Evaluation of the QuarkNet Program: Evaluation Report 2023-2025

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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 2025. 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, 2019-2024a). A distinction difference of this 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 70.

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: Professional Development for HS Teachers
2. (Develop and) Use a Program Theory Model
3. Program Organization
4. Data Activities Portfolio: Brief History and Development
5. Program Implementation and Measuring Fidelity (*Designed* vs. *Implemented* Program)
6. Linking Program Strategies to Outcomes
7. Survey Implementation and Response Rates
8. Summary of QuarkNet Teachers: Demographics
9. School Characteristics and Student Demographics
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 *Matter*
13. Qualitative Analyses: Center-level Portfolios A Narrative Picture of QuarkNet's Influence
14. Center-level Outcomes and Effective Practices
15. Getting the Word Out
16. QuarkNet Success Stories: Case Studies
17. Program and Evaluation Recommendations

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 implementa-

[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.

tion of these principles in their classrooms, delivering its professional development (PD) program in partnership with local centers" (Program Theory Model, PTM, 2019).

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 present evaluation, but we draw on the program's rich 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 55 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).

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

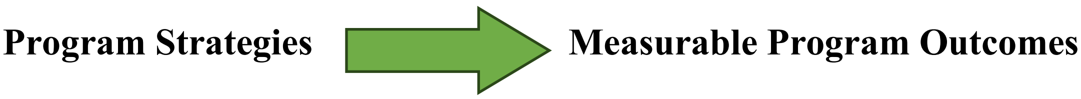


Figure 1. Throughout the evaluation, program engagement (i.e., specifically exposure to core program strategies) provides the context in which assessment has occurred.

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.)

Who is the Audience? 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 program *as implemented* is aligned with the program *as designed* (i.e., its theory). For the external evaluator, the PTM has directed the outcomes-based evaluation.

Exhibit C 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)

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.

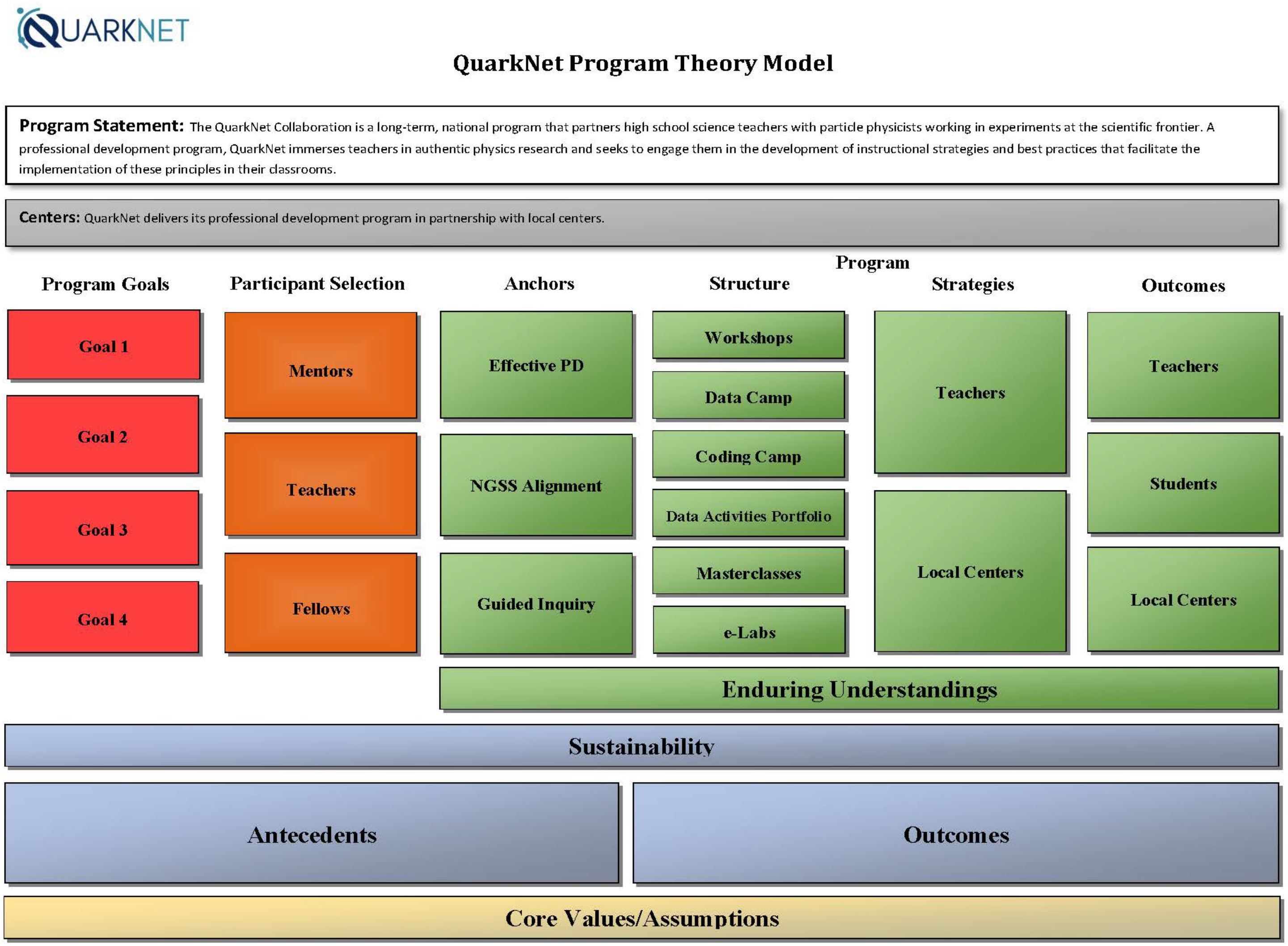


Exhibit B. The second page of the PTM overviews its component parts.

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.

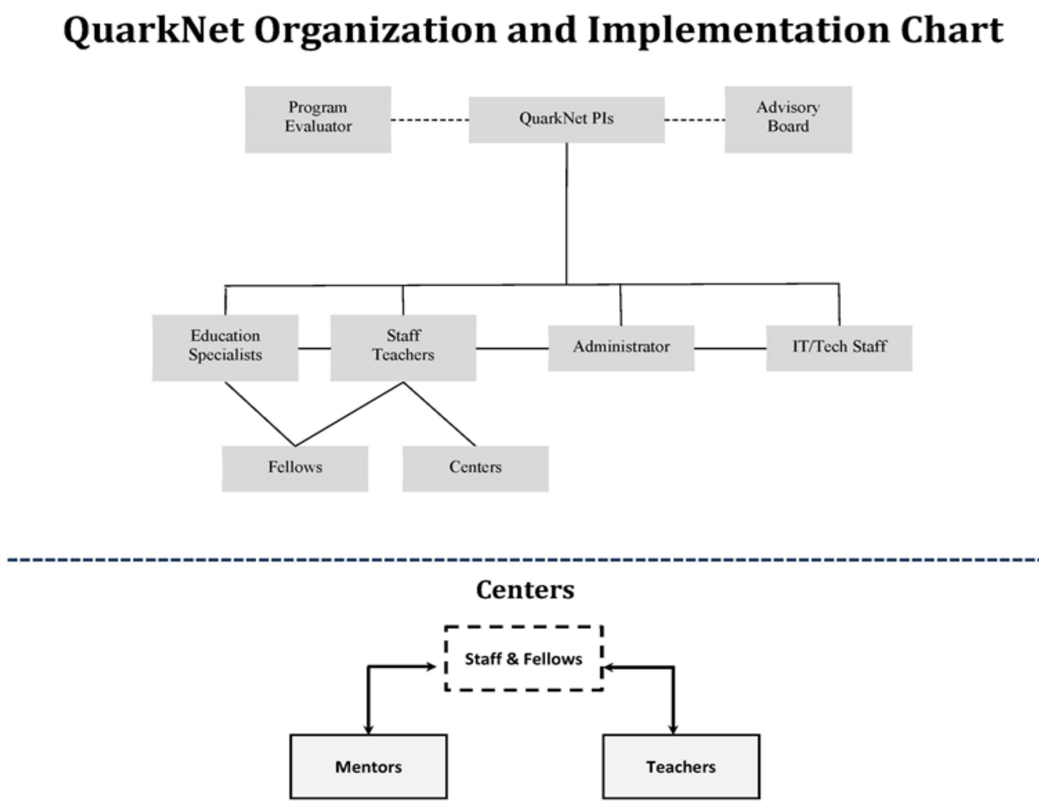


Figure 2. An overview of the organization and implementation of the QuarkNet Program.

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.)

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.

Table 1
QuarkNet Centers through Program Years 2019-2024: 55 Total

Single or combined[a]	Center	Single or combined[a]	Center
1	Black Hills State University	1	University of Alabama
2	Boston/Brown University/ Northeastern University	1	University of California -- Irvine
2	Brookhaven National Laboratory/Stony Brook University		~~University of California -- Riverside~~
1	The Catholic University of America		University of California -- Santa Cruz
1	Colorado State University	1	University of Cincinnati
1	Drew University	1	University of Florida/Middle Florida
2	Fermilab/University of Chicago/College of DuPage	1	University of Hawai'i
	~~Florida Institute of Technology~~	2	University of Illinois at Chicago/ Chicago State University
1	Florida International University	2	University of Iowa/Iowa State University
1	Florida State University	1	University of Kansas
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
	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
2	Rice University/University of Houston	1	University of Wisconsin –Madison
1	Rutgers University	1	Vanderbilt University
2	Southern Methodist University	1	Virginia Center (Hampton, George Mason, William & Mary Universities)
1	Syracuse University	1	Virginia Tech
1	Texas Tech University	1	Virtual Center
1	University at Buffalo – SUNY		~~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 June 2025).

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 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. New activities have been added, and several 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 42 (as of May 2025).

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 created by D. Roudebush, May 2025 and used with permission.) 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, nine DAP activities have been translated into Spanish (as of May 2025).

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	Seven 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).

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.

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 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 that is 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**. 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).

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.

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.

Table 3 provides a list of the current activities in the Data Activities Portfolio (DAP); 40 activities are listed in this table. This represents: 10 activities at Level 0; 13 activities at Level 1; 14 activities at Level 2; 2 activities at Level 3; and 1 activity at Level 4.

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
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 March 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/)

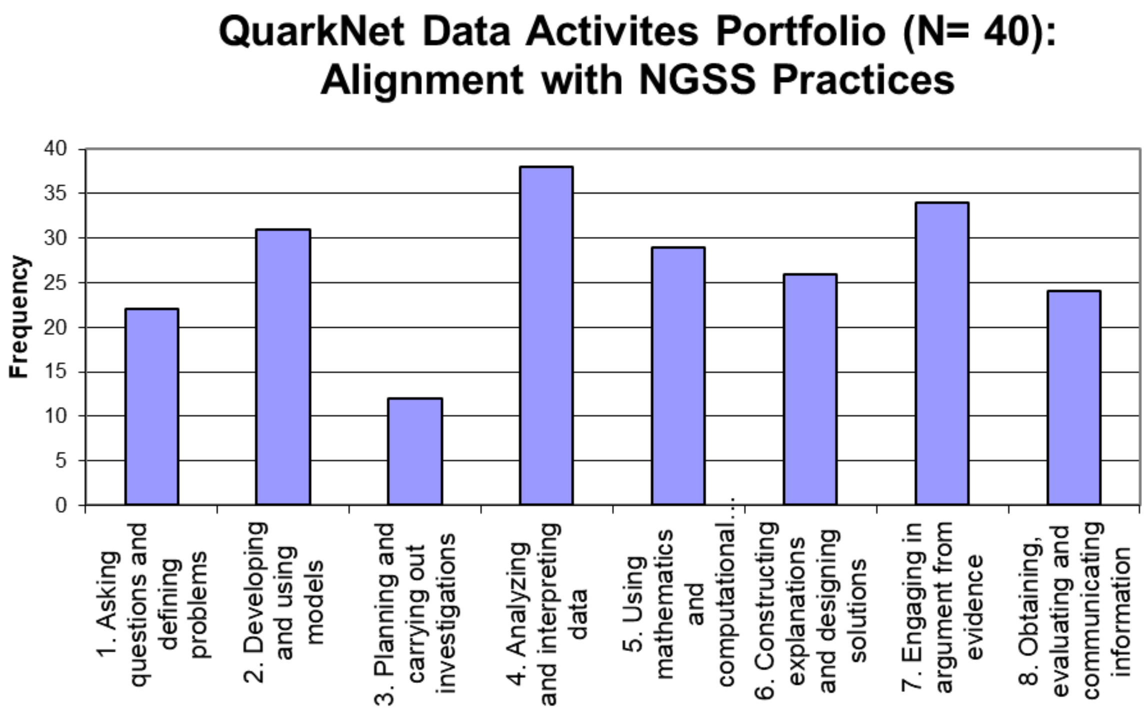


Figure 3. Alignment of Data Activities Portfolio activities with NGSS Science Practices. (Note: The two Step-Up activities are not included in this graph.) (As of 6/15/2025.)

