Evaluation of the QuarkNet Program: Evaluation Report 2019-2020

Prepared by:

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

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Evaluation of the QuarkNet Program:
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Executive Summary

Kathryn Race
Race & Associates, Ltd.

The QuarkNet Collaboration, referred to as QuarkNet, "is a long-term, national program that partners high school science teachers with particle physicists working in experiments at the scientific frontier." QuarkNet is a professional development program that "immerses teachers in authentic physics research and seeks to engage them in the development of instructional strategies and best practices that facilitate the implementation of these principles in their classrooms; delivering its professional development (PD) program in partnership with local centers" (Program Theory Model, PTM, 2019). There are approximately 50 plus such centers across the United States.

Program Goals

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

Overview of Report

This report is a prototype of the final evaluation report that will be submitted at the end of this award period; as such, it presents a draft of the final evaluation report (although it is final as an interim report). In serving as a prototype, the present report and its review demonstrate the shift in evaluation efforts that have occurred from formative (and summative) assessment to an outcomes-based evaluation. In providing this early look, it is hoped that this will provide opportunities to help QuarkNet program staff members better understand this shift. It will also allow opportunities for staff to identify principal needs and concerns that the evaluation may be able to be responsive to; and to give the evaluator time to adjust to these needs and suggestions proposed by staff to aid in the usefulness of evaluation findings and recommendations.

With the onset of a new external evaluator, a new direction for the evaluation was undertaken focused on the following, that is, the: (1) Development of a Program Theory Model (PTM); (2) Assessment of program outcomes at the national and center levels through teacher-level outcomes; and, (3) Assessment of the sustainability of program centers, based on center-level and sustainability outcomes.

The fully-articulated PTM is complete. The process used to create the PTM has been described in this report and the model has been described in detailed. Ideally, a program theory model offers a cohesive and representative picture of the program, "an approximate fit" of the program as *designed*. We have sought consensus on the representativeness of this model with key stakeholders and will revisit the PTM over the course of the award period, as this is needed.

To a large extent the PTM 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 fom Beal & Young, QuarkNet Summative Evaluation Report 2012-2017).

The development of a PTM and a Theory of Change is consistent with common guidelines proffered by the Institute of Education Sciences, U.S. Department of Education and the National Science Foundation (2013). Weiss (1995) noted that grounding evaluation in theories of change means integrating theory with practice. She postulated further that making assumptions explicit and reaching consensus with stakeholders about what they are trying to do, and why, and how, may ultimately be more valuable than eventual findings (Weiss, 1995), having more influence on policy and popular opinion (Rallis, 2013).

We have used the PTM to direct the development of evaluation measures and methods designed to address the remaining two goals. A Teacher Survey and a Center Feedback Template have been designed to measure the teacher-level and center-level outcomes articulated in the PTM, respectively. The first administration of the Teacher Survey coincided with the start of summer workshops that occurred in 2019; and the roll-out of the Center Feedback template began in September 2019. To coincide with the 2020-2021 program year, we have added an Update: Teacher Survey to continue to capture information from participating teachers and to focus on classroom implementation of QuarkNet content and instructional materials.

A total of 265 teachers (a response rate of 78%) participated in the Teacher Survey during the 2019-2020 program year. A profile of participating teachers has been provided in the narrative of this report. Our approach to analysis has been to explore teacher perspectives as to their exposure to core program strategies, perceived approach to teaching, student engagement, the potential influence QuarkNet has had on teachers' approach to teaching and student engagement as well as self-reported use of activities from the Data Activity Portfolio (DAP). When possible, outcomes will be assessed within the context of the degree of program engagement by participating teachers and the delivery of the program through participating centers.

In preliminary analyses ….

Regarding **Core Strategies**, program engagement and measurement of exposure to core program strategies were shown to be related in a meaningful way (that is, more engagement by type of event, the higher the perceived exposure to core strategies; and more reported use of activities from the Data Activities Portfolio in the classroom). This speaks to the fidelity of the *implemented* program as compared to the program as *designed* as perceived by participating teachers who completed the Teacher Survey.

Regarding, **Approach to Teaching,** teaching outcomes were shown to be related to *perceived* QuarkNet's Influence and the use of activities from the Data Activities Portfolio in the classroom as reported by participating teachers. **Use of DAP** activities was shown to be related to exposure to Core Strategies, Approach to Teaching, and all of the types of QuarkNet program events (Data Camp, Variety of Workshops, and Masterclass engagement).

Regarding, **Student Engagement,** QuarkNet's Influence on Student Engagement and Approach to Teaching were related to perceived student engagement in inquiry-based science based on the perceptions of their participating teachers.

Although preliminary, the weight of these analyses suggests that there is a positive relationship between teacher engagement in QuarkNet and exposure to core program strategies; and, that the type and degree of program engagement is related to teacher outcomes (Approach to Teaching), the use of activities from the Data Activities Portfolio in the classroom, and teachers' perceptions of Student Engagement in inquiry-based science.

In assessment of the process of conducting center-level information through the Center Feedback Template, results from the pilot test and a second round of outreach suggest that this process has been helpful for QuarkNet staff teachers, the centers themselves (mentors and lead teachers), and the evaluation. Based on review of very early results, centers (based on ten centers at this point) and teachers indicated that the program offers the opportunity for teachers to engage as active learners, as students, as part of their QuarkNet workshop participation. That is, these centers reported that *"all or most teachers*" engaged as active learners (as students); and, most teachers reported that the opportunity to engage as active learners (as students) was "excellent."

Also, analysis suggests that QuarkNet workshop participation aligns well with the NGSS Science and Engineering practices through engagement in activities in the DAP and through QuarkNet workshop and program participation.

Program Summary and Recommendations

The full impact that coronavirus (COVID-19) has had or will have on QuarkNet remains to be determined for the 2020-2021 program year and beyond. Currently, QuarkNet staff has actively sought to plan and conduct workshops, which previously were held face-to-face, in virtual environment(s). This has included modifying the content by focusing on core concepts as well as the delivery of the workshop or program, such as half-day sessions with small-group breakout sessions, separate off-line time to work on specific tasks, and breaks built into the agenda.

