related to Long-term Outcomes: Teachers.

Recommendation E8: These results have been replicated with additional data from 2025 program year.

E9. Qualitative analyses have supported the results of these quantitative analyses by providing descriptive details including examples of classroom implementation plans of QuarkNet content and materials by participating teachers. This information has been compiled in center-level portfolios (as already mentioned) which have included: teacher responses to open-ended survey questions over time as to the *what/how/why* of classroom implementation; examples of implementation plans created by teachers, as well as examples of teacher work, and student work. Examples of presentations at professional conferences are included as well, when available. And highlighted through success story vignettes.

Recommendation E9: Continue to explore the development and use of these center-level portfolios. Expand these portfolios, as needed, to include supplemental documents that highlight the engagement of teachers and students in the implementation of QuarkNet content and materials. Add success story vignettes as needed.

E10. Continue to work with program staff to help articulate ways in which the PTM can be used and how to facilitate this use. This includes seeing the PTM as representative of the program (as an "approximate fit") and the value of its Theory of Change.

Recommendation E10: It is important that the evaluator remains mindful of the many responsibilities of QuarkNet program staff, mentors and teachers. Work to ensure that evaluation requests are reasonable and doable in a timely manner. And to the extent possible, embed evaluation requests and efforts within the structure and delivery of the program as has been done during this grant period. In addition, work to ensure that evaluation efforts and results are of value (or of potential value) to all those involved in the process. This includes QuarkNet staff and network of partners, advisory board members, participating teachers, NSF and others who may be interested in QuarkNet.

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