As 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). And, 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

Two points seem evident from the distribution shown in Figure 3 that shows the alignment of the activities from the Data Activities Portfolio (DAP) with the Next Generation Science Standards, Science and Engineering Practices. 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 4, 5, 6 and 7 (that is, 4. Analyzing and Interpreting Data; 5. Using Mathematics and Computational Thinking.; 6. Constructing Explanations and Designing Solutions; 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 and 3 activities).

Second, the less frequently noted first three practices (1. Asking questions and defining problems. 2. Developing and Using Models. 3. Planning and Carrying Out Investigations.) 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 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 notable exceptions because these require prior preparation to fully engage in these. 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 understanding*s 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)]

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 • CMS Masterclass WZH-path • How Speedy are These Muons>	2 2 1
2. Scientists use models to make predictions about and explain natural phenomena.	• Cosmic Ray e-Lab • CMS e-Lab	3 3
3. Scientists can use data to develop models based on patterns in the data.	• Mapping the Poles • Making it 'Round the Bend – Qualitative • Making it 'Round the Bend – Quantitative • Mean Lifetime Part 1: Dice • Mean Lifetime Part 3: MINERvA • Introduction to Coding Using Jupyter • Angles and Dimuons • Mean Lifetime 2: Cosmic Muons	0 0 2 1 2 0 1 2
4. Particle physicists use data to determine conservation rules.	• Making Tracks I • Making Tracks II • Rolling with Rutherford • The Case of the Hidden Neutrino • ATLAS Z-path Masterclass • TOTEM 1	0 1 1 1 2 1
5. Indirect evidence provides data to study phenomena that cannot be directly observed.	• Making Tracks I • Making Traces II • Rolling with Rutherford • The Case of the Hidden Neutrino • ATLAS Z-path Masterclass	0 1 1 1 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 • Dice, Histograms & Probability • Histograms: The Basics • Z Mass Spreadsheet Extension	0 0 0 2
7. Scientists form and refine research questions, experiments and models using observed patterns in large data sets.	• Cosmic e-Lab • CMS e-Lab • Research Using Coding	3 3 4
8. The Standard Model provides a framework for our understanding of matter at its most fundamental level.	• Quark Workbench 2D/3D • Particle Transformations • Cosmic e-Lab • CMS e-Lab	0 1 3 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 • Calculate the Top Quark Mass • Energy, Momentum, and Mass • CMS Masterclass WZH-path • CMS Masterclass J/Psi	1 1 1 2 2
11. Fundamental particles display both wave and particle properties and both must be taken into account to fully understand them.	• TOTEM 2 • ATLAS Data Express	2 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 • Mean Lifetime Part 3: MINERvA • Mean Lifetime Part 2: Cosmic Muons	1 2 2
15. Particle physicists must identify and subtract background events in order to identify the signal of interest.	• Signal and Noise: The Basics • Signal and Noise: Cosmic Muons • CMS Masterclass J/Psi	0 1 2
16. Scientists must account for uncertainty in measurements when reporting results.	• What Heisenberg Knew • Histograms: Uncertainty	1 1

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; and January 19, 2023), 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/page/ summer-workshop-opportunities-quarknet-centers) as well as a staff-member representative list (see for example https://quarknet.org/content/ quarknet-center-staff-assignments-january-2020).

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 2024 program years starting with an annual email blast distributed with a link to support information (as already described).

Program Years 2019-2023

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. 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 young women and minorities to 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. Of note, QuarkNet staff added many online-available resources in response to challenges due to the coronavirus starting in March 2020 including program modifications made to help adapt QuarkNet to online teaching venues. 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 2023-2024

The implemented workshops during the 2023-2024 QuarkNet program year are shown in Table 5. Centers could choose among a list of available nationally led workshops, such as: Higgs Boson Discovery; W2D2; ATLAS Workshop; ATLAS Workshop Update; CMS Data Workshop; CMS Data Workshop Update; MINERvA Data Workshop; Belle II Data Workshop; Coding Workshop; Introduction to STEP UP; Muon Study; New Questions in Particle Physics; and Special Relativity. Table 5 focuses on Data Activities Portfolio (DAP) activities included in the workshops as a direct means to bring QuarkNet content into the classroom.

Table 5

2024 QuarkNet Workshops and Meetings: National- and Center-led (December 2023-October 2024)

Center	2024 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	No activity		
Boston Area/Brown University/ Northeastern University[a]	December 8, 2023	Winter Meeting	Center led teacher and fellow presented a talk titled "Relativity and GPS: How Einstein Helps You Find Your Way Home." He reviewed the history of relativity from Galileo to Einstein, discussed efforts to characterize the luminiferous aether, development of the Lorentz transformations, and the importance of the special and general relativistic corrections to the clocks in GPS satellites relative to clocks on Earth that allows accurate position finding with GPS receivers in smart phones. Embedded in the talk were the classic video of the muon time dilation experiment with measurements on Mt. Washington in New Hampshire, and at MIT in Cambridge, Massachusetts, and a short video on the history of the GPS satellite system. He also gave out the teachers' version of the Lorentz Transformation worksheet that he sent to the Boston QuarkNet participants.
	March 9	Particle Physic Masterclass	Thirty-one high school students and five QuarkNet teachers from Massachusetts, Rhode Island, and Vermont participated; Agenda items included get-acquainted exercises; talk on particle physics; talk on analysis of CMS proton collision images; opportunity to talk with physics grad students at lunch; and a visit to lab where a small liquid argon time project chamber is being built. Students and teachers met via a video conference with students from Williamsburg VA, Mexico and Columbia and physicists and fellows at Fermilab.
	June 6	Spring Meeting	Concurred with the presence in Boston of the Large Hadron Collider Physics conference in Boston during early June including a tour of the MIT Media Lab.
	August 20-21	Relativity Workshop	Day 1 focused on the historical development of the idea of relativity from Galileo to Einstein, the development of Lorentz transformations (following Taylor and Wheeler), and the idea of the invariant interval (proper time between events). Day 2 concentrated on the ideas of conservation laws in nature, the relation to continuous symmetries of space and time related to those conservation laws, and the experimental and theoretical development of the m^2 = E^2 - p^2 relation between the mass, energy, and momentum of a particle. the PowerPoint slides and documents used in the workshop are available for download.

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.)

2024 QuarkNet Workshops and Meetings: National- and Center-led (December 2023-October 2024)

Center	**2024 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 27-28	Summer Workshop	Data Activities Portfolio Activities: Quark Workbench Top Quark ATLAS muon track measurement ATLAS masterclass Particle Transformation Teachers prepared and shared implementation plans
Catholic University of America	August 9	Summer Mini-Workshop	Review Level 0-1 Data Activities – Report to group Other events (e.g., Dark Matter Day, WWDD)
	April 27	**ATLAS Masterclass**	Intro to ATLAS and masterclass measurement Students analyze data Discuss results and brain storm questions
Colorado State University	June 6-7 July 25-26	**Summer Workshop**	Tour of SURF Selecting a DAP activity that is new to teacher Share-out discussion about DAP Activities Implementation Plans CRMDs Building Cosmic Watches Lab Tour
	March 10	**NOvA Masterclass** (3 teachers and 30 students)	Part 1 NOvA Analysis Far Detector Part 2 NOvA Analysis Near Detector
Drew University	May 18	**1-day Introduction to QuarkNet**	
Fermilab/University of Chicago/College of DuPage[a]	July 30-31 August 1-2	**QuarkNet Teachers Workshop** (16 teachers)	Series of presentations by scientists, teachers and students; a number of activities working toward the introduction of statistical analysis of data while learning physics Data Activities Portfolio Activities Cosmic Ray: E-lab; Signal and Noise; Speed of Muons; Flux Study; Lifetime Study; Muon Detectors; Time of Flight.

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.)

2024 QuarkNet Workshops and Meetings: National- and Center-led (December 2023-October 2024)

Center	2024 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	No activity		
Florida State University	July 24-25	Coding Workshop	Introduction to Jupyter Probability Muon Mass Implementation Plans
Idaho State University	June 24-27	Quantum and More Workshop	Workshop Aims: Explain a variety of quantum phenomena based on three principles. Apply quantum phenomena to explain particle physics phenomena. Accept the precept, "If you understand quantum mechanics, you don't understand quantum mechanics."
Johns Hopkins University	July 22-26	WZH Workshop	Morning Sessions: Talks and Presentations Afternoon Sessions: Lab Activities (Intro on 22nd) Cosmic Ray Detectors Radio Astronomy: Galactic Rotation Curves Radio Astronomy: Measuring the CMB Temperature Cloud Chambers for the Classroom Link to Data Activities Portfolio
	March	Masterclass	Six schools and over 60 students
Kansas State University	June 24-25	(In Person) NOvA Data Workshop	Engagement in Data Activities: Making Tracks I Mean Lifetime Part 1: Dice Mean Lifetime Part 3: MINERvA NOvA Masterclass Measurement NOvA Far Detector Analysis Part 1 NOvA Near Detector Analysis Part 2 Teachers prepared and shared implementation plans
	May 28	(Virtual) Cosmic Ray Detector Workshop	Typically attended by 4 CRMD teachers.
	March 1	Masterclass	Seven teachers (and their students) participated.
	Feb. 10	Masterclass Orientation	Eight teachers attended.

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.)

2024 QuarkNet Workshops and Meetings: National- and Center-led (December 2023-October 2024)

Center	2024 Dates (All dates except where noted)	Workshop/Meeting	Brief Summary of Activities and Data Activities Portfolio (Level) [and/or classroom use/implementation plans]
Lawrence Berkeley National Laboratory	July10-11	**Particle Physics Data Activities**	Particle Cards Quark Workbench Searching for Higgs in CMS data Z Mass Measurement
	July 8-12	Physics in and through the Cosmology 1-Week In-Person Workshop	A total of 8 teachers and 37 students participated. Discussion on a variety of topics and students worked in groups for an Interview a Scientist Project. Presentation by Nobel Prize winner Saul Perlmutter
	Feb 3	1-Day Workshop	Data Portfolio Activities: Shuffling the Particle Cards Quark Workbench Angels and Dimuons Intro to ATLAS measurement
Louisiana Tech University	No activity		
Northern Illinois University	No activity		
Oklahoma State University/University of Oklahoma[a]	July 29-31	**Relativity Workshop** (Nine teachers)	Mean Lifetime I: Dice Mean Lifetime II: Cosmic Muons How Speedy are These Muons? Relativity Tutorial Energy, Momentum and Mass Z mass calculation
	No dates	Two ATLAS Masterclasses	Attended by 30 students from three different schools.
Purdue University	No activity		
Purdue University Northwest	No activity		

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.)
2024 QuarkNet Workshops and Meetings: National- and Center-led (December 2023-October 2024)

Center	**2024 Dates (All dates except where noted)**	**Workshop/Meeting**	**Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
Queensborough Community College	August 19-23		List of technical papers
Rice University/University of Houston[a]	July 10-14	**CMS Data and Cosmic Ray Workshops**	Data Activities Portfolio Activity Engagement Quark Workbench Making Tracks I – Cloud Chamber Making it Round the Bend Qualitative Quantitative Particle Detectors Tutorial Energy, Momentum and Mass Particle Transformation Mass of Z CMS Masterclass Measurement Mean Lifetime Part 1: Dice Mean Lifetime Part 2: Cosmic Muon How Speedy Are These Muons? QN Experience Share-a-thon
	March 2	Masterclass	About 11 students in attendance.
	Dec. 2023	Forum: Helping Shape the Future of Physics Education in Our Schools	Sixteen teachers in attendance (brought in new teachers to QuarkNet).
Rutgers University	July 1-3, 8-12, 15-16	Workshop	Hands-on work by students and analysis of real data from particle physics experiments. Daily talks and panel discussion
Southern Methodist University	July 16-18	QuarkNet Physics Workshop (20 teachers)	Series of talks and presentations Hands-on Activity: Cloud Chamber Heard presentations from the STARS program

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.)

2024 QuarkNet Workshops and Meetings: National- and Center-led (December 2023-October 2024)

Center	**2024 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 14-16	Summer Workshop (4 teachers)	Muon Tutorial DAP Activities: How Speedy are These Muons? Mean Lifetime Part 1: Dice Mean Lifetime Part 2: Cosmic Ray Muons Mass of Z Intro to Coding As part of DAP activities And for curriculum (e.g., math, physics)
Texas Tech University	June 10-11	Workshop Activities	Hands-on Activities at Quantum Material Lab: Sample Preparation & Measurements (Electrical Transport)
	June 14, 18	Workshop Activities	Hands-on Activities at APD (Advanced Particle Detector) Lab
	June 19	Workshop Activities	Cosmic Ray Experiment, General Discussion, Plans
University of Alabama	No activity		
University at Buffalo -SUNY	No activity		
University of California – Irvine	No activity		
University of California -Santa Cruz	No activity		

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.)