The following program summary and recommendations are proffered:

1. The program has had a long-standing practice of holding regularly-scheduled staff meetings. One of these is staff-wide; one is specific to IT concerns; and, one is specific to program content and development. The evaluator has been invited to attend these weekly meetings, and she has regularly attended the staff-wide meeting. Of importance, these weekly meetings have been especially helpful in discussing and planning program content and delivery modifications as a result of coronavirus, COVID-19. Continue to hold these meetings as determined by the feasibility of everyone's schedule.
2. During the 2019-2020 program year, there has been a concerted effort to help nationally- and center-led workshops document the content of their workshops through the development and use of agenda templates; which are posted on-line. This is a simple and pragmatic step that has been very valuable. First, these agendas can and have been modified and used by QuarkNet centers. In many cases, agenda are modified during the event which memorializes the program in a just-in-time fashion.
3. The documenting of program content through workshop agendas has improved our ability to identify which (and how) activities from the Data Activities Portfolio (DAP) have been incorporated into workshops, especially nationally-led workshops and to a lesser extent but still notable for center-led workshops. This (along with item 2) may help centers prepare their annual reports, which each participating center is asked to do.

4. DAP activities, collectively, have been shown to align well with Next Generation Science Standards Science and Engineering Practices. Of importance, these activities are a bridge for teachers to implement QuarkNet content and materials into their classrooms. Continue to maximize the use of Data Portfolio Activities by teachers at center-led and nationally-led QuarkNet workshops and meetings.
5. Starting with the 2020-2021 program year, staff created a guide to help teachers reflect on and develop implementation plans that can be incorporated into their classrooms using QuarkNet content and instructional materials. Staff members have mandated this discussion in nationally-led workshops and they have strongly encouraged its use in center-run 2020-2021 workshops.
6. As articulated in item 5, continue support of the development by teachers of implementation plans and the subsequent use of these plans by teachers, QuarkNet program staff, and the evaluator.
7. The number (and the quality) of activities in the DAP has increased dramatically from 2017 (the end of the past grant period) to the new program-award period. 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 work-load for their development and eventual use.
8. Consider adding a Project Coordinator position to QuarkNet staff, if not now, in the future. This person could help the education specialist with DAP activity development as well as have other responsibilities such as helping to track participation related to registration, updating teacher profiles on the QuarkNet website; and subsequent stipend payment.
9. 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 program.
10. Continue to support the evaluation and its efforts as reasonable; and continue to work with the evaluator, as planned, to help embed evaluation efforts and requirements within the structure and delivery of the program.

Evaluation Summary and Recommendations

The following evaluation summary and recommendations are proffered:

1. The response rate for the Teacher Survey was 78% during the 2019-2020 program year. This successful return rate 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.
2. Working with QuarkNet staff, the Update Teacher Survey dovetails well with the guidelines for teachers in the development of classroom implementation plans. We think that this will facilitate a meaningful way for participating teachers to reflect and build these plans as well as, hopefully, provide a pathway for documenting and incorporating this information into the evaluation.

3. Initial efforts to distribute and collect center-level information through the Center Feedback Template suggest that this process has been helpful for QuarkNet staff, Center level mentors and lead teachers, and the evaluation.
4. Preliminary analyses from the Teacher Survey suggest that there is a meaningful link between exposure to program strategies and program engagement; and that this engagement is related to teacher outcomes, perceived student engagement, and use of activities from the Data Activities Portfolio in the classroom of participating teachers.
5. Very early data analyses suggest agreement between center-level perceptions and teacher-level perceptions on teachers experiencing activities as active learners (as students) and exposure to instructional materials (and their delivery) that align with the Next Generation Science Standards Engineering and Science Practices.
6. As more centers participate in the Center Feedback Template process, integrate these center-level outcomes data with analysis of teacher-level perceptions and outcomes. Add sustainability outcomes into the mix as the number of participating centers grows.
7. 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.
8. As recommended by the Advisory Board in December 2019 and to the extent possible, extend external evaluation efforts to incorporate QuarkNet's international outreach efforts.
9. Continue to be mindful of the many responsibilities that program staff, mentors and teachers have. 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.
10. 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, participating teachers, NSF and others who may be interested in QuarkNet.

Evaluation of the QuarkNet Program:
Evaluation Report 2019-2020

Kathryn Race
Race & Associates, Ltd.

This report highlights the continuing evaluation efforts, which began anew in 2018-2019, with the advent of the current funding cycle from the National Science Foundation (NSF). As such, portions of this report will draw from the 2018-2019 evaluation report to reflect the continuity of these evaluation efforts (Race, 2019).

QuarkNet: Professional Development for HS Teachers

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

QuarkNet program efforts began in 1999; a brief history of the program is described in Appendix A. The QuarkNet program 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."

It is the current program that is the focus of present evaluation efforts but we will draw on the program's rich history when relevant.

Importance of Centers

In current form, QuarkNet[1] is "first and foremost, a teacher professional development program" (personal communication, email December 11, 2018), with approximately 50 plus 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 teachers who live in the nearby

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[1] Until this award period, QuarkNet had been co-sponsored by the National Science Foundation and the Department of Energy. In-kind support is provided by Fermilab during this current award period as well.

catchment area. In addition to these centers, there is the Virtual Center, which provides a home for teachers who do not live proximal to a particle physics research group. At these 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).

During this award period, a center has been defined as "active" if it provides at least one day of teacher development and "semi-active" if the center and its teachers participate in only International Masterclasses, or another promotional event-program such as International Muon Week, Word Wide Data day, International Cosmic Day or an equivalent activity (personal communication, email December 11, 2018). (The "active" status of each QuarkNet center will be presented later in this report.)

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

As already stated, the QuarkNet program is not new but the external evaluator is starting with the 2018-2019 program year. Accordingly we have proposed a new direction with the evaluation focused on the following: (1) Develop (and use) a Program Theory Model (PTM); (2) Assess program outcomes at the national and center levels through teacher-level outcomes; and, (3) Assess the sustainability of program centers, based on center-level and sustainability outcomes. Based on the PTM, existing and new evaluation measures have been modified and/or created; and implemented to assess teacher-level program outcomes, center-level outcomes and program-center sustainability. These data will be supported by program-operations data obtained from program resource documents (such as agendas and annual reports),and, other teacher- and center-level information; and, we will draw on data from past evaluation efforts when relevant.

Develop (and Use) a Program Theory Model (PTM)

A Program Theory Model (PTM) was developed during the first year of this funding cycle. Because of its significance, we present again the rationale for why it was developed and highlight the important components of the program (and its model). The process used to develop the model is highlighted in Appendix B. In short, we drew from the relevant literature; Next Generation Science Standards (especially the Practices); defined our use of the term “Guided Inquiry;” 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.

Why a Program Theory Model Was Developed

Often the term “logic models” and “program theory models” are used interchangeably. We intentionally use the later term for a variety of reasons. Although logic models often distinctly focus on describing the program as *it is in operation* -- offering an advantage if this is desired -- these models often blur the lines between the designed and implemented program. By developing and using a PTM, we intend to offer a representative picture of how *change* is expected to happen -- at least in theory -- by describing in detail the program *as designed.* PTM models differentiate between the program *as designed* from the program *as implemented* helping to underscore the importance of measuring program fidelity, program “dosage” or participation levels, as well as other operational variables and suggesting at least what, if not how these, might be measured. It also underscores that variations between the *designed* and *implemented* program are expected and that these variations are worth knowing and noting.

Of importance, PTM’s often underscore that the *context* in which the program is implemented *matters*; including program partnerships and supporting institutions. This context can be particularly helpful in suggesting, perhaps the type and continuum of engagement, whether or not to scale-up the program, and, whether replicating or generalizing of the program will work in other settings or situations. And in the case of QuarkNet, the PTM has underscored factors related to the sustainability of the program.

We see the following benefits and uses derived by creating a PTM:

- The program is articulated in a representative way reflecting its integrated components.
- Program strategies and measurable program outcomes logically link together.
- Identified indicators and proposed measures align with priority outcomes.
- Future program modifications, if any, adhere to strategies identified as core to the program.

- Program staff, key stakeholders and the evaluator have a common understanding of the program. (Donaldson, 2007)
- The potential to facilitate the generalization of program and evaluation efforts to other programs with similar goals and outcomes, including participating QuarkNet centers.

These evaluation efforts are consistent with program models or theory of change models that are often developed by evaluators and stakeholders to articulate how program outcomes link to specific program strategies and activities (Brett & Race, 2004; Rogers, Hasci, Petrosino & Huebner, 2000; Race & Brett, 2004; Renger, 2006). As already stated, such models facilitate the achievement of a common understanding of the program by stakeholders and the evaluator (Donaldson, 2007), and serve to conceptualize a program relative to its operation, the logic that connects its activities to the intended outcomes, and the rationale for why the program does what it does (Rossi, Lipsey & Freeman, 2004).

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.

It is important to note that although the PTM is intended to be inclusive, both from the standpoint of providing a consensus as to the model's representativeness of the program among key stakeholders and a comprehensive picture of program outcomes, evaluation efforts will focus on key program outcomes and program sustainability efforts. Thus, not all articulated program outcomes will be assessed.

Theory of Change

To a large extent the Program Theory Model (described shortly) elaborates on how change is expected to occur, based on 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).

PTM Program Anchors

The complexity of the program, its network of partners, and its longevity suggested that the development of such a PTM was warranted. Largely, the creation of this Program Theory Model involved making key program components and strategies -- that have evolved and been implemented over time -- explicit and served to help link these to an outcomes-based evaluation. The PTM was anchored by relevant literature on effective professional development; the Next Generation Science Standards (and other relevant standards); and, our defined use of the term "Guided Inquiry." We also included a framework that adds program sustainability strategies and outcomes into the mix.

Effective Professional Development (PD)

In 2017, Darling-Hammond and her colleagues identified characteristics of effective professional development. Her work was based on the review of 35 studies that met their criteria of methodological rigor; studies, which they noted, built on an expansive body of prior research that has described positive outcomes based on teacher and student self-reports or observational studies. These reviewed studies showed a positive link between teacher professional development, teaching practices, and student outcomes (Darling-Hammond, Hyler & Gardner, 2017). Her work added to the contributions of Desimone (2009), which led to the identification of seven characteristics of effective PD. They posit that successful PD "will generally feature a number of these components simultaneously" (Darling-Hammond, Hyler & Gardner, 2017, p. 4). Table 1 provides a brief description of each of these characteristics.

As shown in this table, the seven characteristics of effective PD as proffered by Darling-Hammond, et al. (2017) are:

1. Is **content focused**.
2. Incorporates **active learning** utilizing adult learning theory.
3. Supports **collaboration**, typically in **job-embedded contexts**.
4. Uses **models and modeling** of effective practice.
5. Provides **coaching and expert support**.
6. Offers opportunities for **feedback and reflection**.
7. Is of **sustained duration**.

Professional Learning Communities, which will be discussed more fully in subsequent evaluation reports, are seen as an important means in which to embed these PD characteristics (Darling-Hammond, Hyler & Gardner, 2017).

Program's Alignment with NGSS Standards

Clearly the QuarkNet program predated the release of the Next Generation Science Standards (1999 versus 2013). That said inquiry, specifically guided inquiry, and a claims-evidence-reasoning approach (McNeill & Krajcik, 2008) were evident as foundational to the program reflected in both its implementation and instructional materials before the emergence of these standards. To reflect both current thinking about best practices in the instruction of science and the implementation model embedded in the program, the Science and Engineering Practices of the NGSS (April, 2013) were explicitly stated as program anchors in the PTM. The eight practices are:

Table 1
Brief Description of Characteristics of Effective Professional Development (PD)
Identified by Darling-Hammond, Hyler and Gardner (2017)

Characteristic of Effective PD	Brief Description
Content Focused	PD that is focused on a discipline-specific curricula or instructional materials; that is "both content specific and classroom based;" that promotes inquiry-based learning in a structured sequence of ideas; and, supported by standards-based instruction and practice. Such PD will provide teachers with opportunities, for example, to study their students' work, test out new curriculum, and study a particular element of pedagogy or student learning in the content area. It is most often job embedded (i.e., situated in the classroom). (pp. 5-6)
Active Learning	PD that addresses "*how* teachers learn as well as *what* teachers learn;" engages teachers directly in the practices they are learning, and is connected to teachers' classrooms and students; where teachers use "authentic artifacts, interactive activities and other strategies;" teachers engage as learners often engaging in the same activities that they are designing for their students; and, where learning opportunities reflect their own interests, needs and experience; and where reflection and inquiry are central. (p. 7)
Collaboration	Seen as an important feature of well-designed PD programs where collaboration can span a host of configurations "from one-on-one or small group interactions to schoolwide collaborations to exchanges with other professionals beyond the school." (p. 9)
Use of Models and Modeling	PD that uses models of effective practice, where "curricular and instructional models and modeling of instruction help teachers have a vision of practice on which to anchor their own learning and growth." (p. 11)
Coaching and Expert Support	PD where experts help "to guide and facilitate teachers learning in the context of their practice" by "employing professional learning strategies" "such as modeling strong instructional practices, supporting group discussions," "share expertise about content and evidence-based practices;" "sharing their knowledge as workshop facilitators." Experts can range from "specially-trained master teachers and instructional leaders to research and university faculty." (pp.12-13)
Feedback and Reflection	Effective PD incorporates two distinct practices feedback and reflection -- that are seen as "powerful tools" and each of which are "critical components of adult learning theory." Effective PD provides "built-in time for teachers to think about, receive input on, and make changes to their practice by provides intentional time for feedback and/or reflection." (p.14)
Sustained Duration	"(M)eaningful professional learning requires time and quality implementation." Effective PD is sustained, providing multiple opportunities for teachers to engage in learning around a single set of concepts or practices; providing the time necessary for learning that is rigorous and cumulative (p. 15)