2024 QuarkNet Workshops and Meetings: National- and Center-led (December 2023-October 2024)

Center	**2024 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 Cincinnati	July 15-17	**Workshop** (10 teachers, 5 of which were new)	Shuffling the Particle Deck Making Track I: Cloud Chamber Exploring the ATLAS detector Rolling with Rutherford World Wide Data Day and other events
University of Florida/Middle Florida	February 10	**QuarkNet Day**	QuarkNet Workbench Angels and Dimuons Mean Lifetime Part 1: Dice Mean Lifetime Part 2: Mean Lifetime Part 2: Cosmic Ray Muons
University of Hawai`i	March 16	**Half-day Workshop** (5 teachers)	Muon Tutorial Mean Lifetime Part 1: Dice Mean Lifetime Part 2: Mean Lifetime Part 2: Cosmic Ray Muons
	March 15	**CMS Masterclass** (26 students from two high schools)	Quark Puzzle Z boson Analyzed data in pairs Discussion of results and videoconference with Fermilab
University of Illinois at Chicago/Chicago State University[a]	August 6-8	**Summer Workshop**	CME Sensitivity and Magnetic Field K-Factor (student presentation) Cosmic Ray E-Lab Muon Speed Measurement Eclipse CME Data Analysis
University of Iowa/Iowa State	No activity		
University of Kansas	No activity		

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.)

2024 QuarkNet Workshops and Meetings: National- and Center-led (December 2023-October 2024)

Center	**2024 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 Minnesota	August 5-7	**Summer Workshop: Quantum and Modern Classroom**	Quantum Workshop activities Light as a wave Light as a particle Quantum Concepts Tutorial Heisenberg's Laser What Heisenberg Knew Implementation Discussion 7 Plans
	March 9	**NOvA Masterclass**	NOvA Masterclass Measurement Part 1& 2 Select Coding Activity Options
University of Mississippi	June	**2 Day Workshop**	Presentations (by physicists and grad students) Neutrino Masterclass Tour of neutrino research lab
University of New Mexico	July 15-17	**Coding and STEP UP Workshop**	Intro to Jupyter Probability Muon Mass Notebook Coding Activities: Physics (Position and Velocity Graphs) Earth Science Earth & Space Science Chemistry Math Physics STEPUP Activities Careers in Physics Women in Physics

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.)

2024 QuarkNet Workshops and Meetings: National- and Center-led (December 2023-October 2024)

Center	**2023 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	Ongoing (Multiple Dates)	Summer Research Program	Research work related to: CMS Hardware, Astrophysics, Digital Visualization, Cosmic Rays, CMS Data, Environmental Sensors, Microtubule Dynamics, CMS Hardware Cable Spark Chamber, and Nuclear. Continued work with Cosmic Watches and Project GRAND. Other projects included Astrophysics, magnetic phenomena, building and testing CO_2 sensors (with Indiana University South Bend), and CMS Data.
	March 12	Belle II Masterclass	Presentations Data Analysis Discussion of results and videoconference (March 21)
	March 9	ATLAS Masterclass	ATLAS and the Standard Model Intro to Measurement Analysis and discussion of results Video conference
University of Oregon	July 2	Workshop	Local workshop
University of Puerto Rico – Mayaguez	Oct. 26	Workshop	Energy, Momentum and Mass Particle Mass Special Relativity
	March 16	MINERvA Masterclass	
	March 1	Masterclass Orientation	

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.)

2024 QuarkNet Workshops and Meetings: National- and Center-led (December 2023-October 2024)

Center	2023 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 Rochester	July 23-24	Summer Workshop	DAP Exploration: Rolling with Rutherford Shuffling the Particle Deck Quark Workbench 2D/3D CMS Masterclass Z-Mass Mean Lifetime Part 1: Dice Mean Lifetime Part 3: MINERvA Coding Notebooks Implementation Plans
University of South Dakota	June 24-25	Workshop	Intro to Jupyter Notebooks Physics Math Chemistry Earth & Space Science DAP Activities Implementation Plans
	March 8	MINERvA Masterclass	Introduction to QuarkNet and Particle Physics Shuffling the Particle Deck
University of Washington	Nov 18	Half-day Workshop	Intro to QuarkNet and various presentations
	June 26-27	Cosmic Ray Workshop	Cosmic Ray Detector Cosmic Ray e-Lab Shuffling the Particle Deck Cosmic Ray studies Cosmic Ray Muon Analysis: Muon Time of Flight Rolling with Rutherford Discussion: Implementation Plans
	March	Masterclass	
University of Wisconsin – Madison	No activity		

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.)

2024 QuarkNet Workshops and Meetings: National- and Center-led (December 2023-October 2024)

Center	**2023 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	June 17-21	Workshop	Cosmic Ray Tutorial Mean Lifetime Part 1: Dice Mean Lifetime Part 2: Cosmic Muon Muon Decay and Relativity How Speedy are These Muons
Virginia Center (Hampton University, the College of William and Mary, and the George Mason University)[a]	Oct. 28	Workshop	Presentations Reviewed Data Activities Portfolio activities Discussed World Wide Data Day and Masterclass
	July 29-31	NOvA Workshop	DAP: Shuffling the Particle Deck Neutrino Tutorial Mean Lifetime Part 1: Dice Mean Lifetime Part 3: MINERvA Prep NOvA Masterclass Measurement NOvA Part 1: Far Detector Analysis NOvA Part 2: Near Detector Analysis
	March 23	CMS Masterclass	~ 35 students from Virginia and Maryland high schools Analysis of CMS data; heard presentations including a former Masterclass student who is working at CERN
Virginia Tech University	June 5-7	Special Relativity Workshop	Focus on recruitment and growth bringing in new teachers Intro to Particle Physics Activities Intro to QuarkNet Creating lesson plans from DAP Talk on Relativity Tour of High Energy Physics
Virtual Center	Monthly Zooms		Various topics
	July 31- August 2	In-person Workshop: Albuquerque	Light as a Wave and the Mathematics of Interference Patterns; Light as a Particle; Heisenberg Uncertainty Principle; Electron Diffraction Activity; Application of Wave Particle Duality: Totem

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]Counted as a double center.

Table 5 (con't.)

2024 QuarkNet Workshops and Meetings: National- and Center-led (December 2023-October 2024)

Center	**2023 Dates (All dates except where noted)**	**Workshop/Meeting**	**Brief Summary of Activities and Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
Data Camp	July 14-19	Week Long Camp	How We Roll Virtual Tour of CERN Broken Squares Activity Intro to Coding Top Quark CMS Calibrations DAP Activities Work on Particle and subsequent presentation of work g-2 talk Other Coding Activities Implementation Plan

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]Counted as a double center.

Other activities that occurred during these programs may be highlighted (such as, select talks on cutting edge topics in particle physics; or center tours on experiments/laboratory research). DAP activities implemented during the workshops are documented, as well, these are a frequent and an integral part of a workshop, especially for nationally-led workshops. This focus, and its documentation, coincides with the improved 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 is in line with effective teacher professional development practices outlined by Darling-Hammond, et al., (2017). Of importance, teachers are given time to reflect on how they might use these activities in their classroom, a primary purpose of the DAP, and incorporate these into implementation plans.

6. Linking Program Strategies to Outcomes

Appendix G provides, in detail as outlined in the PTM, how core strategies link to program outcomes. The first of these 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.*

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

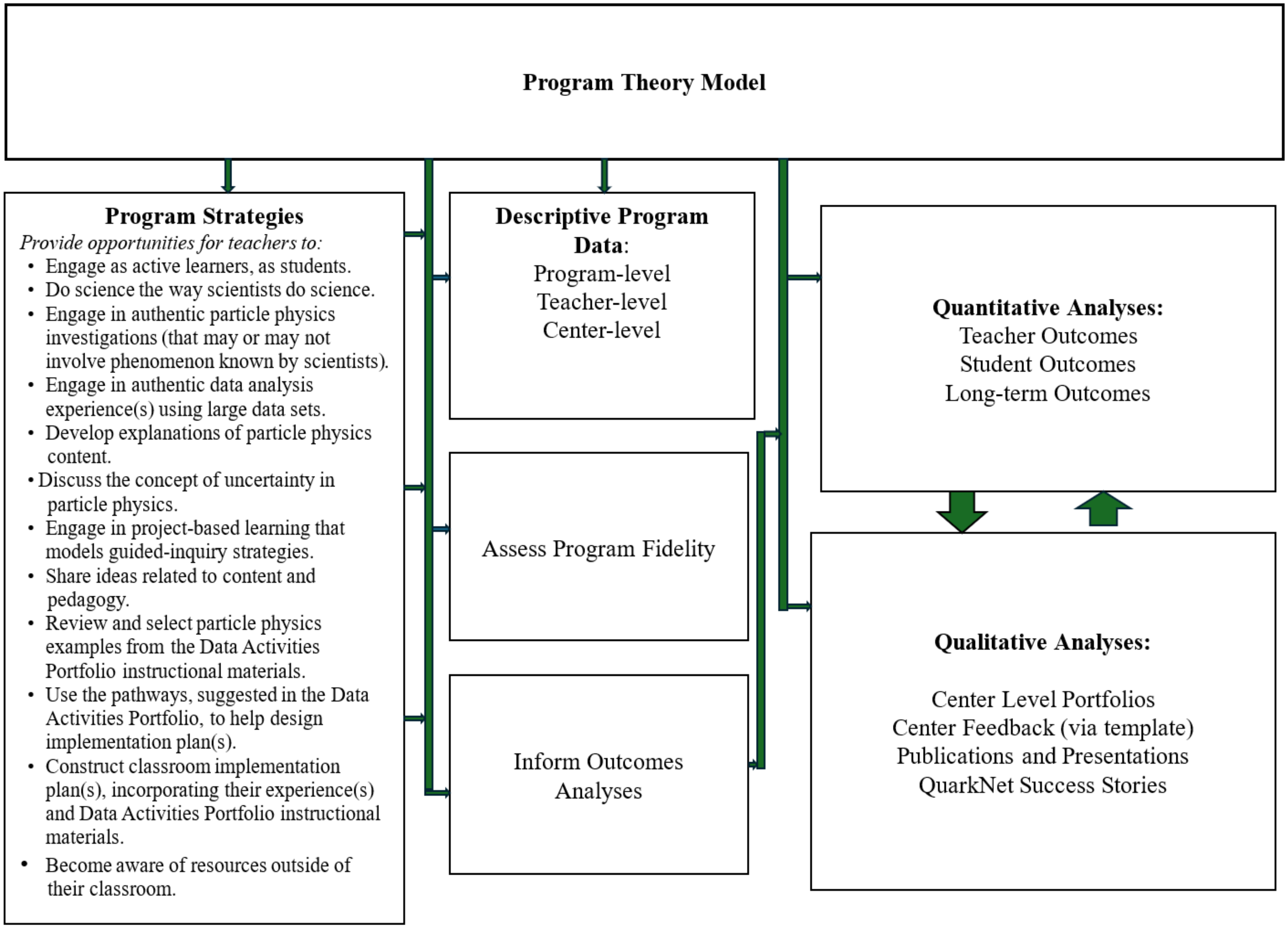


Exhibit F. Overview of Program and Outcomes Data

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. as 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 55 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.

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

Program Year[g]	Number of Enrolled Teachers	Number of Completed Surveys	Total
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.
[e]All teachers completed the full survey to coincide with the renewal grant award.
[f]In 2023, 135 teachers completed the full survey and 116 teachers completed the update survey.
[g]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 and 2023 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 2024 survey responses were linked so that year-to-year comparisons for these teachers could be made.

A total of 702 QuarkNet teachers completed their full survey; this represents a unique count of teachers across the 2019-2024 program year period. As this is a unique count, this does not represent the number of teachers who participated in a given program across multiple years. An estimate of the total number of teachers who engaged in QuarkNet during this time period – and under the umbrella of survey outreach is at least 1,400 program participants (some teachers are likely counted multiple times).

In addition to completed full surveys, 478 Update Surveys were completed across a 3-year period of 2020-2022 and in 2024. 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. And 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.

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 2019-2024 program years and who completed the full Teacher Survey A total of 657 teachers responded to this question -- 45 teachers did not indicate their gender – for a total of 702 teachers. Survey responses labeled as 2020 through 2024, 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, 50% of participating teachers are men (351); 43% are women (43.6%) and 6.4% did not provide an answer to this question (based on survey responses). Registration information from the 2024 program year suggest similar percents, that is, 48% teachers are men, 47% are women and 5% preferred not to answer this question.

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.

Teachers *New* to QuarkNet

The table in Appendix L represents a unique count of teachers who reported that they were new to the QuarkNet program during the 2019-2022 program years by center. And it includes a similar breakdown for the 2023 and 2024 program years, respectively. These counts are based on survey responses for a unique count total of 702. 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)?*

Table 7
Full Teacher Survey: Gender of QuarkNet Teachers

Program Year: Unique Count	Gender						Total	
	Men		Women		Not Specified			
(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	34	(42.5%)	46	(57.5%)	0	(0%)	80	(100%)
2019	157	(60.8%)	100	(38.7%)	1	(<.05%)	258	(100%)
Total	351	(50.0%)	306	(43.6%)	45	(6.4%)	702	(100%)

Note. Please note that this represents a unique count of teachers. Numbers for 2020-2024 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 45 survey respondents did not specify their gender. [$\chi^2_{(10,\ 702)} = 96.1983$, $p < .001$ (comparing gender across program years).]