Source. This table directly quotes and paraphrases descriptions contained in Darling-Hammond, Hyler & Gardner (2017).

1. Asking questions (for science) and defining problems (for engineering).
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 (for science) and designing solutions (for engineering).
7. Engaging in argument from evidence.
8. Obtaining, evaluating, and communicating information.

As important the Disciplinary Core Ideas and Crosscutting Concepts (NGSS) were included as well. These are:

1. Patterns
2. Cause and Effect
3. Scale, Proportion and Quantity
4. Systems and System Models
5. Energy and Matter in Systems
6. Structure and Function
7. Stability and Change of Systems

(See NGSS at https://www.nextgenscience.orghttps://www.nextgenscience.org.)

Program's Use of the Concept of Guided Inquiry

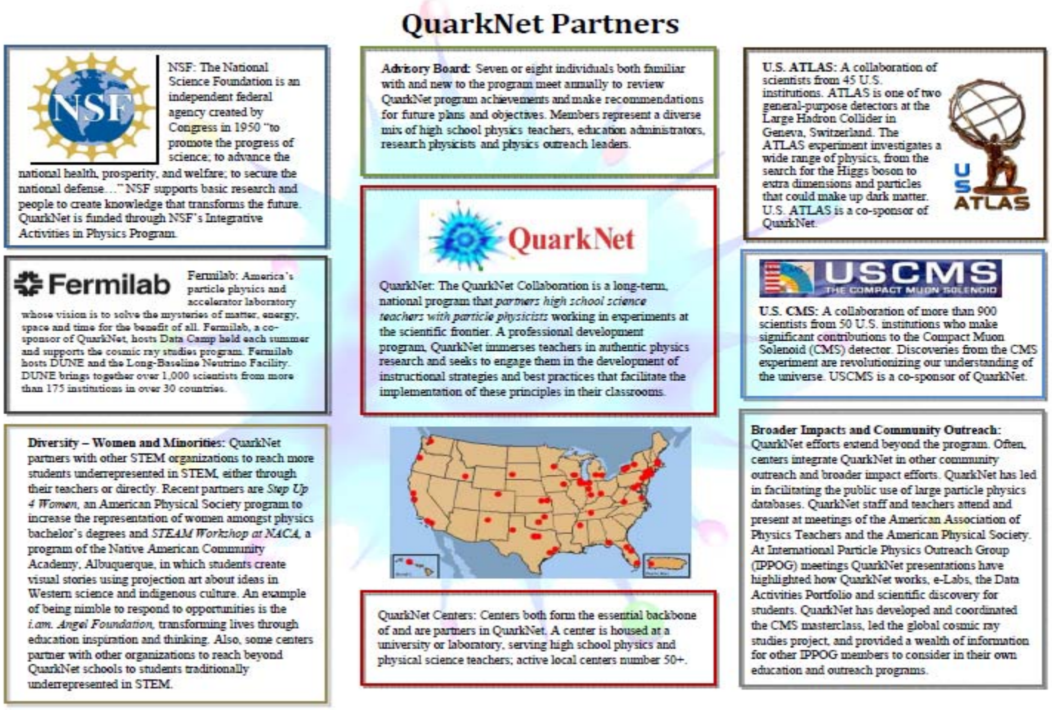
In the PTM and in the *implemented* program, guided inquiry is operationally defined using Herron's model of inquiry (Herron, 1971) as modified by Jan-Marie Kellow (2007). That is, as defined, guided inquiry is seen as to occur in situations where the teacher provides the problem or question; and for structured inquiry in situations where the teacher provides the problem and procedure. Further, as modified, in guided inquiry the solution is not already existing/known in advance and could vary from student to student. Students *either* investigate a teacher-presented question (usually open-ended) using student designed/selected procedures *or* investigate questions that are student formulated (usually open-ended) through a prescribed procedure (some parts of the procedure may be student/designed/selected).

In QuarkNet's case, it is likely that the teacher may be a mentor or lead/associate/staff teacher; and, the student(s) -- may be participating teacher(s) engaged in active learning as students--; or, actual students engaged in activities from the Data Activity Portfolio.

In summary, information from these sources were culled into drafts of the PTM; and, shared and revised during iterative meetings with the PIs and key stakeholders until agreement was reached on the content of its component parts. Once the narrative of the PTM was agreed upon, a detailed, graphic presentation of it was created.

QuarkNet Program Theory Model

In its fully articulated form, the PTM describes the QuarkNet program *as designed* (as already stated). The model identifies program strategies framed within the specific program structure and components, and seeks to describe how outcomes logically link to the program. In the model, a program statement, program centers, program goals, assumptions/core values, participant selection and key program components including



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.

Diversity – Women and Minorities: QuarkNet partners with other STEM organizations to reach more students underrepresented in STEM, either through their teachers or directly. Recent partners are *Step Up 4 Women*, an American Physical Society program to increase the representation of women amongst physics bachelor's degrees and *STEAM Workshop at NACA*, a program of the Native American Community Academy, Albuquerque, in which students create visual stories using projection art about ideas in Western science and indigenous culture. An example of being nimble to respond to opportunities is the *i.am. Angel Foundation*, transforming lives through education inspiration and thinking. Also, some centers partner with other organizations to reach beyond QuarkNet schools to students traditionally underrepresented in STEM.

Advisory Board: Seven or eight 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.

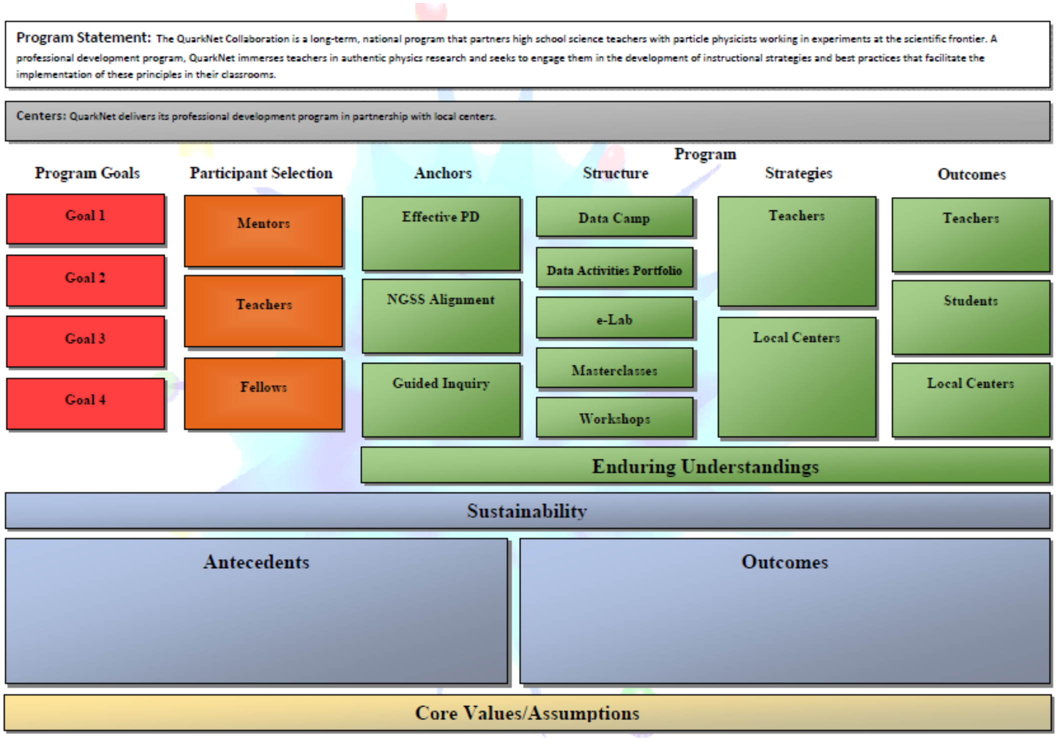
QuarkNet Centers: Centers both form the essential backbone of and are partners in QuarkNet. A center is housed at a university or laboratory, serving high school physics and physical science teachers; active local centers number 50+.

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 and Community Outreach: QuarkNet efforts extend beyond the program. Often, centers integrate QuarkNet in other community outreach and broader impact efforts. QuarkNet has led in facilitating the public use of large particle physics databases. QuarkNet staff and teachers attend and present at meetings of the American Association of Physics Teachers and the American Physical Society. At International Particle Physics Outreach Group (IPPOG) meetings QuarkNet presentations have highlighted how QuarkNet works, e-Labs, the Data Activities Portfolio and scientific discovery for students. QuarkNet has developed and coordinated the CMS masterclass, led the global cosmic ray studies project, and provided a wealth of information for other IPPOG members to consider in their own education and outreach programs.

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



Program Statement: 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.

Centers: QuarkNet delivers its professional development program in partnership with local centers.

Exhibit B. The second page of the PTM which over views its component parts.

anchors, the program's structure, core strategies and program outcomes are stated or described. In addition, enduring understandings and a sustainability framework are included.

The first two pages of the PTM are presented here (Exhibit A and B, previous page); the full model shown in Appendix C. These first two pages serve as an abbreviated version of it and may be very useful depending upon the audience. The first page of the model 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.

The remaining pages shown in Appendix C (pages three through seven) provide specifics and details of each element of the PTM. The core of the Program Theory Model is the relationship between -- program anchors, program structure, program strategies -- and program outcomes, and as described earlier the context in which the program operates.

The details reflected in the PTM are at the strategic level, and are deliberatively not activity specific. The intent is to capture ideas core to the program or "its big ideas" as well as the supportive structure of the program in which these strategies are embedded. The component, *Enduring Understandings,* previously developed and recently revised by Young, Bardeen, Roudebush, Smith and Wayne (2019), was included in the PTM because it succinctly describes expectations about understandings -- that are core to the program and reflective of particle-physics science practices and good science practices in general. Ultimately, the PTM can be viewed as a "blue print" as to how change is expected to happen through the program's underlying components and strategies (DuBow & Litzler, 2019).

At the program level, the information presented in the PTM is not intended to be prescriptive; an in-depth look at the program would likely be supported with other information; for example, details about the sequencing of Data Activities Portfolio activities and highlighting how these instructional materials align with other science standards such as AP or IB Physics Science Standards.

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

Details in the PTM regarding program strategies and its 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.

Program Structure of QuarkNet

The structure of the QuarkNet program includes specific and varied program events that are part of the national and center-level program. The key program structure includes:

Data Camp

Data Camp is a 1-week program offered annually in the summer at Fermilab. It 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 (Large Hadron Collider) data. The camp emphasizes an authentic data analysis experience, in which the teachers are expected to engage as students as active learners of a challenging topic they may initially have known very little about. In the beginning of the week, teachers receive an authentic CMS (Cosmic Muon Soleniod) dataset and work in small groups to analyze the dataset. Groups use these data 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 data. Then, teachers explore various instructional materials in the Data Activities Portfolio (to be explained shortly) that offer them help in incorporating particle physics concepts into their everyday lessons and propose an implementation plan for their classrooms. Throughout the week, teachers take tours (e.g., LINAC tunnel, MINOS experiment) and participate in seminars held by theoretical and experimental physics.

e-Lab

e-Lab is 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 CMS experiment at CERN2's 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 [CERN, Conseil Européen pour la Recherche Nucléaire].