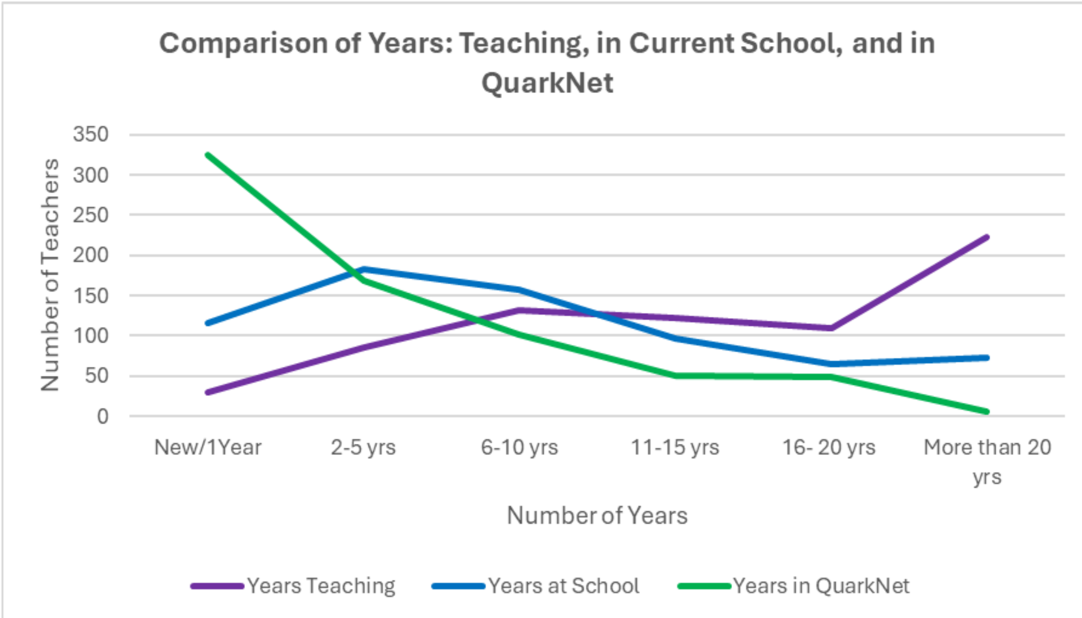
Most often, teachers new to the program either indicated that they were new; or had participated for one year or less in the program. When describing their participation as in and around one year, teachers frequently indicated that the workshop in question was their first. For this reason, the table includes both “new” and “1-year” responses as a representative number of new teachers. As indicated in Appendix L, these 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. 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%). The full survey was able to gather data on 66 of these teachers out of a total of 199 matched surveys – this also represents about 33% of participating teachers.

Years in QuarkNet, Years Teaching and Years at Current School

Figure Set 4 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 4.62 years (Standard Deviation, SD = 5.64), with a median of 2.0 years (50th percentile).

Collectively, these teachers had a mean number of years teaching of 16.12 years (SD= 10.18) (median 15.0 years); and a mean of 9.109 years at his/her school (SD = 7.99) (7.0 median years); with a few participating teachers who are retired.



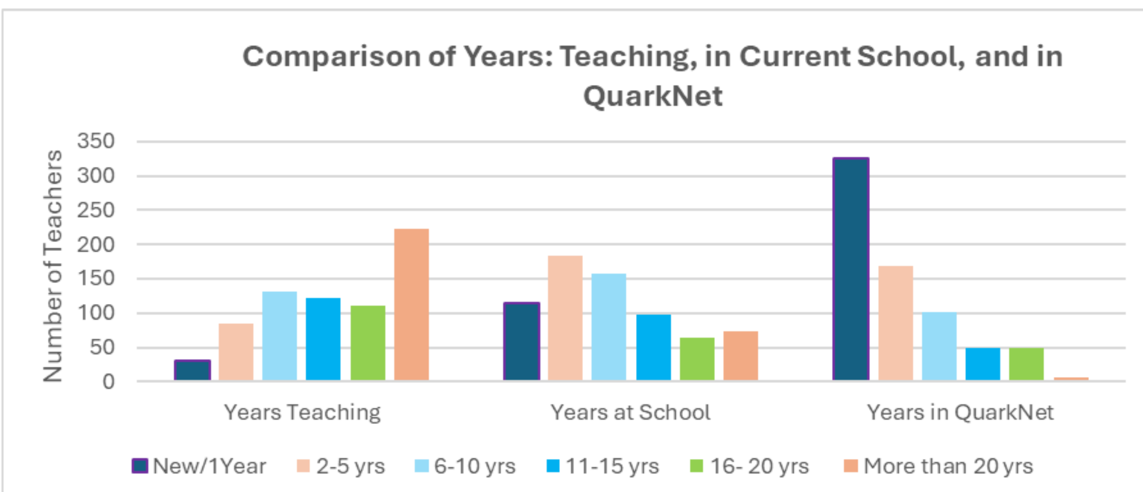


Figure Set 4. Comparison of the number of years: Teaching; at current school; and participating in QuarkNet (at the time the teacher completed his or her full survey).

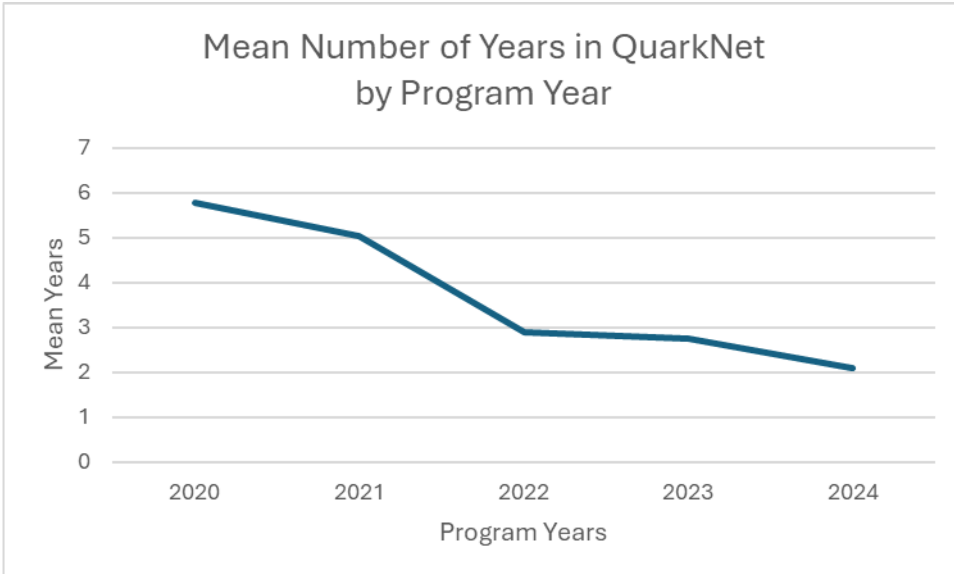


Figure 5. Over several program years, QuarkNet has been trending toward bringing in *new* teachers to the program (based on a unique count of teachers each year for a total of 702 teachers).

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 6 Analysis of Variance (ANOVA, Gender =2 and Program Year = 6), male teachers reported a higher mean number of years in QuarkNet (5.41; SD = 5.91) compared to female teachers (Mean = 3.66; SD =4.89) [$F_{(1, 643)} = 8.11$, $p < .005$]. Regarding program year, teachers reporting in program years 2022-2024 indicated a fewer number of years of QuarkNet participation (Mean = 2.89 SD = 4.53 in program year 2022; Mean = 2.33 SD = 3.82 in program year 2023; Mean = 2.30 SD= 4.77 in program year 2024) compared to teachers who completed their surveys in 2019, 2020, or 2021[$F_{(5, 643)} = 12.24$, $p < .001$]. (See Figure 5.)

As one would expect, the number of years teaching and years at current school is positively correlated and notably high (r = .65); slightly lower but still high was the positive correlation between years teaching and QuarkNet experience (r = .45); and, years at current school and QuarkNet experience (r = .39).

School Location

Teachers were asked the best descriptor for the location of the school they represented. As shown in Table 8, most often participating teachers represented schools in suburban areas (204 or 32.9%); followed by urban, central city (202 or 27.0%); urban (153 or 21.2%); or rural (133 or 18.9%). Over the course of several program years, it is important to note that QuarkNet teachers are trending toward representing urban and urban center city locations and less so from schools in suburban locations, a trend that is statistically significant [$\chi^2_{(15, 692)} = 155.34$, $p < .001$].

Table 8
QuarkNet Teachers: School Location and Teaching Physics

Demographic	Program Year: Unique Count						
	2019	2020	2021	2022	2023	2024	Total
School Location							
Rural	48 (19.0%)	15 (19.2%)	16 (23.9%)	12 (15.6%)	23 (18.1%)	19 (21.1%)	133 (18.9%)
Suburban	124 (49.0%)	38 (48.7%)	12 (17.9%)	8 (10.4%)	16 (12.6%)	6 (6.7%)	204 (32.9%)
Urban	49 (19.4%)	15 (19.2%)	7 (10.4%)	25 (32.5%)	32 (25.2%)	25 (27.8%)	153 (21.2%)
Urban, Central City	32 (12.6%)	10 (12.8%)	32 (47.8%)	32 (41.5%)	56 (44.1%)	40 (44.4%)	202 (27.0%)
Total	253 (100%)	78 (100%)	67 (100%)	77 (100%)	127 (100%)	90 (100%)	602 (100%)
Teach Physics?							
Yes	223 (87.5%)	58 (73.4%)	47 (69.1%)	59 (77.6%)	89 (70.1%)	69 (76.7%)	545 (78.4%)
No	32 (12.5)	21 (26.6%)	21 (30.9%)	17 (22.4%)	38 (29.9%)	21 (23.3%)	160 (23.0%)
Total	255 (100%)	79 (100%)	68 (100%)	76 (100%)	127 (100%)	90 (100%)	695 (100%)

Please note that this represents a unique count of teachers. Numbers in 2020, 2021, 2022,and 2023 **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. Eight teachers did not indicate the location of their school. And seven teachers did not indicate whether or not they were teaching physics at the time they completed their survey.

School location was not statistically related to the gender of participating teachers.

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 [$\chi^2_{(5, 695)} = 22.35$, $p < .001$] from a percent high of 88% to a low of 69%. Slightly more female teachers do not teach physics as compared to male teachers [$\chi^2_{(1, 650)} = 16.94$, $p < .001$]. 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	217	Cosmic Ray e-Lab Advanced Topics	37
ATLAS	59	Neutrino Data Workshop	132
CMS Data Workshop	116	ATLAS Masterclass	68
CMS e-Lab Workshop	95	CMS Masterclass	128
Cosmic Ray e-Lab Intro	211	Neutrino Masterclass	60
Other QuarkNet Events			
International Muon Week	40[a]	International Cosmic Day	36[a]
CERN	57	World Wide Data Day	26[a]
Greece Trip	13		
Coding Workshops/ Coding Camp 1 and Coding Camp 2[b]			~250[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 (2020-2023). The number of participants in coding events **does not** represent a unique count of teachers and was taken from Race, September 2024. 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, except for coding events). As to specific programs, most often, teachers indicated that they had participated in Data Camp (205) and Cosmic Ray e-Lab introduction (192). 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.

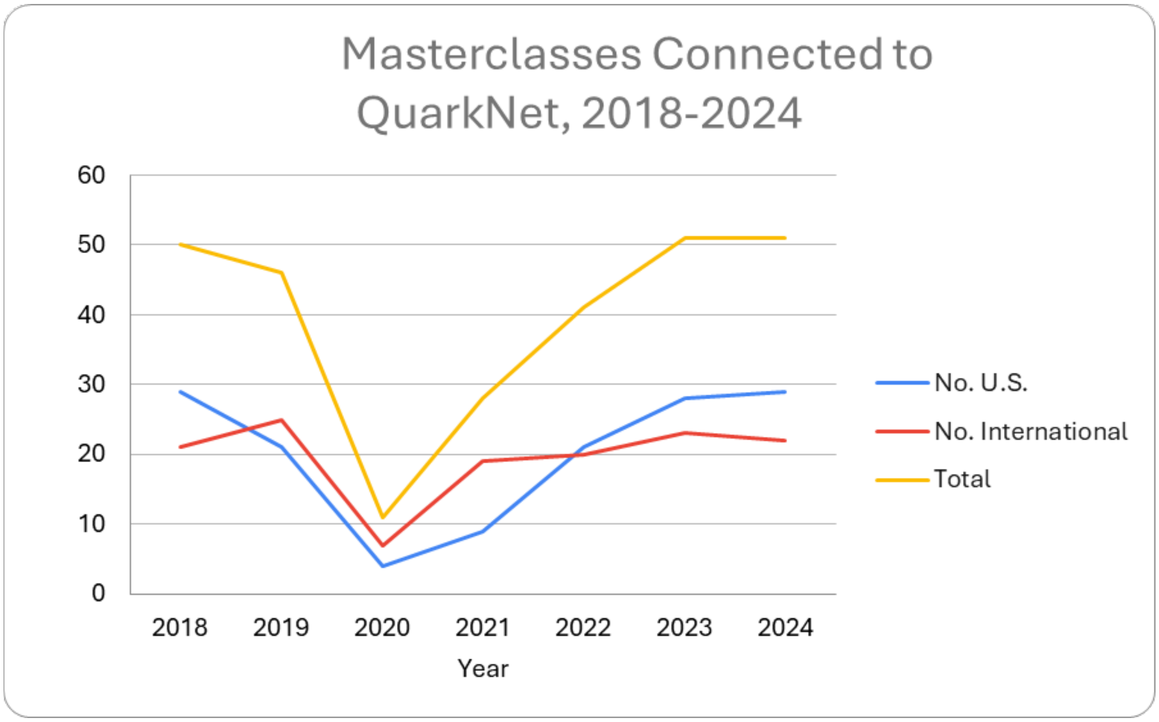


Figure 6. QuarkNet Masterclasses by program year (data from K. Cecire, 2024).