Masterclass: U.S. Model

In the U.S. Model, Masterclass is a one-day event in which students become “particle physicists for a day." Teachers and mentors participate in an orientation by QuarkNet staff or fellows. Teachers implement about 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 explain the measurements they will make using authentic particle physics data. Working in pairs, students are expected to analyze the data in visual event displays; to characterize the events; pool their data with peers; and draw conclusions, helped by one or more particle physicists and their teacher. At the end of the day, students may gather by videoconference with students at other sites to discuss results with moderators at Fermilab or CERN. Some masterclasses take place at schools with teachers providing the particle physics and measurement information. U.S. Masterclasses are part of a larger program, International Masterclasses.

Workshops

The primary vehicle through which participating QuarkNet teachers receive professional development are workshops conducted through the national program or at the center level.

Center-run Workshops**.** A center's second year involves new associate teachers in a multi-week experience that focuses on a research scenario prepared by their mentor(s) with support from lead teacher(s). The mentor models research, similar to Data Camp, -- teachers, as students and active learners, have an opportunity to engage in an experiment, receive and analyze data, and present results. Then teachers have time to create a plan to share their experiences with their students and often use instructional materials from the Data Activities Portfolio in this planning.

During a center's third year and after, lead teacher(s) and mentor(s) have flexibility to organize 4-to-5 day workshops to meet local needs and interests. These workshops vary in content and structure. Centers may meet only during the summer, only during the school year or both during the summer and school year. Some centers meet even more frequently depending upon interest and availability of teachers. These workshops may include a national workshop and offer a learning-community environment with opportunities for teachers to interact with scientists, and learn and share ideas related to content and pedagogy.

National Workshops. On request, QuarkNet staff and/or fellows conduct workshops held at local centers. These workshops typically occur during the summer and can vary in length from several days to a week period. Content includes, for example, cosmic ray studies, LHC or neutrino data, and related instructional materials from the Data Activities Portfolio. National workshops also support opportunities for teachers to work in a learning-community environment, learn and share ideas related to content and pedagogy, and develop classroom implementation plans (PTM, 2019).

Data Activities Portfolio

The Data Activities Portfolio is an online compendium of particle physics classroom instructional materials organized by data strand and expected level of student engagement (https://quarknet.org/data-portfolio). This compendium is an important component of the program connected to the national program's Data Camp as well as to other national and center-run workshops and programs where teachers have opportunities to explore these sequenced lessons and to develop classroom implementation plans. These instructional materials are based on authentic experimental data used by teachers to give students an opportunity to learn how scientists make discoveries. Strands include LHC, CMS, Cosmic Ray Studies, and neutrino data. Curriculum topics include, for example, activities related to conservation laws; and, electricity and magnetism. Activities increase in complexity, sophistication and expected student engagement from Levels 0 to 4 (level 4 activities are in the works). Draft instructional materials are reviewed by QuarkNet staff based on specified instructional design guidelines and are aligned with NGSS, IB, and AP science standards (Physics 1 and Physics 2) as relevant.

Table 2
Data Activities Portfolio: Level Definitions

Level	Description of Expected Student Engagement
0	Students build background skills and knowledge needed to do a Level 1 activity. Students analyze one variable or they determine patterns, organize data into a table or graphical representation and draw qualitative conclusions based on the representation of these data.
1	Students use background sills developed in Level 0. They calculate descriptive statistics, seek patterns, identify outliers, confounding variables, and perform calculations to reach findings; they may also create graphical representations of the data. Datasets are small in size. The data models come from particle physics experimentation.
2	Students use skills from Level 1 but must apply a greater level of interpretation. The analysis tasks are directed toward specific investigations. Datasets are large enough that hand calculation is not practical, and the use of statistics becomes central to understanding the physics. They perform many of the same analysis tasks but must apply a greater level of interpretation.
3	Students use the skills from Level 2. They develop and implement a research plan utilizing large datasets. They have choices about which analyses they do and which data they use; they plan their own investigations.
4	Students use the skills from Level 3. They identity datasets and develop code for computational analysis tools for the investigation of their own research plan.

Note: Level 4 activities are in development.

By selecting activities from across available levels, teachers can develop a sequence of lessons or activities appropriate for their students and to help build student skills-sets by moving from simple to more complex. Teachers can also search for activities by a specific NGSS Practice or across all applicable practices.

Through guidance from teachers, students are provided the opportunities shown in Table 2, which shows five instructional levels of these instructional materials; level 0 and level 4 are new to this award period. Masterclasses and e-Labs offer additional options at levels 3 and 4 with project maps offered as guidance for Masterclass implementations.

Linking Program Strategies to Outcomes

The principal intent of the PTM is to logically link core strategies to program outcomes. Tables 3 and 4 reflect this alignment, first by showing the alignment of program anchors, -- that is, effective professional development, NGSS standards and guided inquiry, -- with core strategies (Table 3). This table (and this section of 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*

Table 3. QuarkNet: Aligning Program Anchors and Core Strategies

Program Anchors: Effective Professional Development and Best Practices	Core Strategies: What Happens in QuarkNet?
Characteristics of Effective Professional Development[1] • Is content focused • Incorporates active learning utilizing, adult learning theory • Supports collaboration**,** typically in job-embedded contexts • Uses models and modeling of effective practice • Provides coaching and expert support • Offers opportunities for feedback and reflection • Is of sustained duration. [1]Darling-Hammond, L., Hyler, M.E., & Gardner, M. (2017, June). Effective teacher professional development. Palo Alto, CA: Learning Policy Institute.	QuarkNet is not static but evolves to reflect changes in particle physics and the education context in which it operates. **Teachers** *Provide opportunities for teachers to be exposed to:* • Instructional strategies that model active, guided-inquiry learning (see NGSS science practices). • Big Idea(s) in Science (cutting-edge research) and Enduring Understandings (in particle physics). *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. **Local Centers (**Each center seeks to foster lasting relationships through collaboration at the local level and through engagement with the national program.) *In addition, through sustained engagement provide opportunities for teachers and mentors to:* • Interact with other scientists and collaborate with each other. • Build a local (or regional) learning community.
Pedagogical and Instructional Best Practices Aligns with the **Science and Engineering Practices** of the NGSS APPENDIX F – Science and Engineering Practices in the NGSS (2013, April). As suggested, these practices are intended to better specify what is meant by inquiry in science. https://www.nextgenscience.org 1. Asking questions (for science) and defining problems (for engineering). 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 (for science) and designing solutions (for engineering). 7. Engaging in argument from evidence. 8. Obtaining, evaluating, and communicating information. Content addresses **Disciplinary Core Ideas and Crosscutting Concepts** (NGSS): 1. Patterns 2. Cause and Effect 3. Scale, Proportion and Quantity 4. Systems and System Models 5. Energy and Matter in Systems 6. Structure and Function 7. Stability and Change of Systems **Guided Inquiry** Guided inquiry (teacher provides problem or question) and Structured inquiry (where teacher provides problem and procedure) [Herron, M.D. (1971). The nature of scientific enquiry. *School Review, 79*(2), 171- 212.] **Guided Inquiry** - The **solution is not already existing/ known in advance** and could vary from student to student. **Students EITHER investigate a teacher-presented question** (usually open-ended) **using student designed/selected procedures OR investigate questions that are student formulated** (usually open-ended) **through a prescribed procedure** (some parts of the procedure may be student designed/ selected). (2007 Jan-Marie Kellow)]	