<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.

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 report to IRIS-HEP on this engagement (Race, September 2023); although this is not a unique count of teachers.

A graph created by Cecire, (see Figure 6 displayed here with permission) 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 more accurate picture of the possible opportunities for QuarkNet teachers to engage in QuarkNet masterclasses across the current grant period.

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)

Note. Data compiled by M. Adams used with permission. 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.

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. It also reflects 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 reports the number of DAQs used in analyses. A total of 308 and 351 e-Lab plots were saved in 2024 and 2023, respectively. (Historic totals for plots and file uploads are 26,896 and 134,781, respectively.)

It should be noted that these tables represent data that are more complicated than these simple tables imply; each represents a snapshot and “not necessarily the final word” (email Adams 3/6/25).

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).

Participation by program year differences may likely be linked to the onset of COVID which altered the implementation of QuarkNet especially during the 2020 and 2021 program years. For example, Data Camp (fundamentally an in-person event) was implemented only in 2019 and returned again in 2022 and 2023. Those teachers who indicated that they had participated in Data Camp, as reflected in program years 2020 and 2021, were reporting past engagement in QuarkNet and 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 2020-2023 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 2020-2023 program years. And the number of masterclasses was more than expected engaging in masterclasses in 2019 as compared to 2020-2023 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	
Data Camp[a]							
Yes	112	33	14	24	22	78	283
No	146	47	54	53	106	12	418
Total	258	80	68	77	128	90	701
Variety of Prior Workshops[b]	–						
None	79	37	35	46	88	63	348
One workshop	79	19	20	17	29	20	184
Two or more	100	24	13	14	11	8	170
Total	258	80	68	77	128	91	702
Masterclasses[c]							
None	147	56	52	69	105	80	509
One or more	111	24	26	8	23	11	193
Total	258	80	68	77	128	91	702

[a][$\chi^2_{(5, 701)} = 50.54$, $p < .001$]; [b][$\chi^2_{(10, 701)} = 88.01$, $p < .001$]; [c][$\chi^2_{(5, 702)} = 59.96$, $p < .001$]

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 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.

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.

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

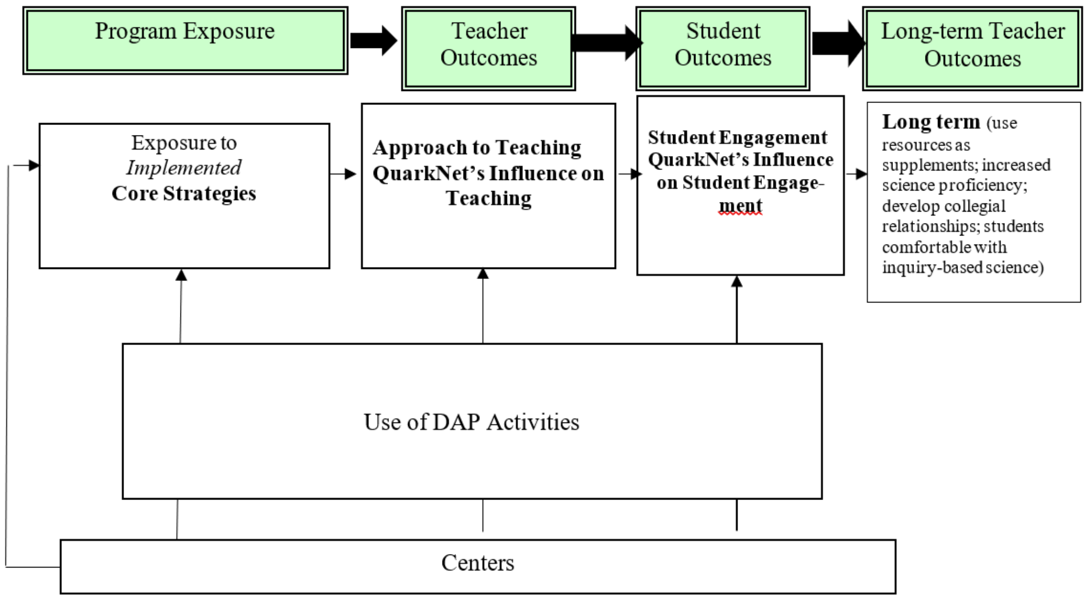


Figure 7. Teacher (and their Students) and Long-term Outcomes: Overview of Analyses

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 2024 Full Teacher Surveys and have conducted a descriptive look at responses from the 2020 through 2022 program years, and then again in 2024, 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.* We reserve judgment as to the best model(s) to use at this time because these analyses are preliminary. Additional data added into this mix over the course of the past and current grant period have permitted the incorporation of center-level data into these models, when statistically feasible. We had used qualitative analyses to describe how teachers have incorporated QuarkNet content and materials in their classrooms within the context of center-level program engagement. 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.

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. A *new* 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 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. (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 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*

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 **Core Strategies**[a] scores and **Approach to Teaching** 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 Masterclass.	
Masterclass	Participation in Masterclasses (one or more) as reported by teachers was statistically significantly related to **Student Engagement**, and **QN's Influence on Student Engagement** scores.	Higher **Student Engagement** scores were also statistically significantly related to reported workshop 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 2023 program years.

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.

These analyses, although encouraging, are limited in that each *does not* take into consideration 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.

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, 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 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); this represents nearly two-thirds of participating centers. Data from a total of 513 teachers were potentially eligible for analysis inclusion, representing slightly more than 75% of participating teachers who completed their surveys. In practice, however, the number of teachers included in these analyses reduced to about two-thirds of the teacher data that we have in order to meet full data-set requirements.

A hierarchical linear regression analysis based on these 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 are modeled in Figure 9 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 [$F_{(3, 424)} = 77.32$, $p < .001$]. Figure 10 shows details of the survey items that comprise each of these scale scores.

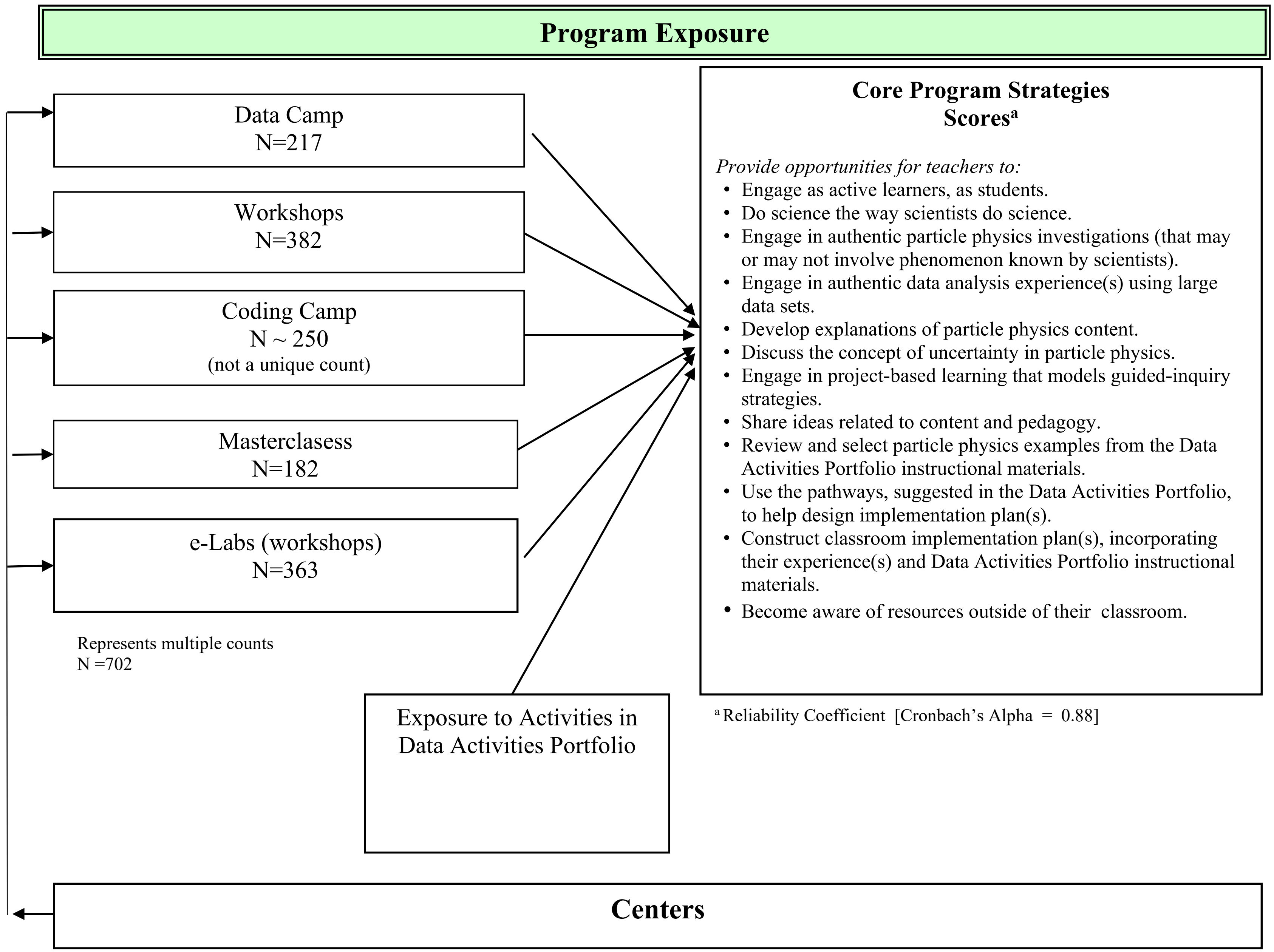
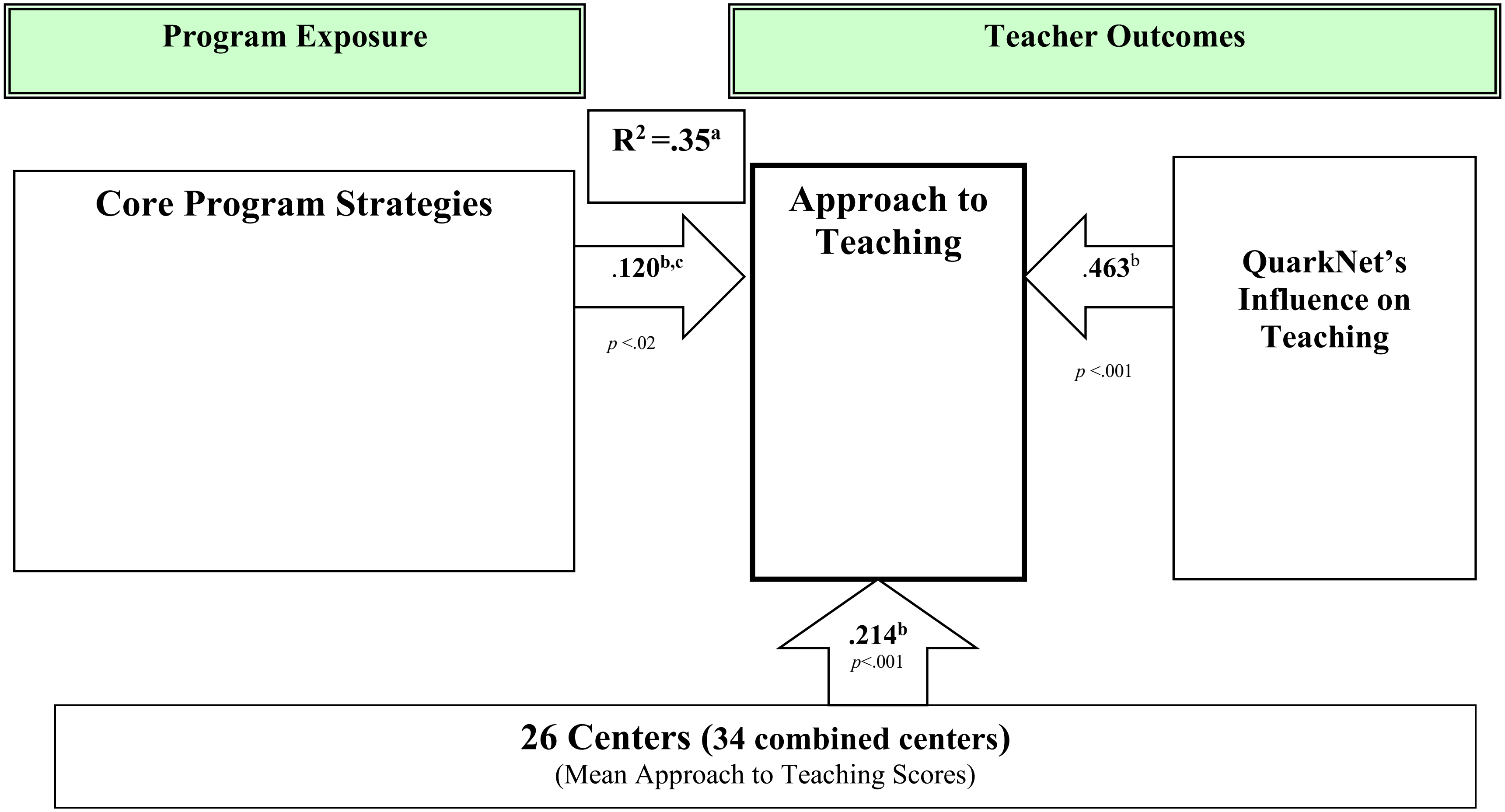


Figure 8. The relationship between engagement in QuarkNet program components and the measure of Core Strategies.