Table 4. QuarkNet: Aligning Core Strategies and Program Outcomes

Core Strategies: What Happens in QuarkNet?	Program Outcomes
QuarkNet is not static but evolves to reflect changes in particle physics and the education context in which it operates. ***Teachers:*** *Provide opportunities for teachers to be exposed to:* • Instructional strategies that model active, guided-inquiry learning (see NGSS science practices). • Big Idea(s) in Science (cutting-edge research) and Enduring Understandings (in particle physics). *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. **Local Centers** (Each center seeks to foster lasting relationships through collaboration at the local level and through engagement with the national program.) *In addition, through sustained engagement provide opportunities for teachers and mentors to:* • Interact with other scientists and collaborate with each other. • Build a local (or regional) learning community.	**Teachers** *Translate their experiences into instructional strategies, which reflect guided inquiry and NGSS science and engineering practice and other science standards as applicable. Specifically:* • Discuss and explain concepts in particle physics. • Engage in scientific practices and discourse. • Use particle physics examples, including authentic data, when teaching subjects such as momentum and energy. • Review and use instructional materials from the Data Activities Portfolio, selecting lessons guided by the suggested pathways. • Facilitate student investigations that incorporate scientific practices. • Use active, guided-inquiry instructional practices in their classrooms that align with NGSS and other science standards. • Use instructional practices that model scientific research. • Illustrate how scientists make discoveries. • Use, analyze and interpret authentic data; draw conclusions based on these data. • Become more comfortable teaching inquiry-based science. • Use resources (including QuarkNet resources) to supplement their knowledge and instructional materials and practices. • Increase their science proficiency. • Develop collegial relationships with scientists and other teachers. • Are life-long learners. **(And their) Students will be able to:** • Discuss and explain particle physics content. • Discuss and explain how scientists develop knowledge. • Engage in scientific practices and discourse. • Use, analyze and interpret authentic data; draw conclusions based on these data. • Become more comfortable with inquiry-based science. **Local Centers** • Model active, guided-inquiry instructional practices that align with NGSS and other science standards that model scientific research. *Through engagement in local centers* ***Teachers as Leaders:*** • Act in leadership roles in local centers and in their school (and school districts) and within the science education community. • Attend and/or participate in regional and national professional conferences sharing their ideas and experiences. ***Mentors:*** • Become the nexus of a community that can improve their teaching, enrich their research and provide broader impacts for their university. ***Teachers and Mentors:*** • Form lasting collegial relationships through interactions and collaborations at the local level and through engagement with the national program.

particle physics. There are two strategies relate to local centers, these are: *Interact with other scientists and collaborate with each other*; and, *Build a local (or regional) learning community*. More will be said about centers latter in this report.

Table 4 (previous page) 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.*

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.*

As will be seen in subsequent sections of this report, program outcomes directed toward teachers are measured by a Teacher Survey (or subsequently a short update) distributed on an annual basis. And program outcomes related to mentors and interactions between mentors and teachers are 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 will be supported by, for example, links to operations data and implementation plans developed by participating teachers (when available); and, possibly select interviews with participating teachers and/or classroom observations.

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. 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) are offered. Understanding and grounding the program in strategies increases the likelihood of providing teachers with professional development that reflects their individual, as well as center, needs and at the same time provides a framework that aligns with effective practices reflected in the educational research literature.

Enduring Understandings

Table 5 presents the Enduring Understandings of Particle Physics 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 recommend four criteria, i.e., to what extent does the idea, topic or process:

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

Sample (2011) noted that uncoverage implies depth over breath; determining how much material to cover; how deep to go and how deeply to dig down into core principles or processes of a given discipline to gain a lasting understanding. Thus, enduring understandings are defined as "statements summarizing important ideas and core process 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." (http://www6.grafton.k12.wi.us/district/eclipse/essential questions/enduring.html)

Sustainability Framework

Atypical of PTM's, a sustainability framework has been included. Its inclusion seems particularly warranted given the longevity of the program, and the multiple centers that serve as partners and the program's "essential backbone." Of importance, this framework is intended to help us think about sustaining a program beyond its funding period – asking how and in what ways this may be possible and to what end. This framework, shown in Table 6, is based on the work of Scheirer and Dearing (2011) and has been been modified as recommended by Schierer, Santos, Tagai, Bowie, Slade, Carter and Holt (2017) to better reflect the QuarkNet program. We have adopted Scheirer and Dearing's 2011) definition as well, "Sustainability is the continued use of program components and activities for the continued achievement of desirable program and populations outcomes" (p.2060).

Table 5
Enduring Understandings of Particle Physics

1. Scientists make a claim based on data that comprise the evidence for the claim.
2. Scientists use models to make predictions about and explain natural phenomena.
3. Scientists can use data to develop models based on patterns in the data.
4. Indirect evidence provides data to study phenomena that cannot be directly observed.
5. Scientists can analyze data more effectively when they are properly organized; charts and histograms provide methods of finding patterns in large datasets.
6. Scientists form and refine research questions, experiments and models using patterns in large data sets.
7. The Standard Model[1] provides a framework for our understanding of matter at its most fundamental level.
8. The fundamental particles are organized according to their characteristics in the Standard Model.
9. Particle physicists use conservation of energy and momentum to measure the mass of fundamental particles.
10. Fundamental particles display both wave and particle properties, and both must be taken into account to fully understand them.
11. Particle physicists continuously check the performance of their instruments by performing calibration runs using particles with well-known characteristics.
12. Well-understood particle properties such as charge, mass, momentum and energy provide data to calibrate detectors.
13. 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.
14. Particle physicists must identify and subtract background events in order to identify the signal of interest.