Reliability Coefficients:

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

$F_{(3, 424)} = 77.32$, $p < .001$

[a]Percent variance explained

[b]Standardized beta weights

[c]Beta weight reduced to .069 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

Teacher Outcomes

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.

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.

To summarize results from analyses thus far, 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.

It is important to note that the 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 each program year provides additional data to include in these efforts). This consistency continues to build our confidence in using and interpreting these results to support the assessment of QuarkNet's outcomes.

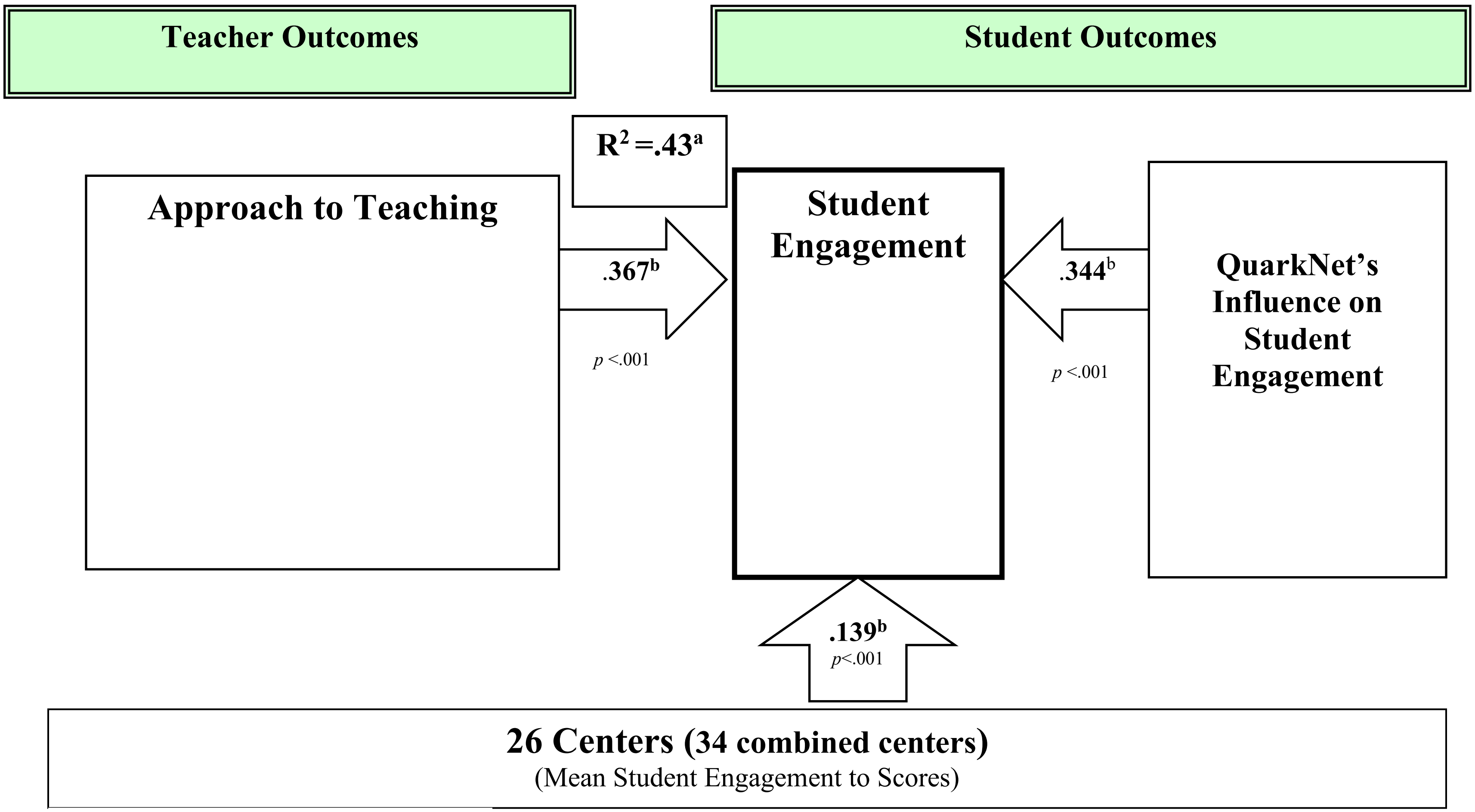
Student Engagement

How is QuarkNet related to Perceived Student Engagement?

In a similar vein, we look 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.

Similarly, 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 [$F_{(3, 383)} = 94.43$, $p < .001$]. Figure 12 shows this relationship detailing the survey items that comprise each of these scale scores.

It should be noted that efforts to model QuarkNet's impact on student engagement have varied over time; however, recent analyses suggest that this model may be becoming more stable and indicative of possible relationships between QuarkNet participation by teachers and their perceived value that this participation has had on the engagement of their students.



Reliability Coefficients:	
Approach to Teaching	0.87
Student Engagement (SE)	0.83
QN's Influence on SE	0.95

$F_{(3, 383)} = 94.43$, $p < .001$
[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.

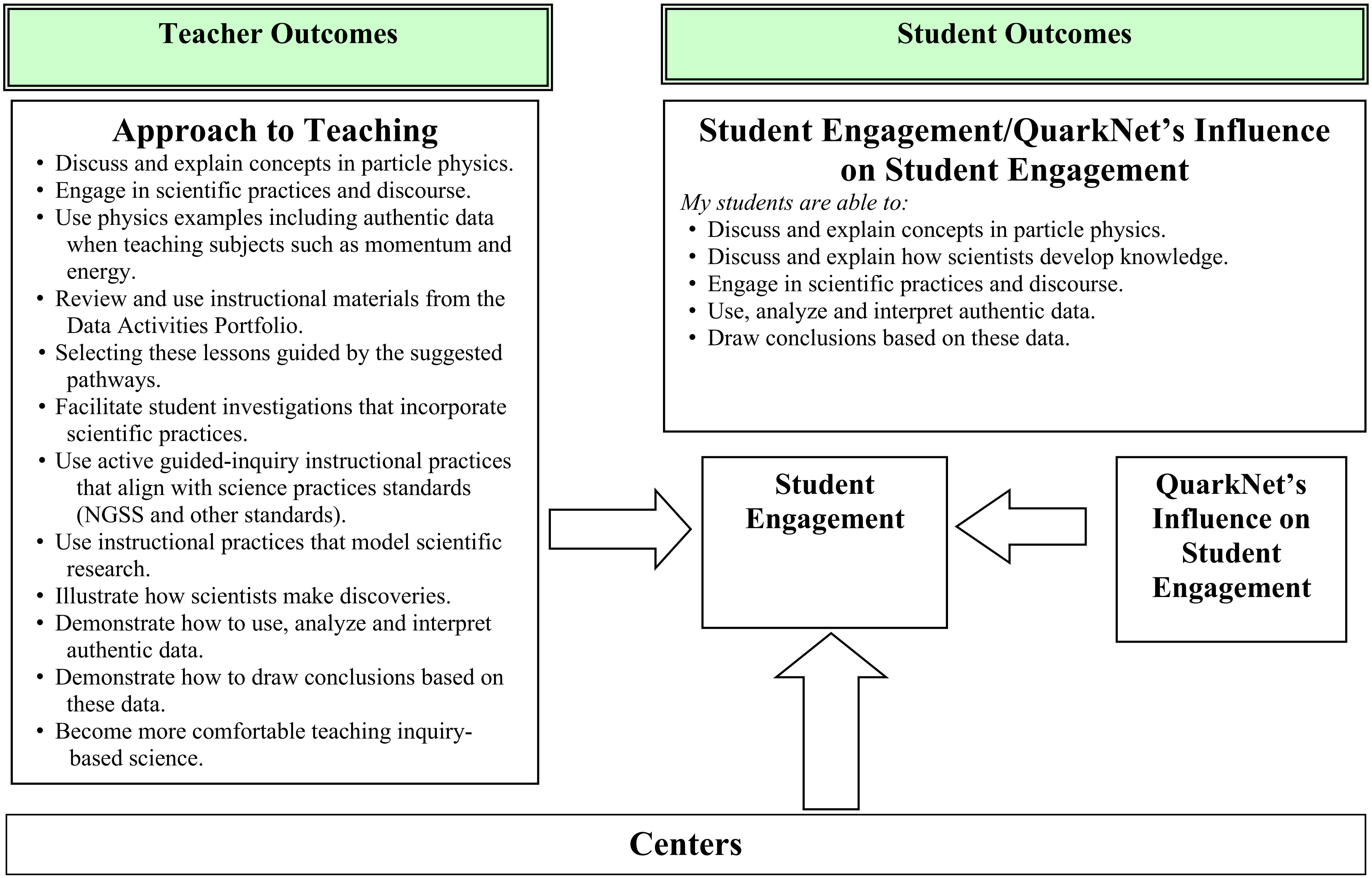


Figure 12. Survey items included in the measurement of Approach to Teaching scores, QuarkNet's Influence on Student Engagement scores and Student Engagement scores as assessed using a hierarchical linear model.

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 [$F_{(3, 386)} = 66.64$, $p < .001$]. These results have remained consistent over the past two program years.

Summarizing Results from Quantitative Analyses

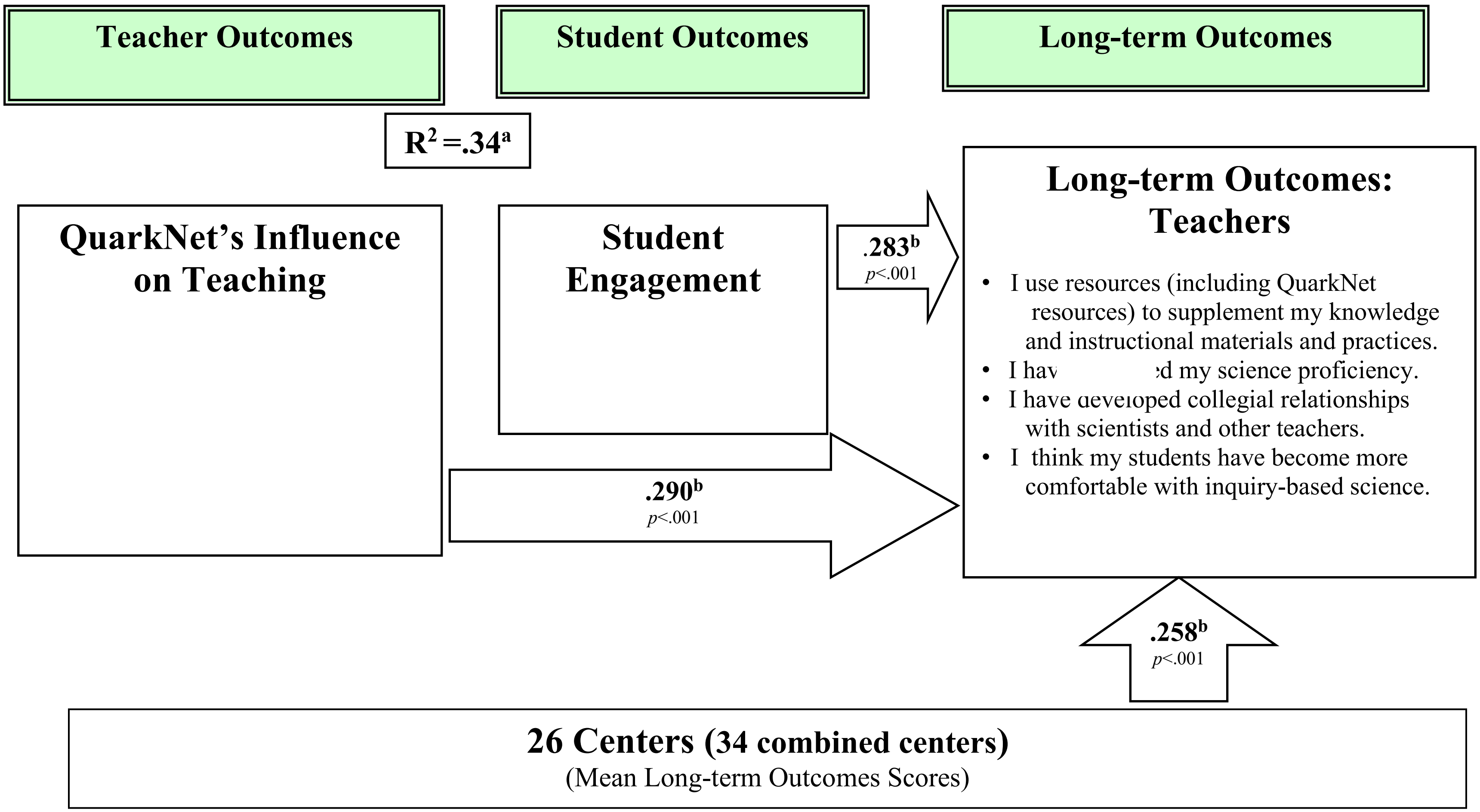
In quantitative analyses, we have used sets of survey item responses to form scale scores that measure exposure to QuarkNet, as well as teacher-, student- and long-term outcomes. Statistical analyses support the reliability (i.e., internal consistency) and use of these scales where the higher the score 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).

These analyses suggest that Data Camp and (Variety of) Workshops each contribute to teachers' reported engagement in Core Strategies while participating in QuarkNet, 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.

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. 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 shown to be positively and statistically related to QuarkNet's Influence on Student Engagement, Approach to Teaching and Centers (as measured by mean Student Engagement scores) (with noted caveats). 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	0.87
Student Engagement (SE)	0.83
Long-term Outcomes	0.81

$F_{(3, 386)} = 66.64$, $p < .001$
[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.

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

To support these quantitative analyses, we have conducted qualitative analyses highlighting information from these same 26 (34 combined centers). 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).

Each center-level portfolio starts with a brief explanation of what is contained in it. This is followed by a table that summarizes responses from teachers as to 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 also presented anonymously 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.

Each table is followed by, when this information is available, 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.

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

<u>Survey Response Tables</u>. The responses to open-ended survey questions suggest a variety of ways in which QuarkNet content and materials are implemented in teachers' classrooms. Specific examples of DAP activities 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, as expected, is mentioned 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.

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, national-led QuarkNet workshop leaders 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.

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. That said, a review of several QuarkNet Center-level portfolios will give the reader a much better sense of these implementation examples.

Implementation Plans. In a bit more detail, implementation plans proposed by teachers are included in these 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 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.

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., Fermilab/University of Chicago combined center)

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.)

14. Center-level Outcomes and Effective Practices

During the previous grant period, the involvement of center-level engagement in QuarkNet was measured through the Center Feedback Template; this was added 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.

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

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

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 *Almost all/Most* Teachers 19/25	63% of teachers reported opportunities to form collegial relationships with scientists/teachers as *Excellent* 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).

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 2024 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.

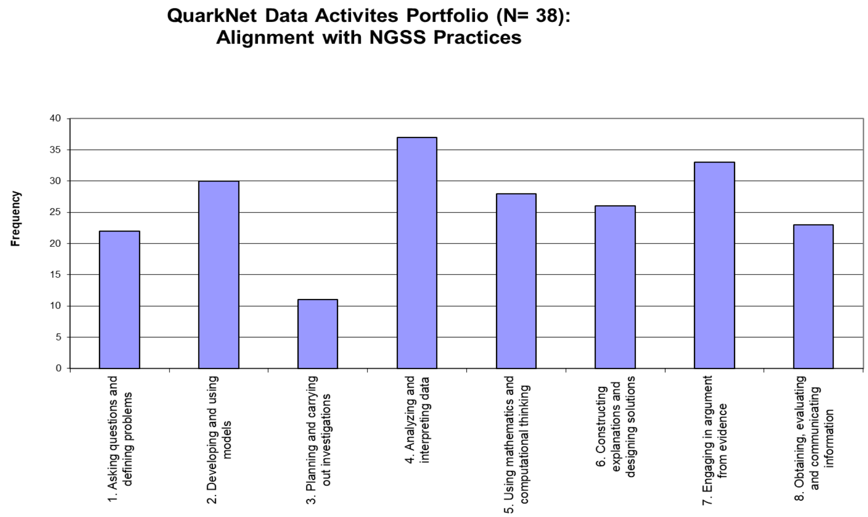
Taken together data in these two graphs suggest the alignment of NGSS science practices evident in DAP activities at the program level as *designed;* and as *implemented* --- via workshops held across the program years during this (and previous) grant periods.

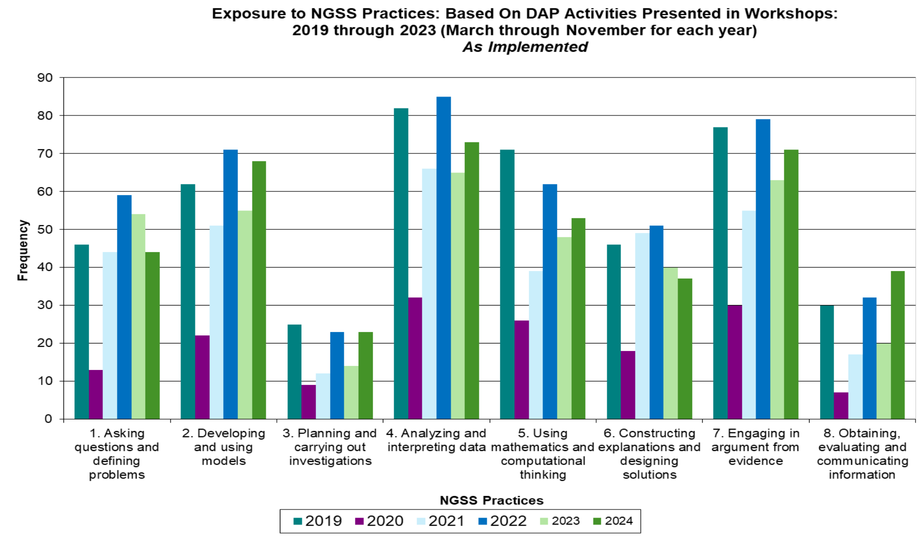
(Also evident, the graph in the upper right-hand corner suggests that the implementation level of embedded DAP activities returned to pre-COVID levels, comparing data from 2019, 2022-2024 program years.)

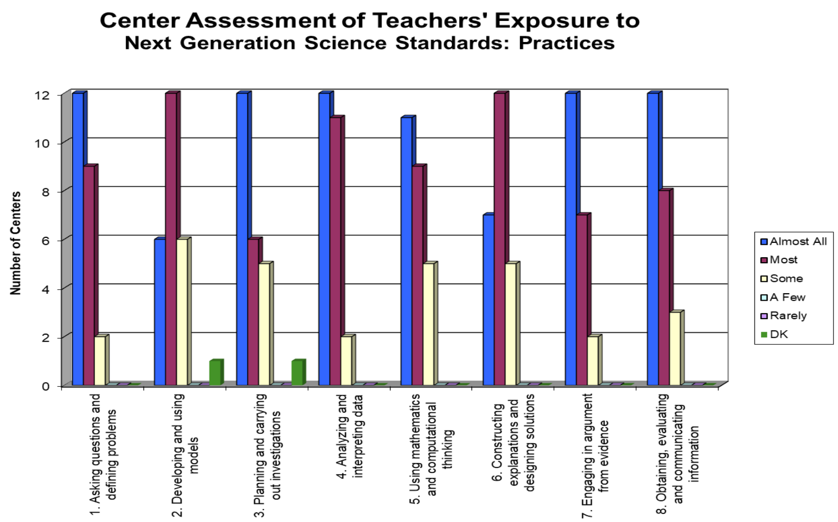
The next graph in the lower left-hand corner presents the perceived engagement in NGSS practices by teachers based on center-level assessment of their *implemented* program. This reflects an assessment of engagement at the individual teacher level. (Based on responses from Center Feedback Templates.) 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).







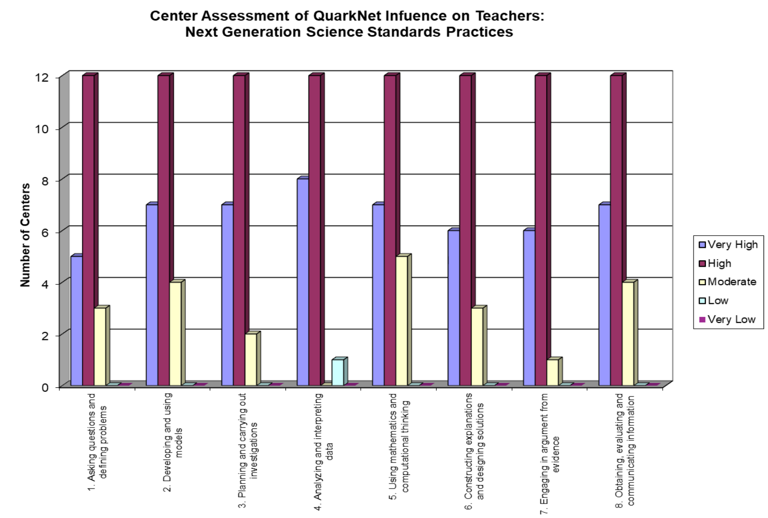


Figure Set 14. Alignment of Next Generation Science Standards (NSS) science practices and activities from the Data Activities Portfolio as designed (upper left-hand corner). Then, the exposure to NGSS practices based on *implemented* QuarkNet workshops held during the 2019 through 2022 program years (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
Presentations and Posters Presented in 2023 by QuarkNet Staff and Teachers

Author (Last, First)	**Role (staff, fellow, etc.)**	**Center (if applicable)**	**Date**	**Title**	**Format (Publication, Presentation or Poster)**	**Name of conference, publication, etc.**
Cecire, Kenneth, et al[c]	Staff	Notre Dame	08/09/2023	Adapting the Cosmic Watch for the Classroom	Poster and Proceedings Paper	International Cosmic Ray Conference 2023
Assamagan, Ketevi, et al[b]	Staff		07/2023	The African School of Physics Reaches a New Level	Article	African Physics Newsletter
Wood, Shane, et al[a]	Staff		04/22/2023	QuarkNet: Sustained Professional Development for High School Teachers	Presentation	MN Section AAPT Meeting 2023
Wood, Shane	Staff		04/16/2023	Particle Physics Masterclasses	Presentation	APS April Meeting 2023
Wood, Shane	Staff		01/16/2023	Neutrino Physics Masterclasses	Presentation	AAPT Winter Meeting 2023

[a]With Jon Anderson, Minnesota lead teacher. [b]Cecire contributed
[c]With Jeffrey Chorny, Daniel Kallenberg, Maggie Karban, Rowan McNeely, and Jeremy Wagner
Excerpt from information compiled by K. Cecire and S. Wood.

- (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 35 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 and each individual was an active participant 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 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 80 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).

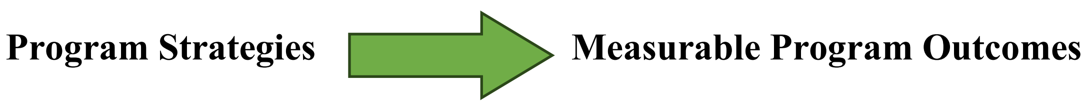


Figure 1. Throughout the evaluation, program engagement (i.e., specifically exposure to core program strategies) provides the context in which assessment has occurred.

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.

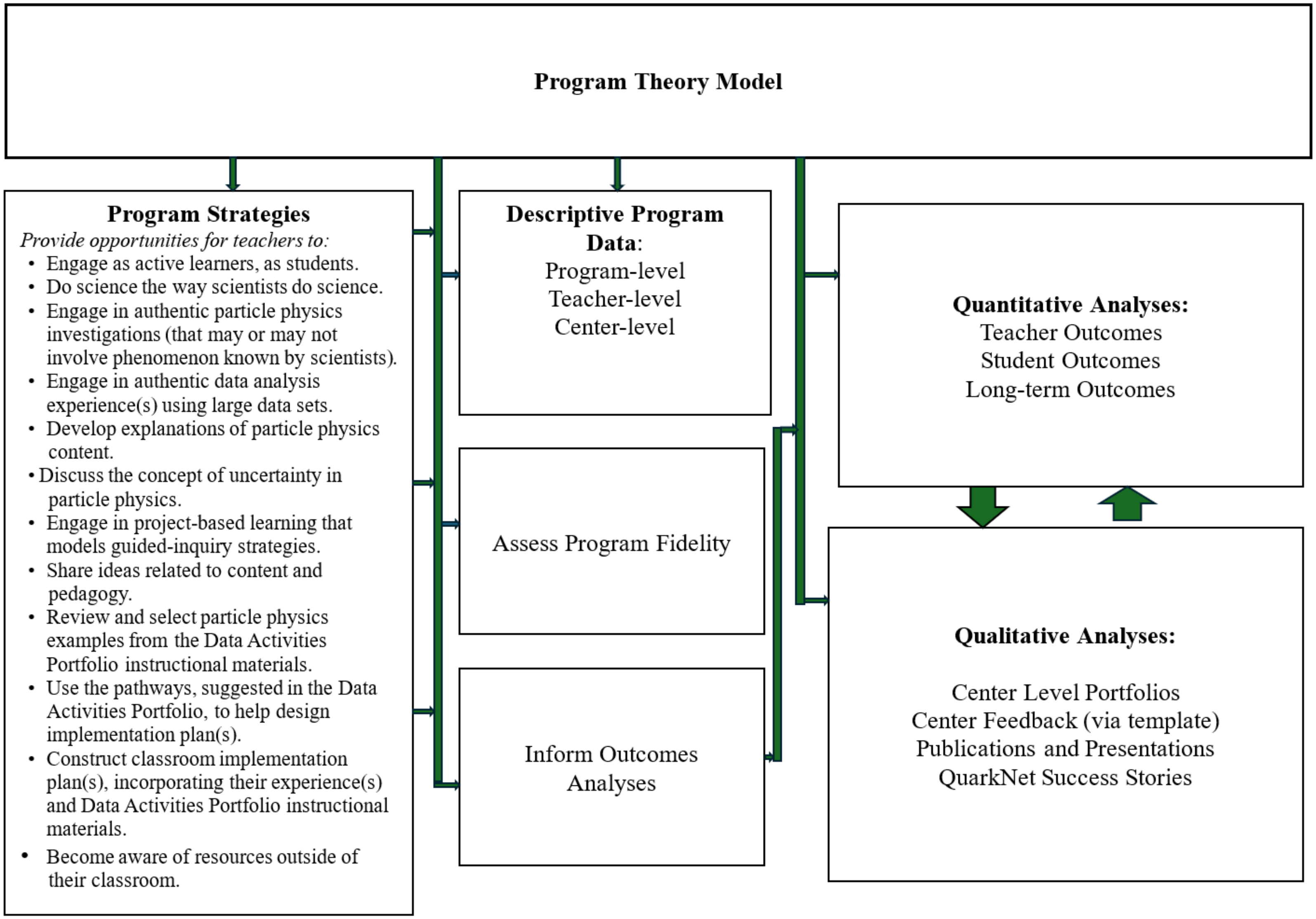


Exhibit F. Overview of Program and Outcomes Data

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

The summary of evaluation results is highlighted in Table 15, using the outline highlighted below to achieve this purpose. The narrative of the evaluation report used this organization and has detailed support for the conclusions presented for each of the following:

1. QuarkNet: Professional Development for HS Teachers
2. (Develop and) Use a Program Theory Model
3. Program Organization
4. Data Activities Portfolio: Brief History and Development
5. Program Implementation and Measuring Fidelity (*Designed* vs. *Implemented* Program)
6. Linking Program Strategies to Outcomes
7. Survey Implementation and Response Rates
8. Summary of QuarkNet Teachers: Demographics
9. School Characteristics and Student Demographics
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 *Matter*
13. Qualitative Analyses: Center-level Portfolios A Narrative Picture of QuarkNet's Influence
14. Center-level Outcomes and Effective Practices
15. Getting the Word Out
16. QuarkNet Success Stories: Case Studies
17. Program and Evaluation Recommendations

Table 15
QuarkNet Evaluation: Summary of Major Efforts and Results

Evaluation Effort	Source(s) of Information	Highlighted Major Results
1. QuarkNet: Professional Development for HS Teachers Appendix A highlights program history.	• Review of previous program and evaluation documents • QuarkNet staff expertise	• Brief program history presented. • Importance of Centers noted. • Four Program Goals presented. • Approach to evaluation provided (three themes).
2. (Develop and) Use a Program Theory Model Appendix B summarizes the protocol used to develop this model. Appendix C presents the full model (PTM).	Created by working groups based on: • Structured interviews with key QuarkNet staff • Relevant literature • QuarkNet staff expertise 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.) • Offers a 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.*
3. Program Organization (See Figure 2 for chart.) (See Table 1 for list of QuarkNet centers.)	• Organization and Implementation Chart (developed by QuarkNet staff) • Program's website https://quarknet.org/	• Overviews the administration and implementation of the program. • Key role of centers noted (presently 55 centers). • Importance of QuarkNet's website presented.
4. Data Activities Portfolio: Brief History and Development Appendix D overviews protocol. Appendix E presents a brief history of Data Activities Portfolio (DAP) growth. (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) • Organized by key search options • Pathway and Template documents created to support development of activities • Supported with resources (e.g., teacher/student notes)	• Organized by required student skills sets (Levels 0-4) (developed by QuarkNet staff). • Criteria used to determine the alignment of DAP with Next Generation Science Standards (NGSS) defined by QuarkNet staff. (See Table 2 in full report.) • DAP *as designed* aligns well with Next Generation Science Standards (NGSS), (see Table 3) and • QuarkNet's defined Enduring Understandings (see Table 4). • 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
5. Program Implementation and Measuring Fidelity (*Designed* vs. *Implemented* Program) Previous program years are highlighted in a series of tables in Appendix F. (See Table 5 in evaluation report for 2024 program year summary.)	• Program Theory Model • Workshop Agendas • Center Annual Reports • Virtual site visits by the evaluator	• Workshop summary tables highlight the *implemented* QuarkNet program. (See Table 5.) • Workshop agendas incorporate DAP activities offering opportunities for teachers to engage in these as active learners. • *Implemented* activities align well with NGSS Science Practices (see Figure Set 14). • Creates predicate to compare program engagement to program outcomes (presented here shortly).
6. Linking Program Strategies to Outcomes Appendix G presents a series of tables that link core program strategies to relevant education literature, followed by linking core strategies to program outcomes. Appendix H presents Full Teacher Survey. Appendix I presents Update Survey. Appendix J presents Center-level Feedback Template.	• Program Theory Model • Linking Program Engagement to Outcomes (evidence of program engagement) • Sources of Outcomes Data delineated • Appendix K shows statistical support for use of scale scores	• Overview outcomes data sources: • Teacher Full Survey • Update Survey (Spanish language version also) • Center Feedback Process and Template • Virtual Workshop Visits by Evaluator
7. Survey Implemented and Reponses Rates (See Table 6.)	• Teacher surveys (full/update) were conducted during 2019-2024 program years • Survey implemented during workshop participation with follow-up email as necessary • Raw data from the full teacher survey and the update survey • Data retrieved from Survey Monkey • 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. • 83% response rate for 2024 program year.

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

Evaluation Effort	Source(s) of Information	Highlighted Major Results
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. • Over the 2019-2024 program years program engagement is close to parity: 50% for men; 43.6% for women; and 6.4% not specified (based on survey data). • From 2024 program registration information, 48% are men. 47% are women and 5% preferred not to answer.
b. Teachers *New* to QuarkNet Appendix L presents these data by QuarkNet center and program years.	• Full Teacher Survey • Operations Data (teachers receiving stipends)	• For 2019-2022 program years, 36% of teachers were new/1-year in program. • For the 2023 program year, this percent was 33%. • In 2024 program, 33% of teachers were new/1-year in program (information from attendance records and survey responses).
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 4.62 years (median 2.0 years). • Mean number of years teaching is 16.12 years (median 15 years). • Mean number of years at current school is 9.09 years (median 7 years).
d. School Location (See Table 8.)	• Full Teacher Survey	• Over 50% (51.3%) of schools where participating teachers teach are in urban/urban central city locations. • 29.5% of schools are in suburban locations. • 19.2% of schools are in rural locations.
e. Teaching Physics (See Table 8.)	• Full Teacher Survey (at the time teachers completed their survey)	• A total of 74.8% of teachers reported teaching physics. • Over time, there has been a tendency for more teachers to report that they are not teaching physics. • Other fields mentioned include Chemistry, Physical Science, Earth Sciences, Biology, Statistics, Math. • 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
8. Summary of QuarkNet Teachers: Demographics (con't.)		
f. QuarkNet Participation (See Tables 9-10.) (See Figure 6.)	Full Teacher Survey	• Any and all programs (as reported when survey was completed) that teachers participated in at the time they completed their full survey. • Program engagement linked to exposure to core program strategies.
g. QuarkNet Participation and Program Year (See Table 11.)	Full Teacher Survey	• Outcomes do not vary by which year a teacher participates in QuarkNet.
9. School Characteristics and Student Demographics (based on publicly available school-level information) **a. Location** **b. Enrollment size** **c. Student: Gender (%), Ethnicity/Race (%); Free or Reduced Lunch (%)**	• Large scale case study • Either www.publicschoolreview.com or www.privateschoolreview.com • Information accepted at face value. • Based on teachers enrolled in QuarkNet during the 2022 program year. • ~ 250 teachers from ~120 schools.	• Organized by center. • 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.
10. Overview of Analyses: Teacher (and their Students) and Long-term Outcomes (See Figure 7.)	• Full Teacher Survey: Quantitative Data Analyses	• Maps out key outcomes analyses • Statistical analyses support the use of scale scores as program exposure/outcome measures. • Outcomes measures are: Core Strategies (exposure), Approach to Teaching, QuarkNet's Influence on Teaching, Student Engagement (as perceived by teachers), QuarkNet's Influence on Student Engagement and Long-term Outcomes.

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

Evaluation Effort	Source(s) of Information	Highlighted Major Results
11. Unique Contributions of QuarkNet Program Components **a. Data Camp** **b. (Variety of) Workshops** **c. Masterclasses** (See Table 12 in full report.) 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.) • 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 • 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.) • Thus, analyses suggest that each of the major components of QuarkNet contribute *uniquely* to outcomes as measured. • 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 • Hierarchical linear regression analyses that account for teachers nested in QuarkNet Centers. • Using scale scores to measure outcomes.	• See Figure 8 for a schematic on the relationship between program engagement and exposure to core program strategies. • QuarkNet Centers *matter* when assessing teacher, student, and long-term outcomes. (See below for short summary of each.)
a. Approach to Teaching (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' use of content and instructional practices in their classrooms (i.e., Approach to Teaching). These results are statistically significant [$F_{(3, 424)} = 77.32$, $p < .001$]. 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
12. How QuarkNet Engagement is Related to Outcomes: QuarkNet Centers *Matter* (con't.)	• Full Teacher Survey • Hierarchical linear regression analyses that account for teachers nested in QuarkNet Centers. • Using scale scores to measure outcomes.	
b. Student Engagement (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 [$F_{(3, 383)} = 94.43$, $p < .001$].
c. Long-Term Outcomes (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 [$F_{(3, 386)} = 66.64$, $p < .001$].
13. Qualitative Analyses: Center-level Portfolios A Narrative Picture of QuarkNet's Influence Compiled for 26 (34 combined) centers included in the quantitative analyses.	• Full Teacher Survey (open-ended questions) • Update Survey (open-ended questions) • Virtual workshop site visits by evaluator • Teacher Implementations Plans (workshop agendas/center annual report) • Examples of teachers' work • Examples of student work	Organized by center, portfolios are comprised of: • Teachers reported planned or actual use of QuarkNet content and materials in their classroom over time (based on survey responses). When available: • Implementation plans prepared by teachers or groups of teachers and posted on QuarkNet website are included. • Examples of teacher work (during workshops, science fairs, presentations at workshops/ professional conferences) are included. • 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
14. Center-level Outcomes and Effective Practices (See Figure Set 14 for comparisons of designed vs. implemented and teacher-level and center-level responses.)	• Center Feedback Template • 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. • Comparisons suggest good agreement on select responses by individual QuarkNet teachers and QuarkNet centers [26 (34 combined) centers]. • Results suggest good alignment of centers to meet the criterion of each of 10 effective practices. • Offers a suggestion of program sustainability (i.e., what is being sustained).
15. Getting the Word Out Compiled by K. Cecire and S. Wood	• https://quarknet.org/content/publications-presentations-and-posters-sept-2018-sept-2023 • 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. • From June 2023 to present, an additional 35 presentations, posters, and publications by staff, teachers and/or students have been posted.
16. QuarkNet Success Stories: Case Studies **Supplement I Final | QuarkNet** **Supplement II Final | QuarkNet**	• Testimonials • Interviews with select staff, teachers and former students • Emails from staff about former students • Evaluation Team | QuarkNet	• In more detail 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 • Each vignette prepared with the active participation of the individual highlighted. • The first report highlights individuals from four QuarkNet centers. The second report highlights individuals from one QuarkNet center. • Staff, teacher and student work examples are proffered including publications, and presentations.
17. Program and Evaluation Recommendations	• Culmination of information sources contained in this evaluation	• A total of 10 program recommendations and • 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. 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.

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 lasting 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 2024 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 and 2024 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. (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 based on 2024 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.

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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