Note. Developed by Young, Bardeen, Roudebush, Smith & Wayne, 2019

[1] The Standard Model of Particle Physics: the current theoretical framework that describes elementary particles and their forces (six leptons, six quarks and four force carriers). Physicists (and other scientists) can understand every phenomenon observed in nature by the interplay of the elementary particles and forces of the Standard Model. The search beyond the Standard Model of Particle Physics may lead to a larger, more elegant "theory of everything." (http://www.fnal.gov/pub/science/inquiring/matter/ww_discoveries/index.html)

Table 6
PTM: QuarkNet Sustainability Framework[a]

Antecedents	Outcomes
Characteristics of the Specific Program 1. Fidelity to PTM core strategies as implemented (national or center-level).[b] 2. Evidence of flexibility/adaptability at the center level (if/as needed). 3. Evidence of effectiveness. **Organizational Setting at the Center-level Program**[c] 1. (Good) fit of program with host's organization and operations. 2. Presence of an internal champion(s) to advocate for the program. 3. Existing capacity and leadership of the organization to support program. 4. Program's key staff or clients believe in the program (believe it to be beneficial). **Specific Factors Related to the Center-level Program** 1. Existing supportive partnerships of local organizations (beyond internal staff). 2. Potentially available/existing funders or funding. 3. Manageable costs (resources and personal; supported by volunteers).[d]	1. Program components or strategies are continued (sustained fidelity in full or in part).[e] 2. Benefits or outcomes for target audience(s) are continued.[e] 3. Local/center-level partnerships are maintained.[f] 4. Organizational practices, procedures and policies in support of program are maintained. 5. Commitment/attention to the center-level program and its purpose is sustained.[f] 6. Program diffusion, replication (in other sites) and/or classroom adaptation occur.[f]

[a] This framework is based on the work of Scheirer and Dearing (2011); adopting their definition of sustainability, as well: "Sustainability is the continued use of program components and activities for the continued achievement of desirable program and population outcomes" (p. 2060). The QuarkNet Sustainability framework has been modified to better reflective the QuarkNet program (as recommended by Scheirer, et al., 2017). (See notes below.)

[b] Program fidelity, as *implemented*, has been added as a program characteristic.

[c] The language used to describe these organizational characteristics has been modified slightly to better fit the *QuarkNet* program.

[d] This cost component was moved to environmental or contextual concerns of the specific program.

[e] The order of these two outcomes are reversed from the original.

[f] The language of this characteristic was modified to better fit the QuarkNet program.

In a way, the sustainability framework can be seen as a restatement of long-term outcomes that are often articulated in a PTM. At the same time, it attempts to distill the program components that might have the greatest influences on sustainability (referred to as antecedents).

As will be seen in subsequent sections of this report, the sustainability framework will be 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.

Before embarking on a discussion of measured teacher-level and center-level outcomes and preliminary results, it is important to briefly highlight a picture of the *implemented* program.

Implementation of QuarkNet Program

An overview of the roles and responsibilities of key QuarkNet stakeholders is shown in Figure 1. 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; meetings with IT QuarkNet developers focused on IT needs and updates; and a curriculum development team focused on workshop content and activity development of the Data Activities Portfolio (personal communication, email M. Bardeen, April 17, 2019).

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 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' experiences working with a local center or on national program such as Data Camp (PTM, 2019). Fellows may interact with any of the centers. As already stated the primary vehicle through which participating QuarkNet teachers receive professional development is a workshop conducted through the national program or that is center-run.

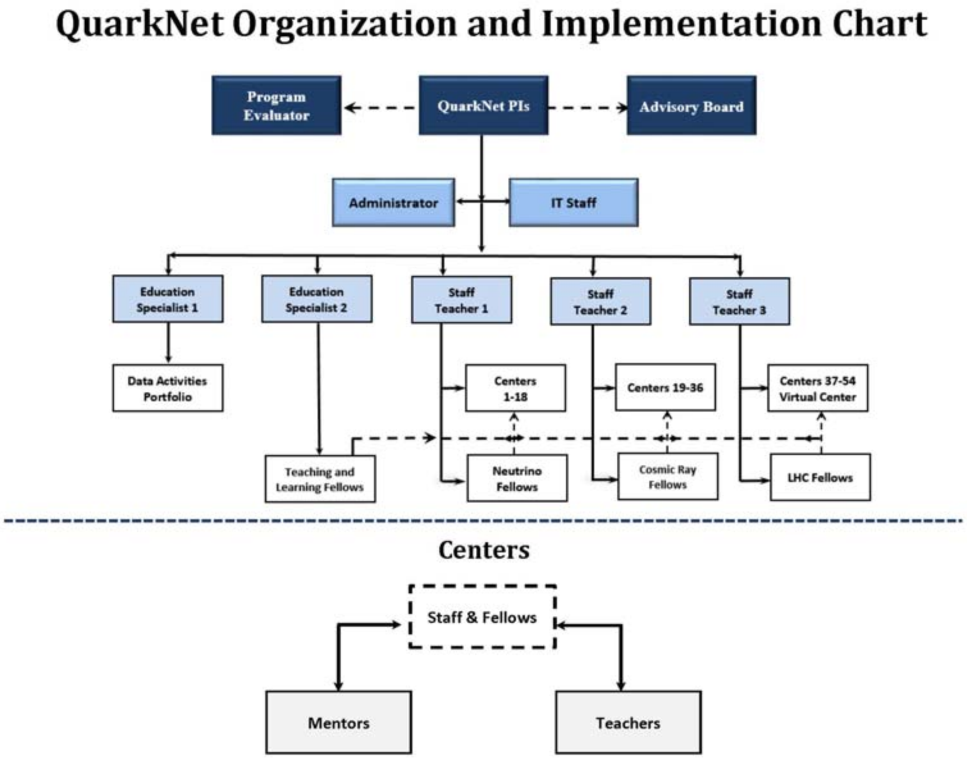


Figure 1. An overview of the organization and implementation of the QuarkNet Program.

In an email distributed by the co-PIs (Wayne, Bardeen and Swartz) a center was 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 7.)

Data Activities Portfolio: Instructional Design and Review of Activities

Figure 2 shows the process used to develop and review activities for inclusion in the Data Activities Portfolio; this process follows the design recommendations by Wiggins and McTighe (2005) as already noted. This process has evolved since the start of QuarkNet; outlined in 2015, by Young, Roudebush and Bardeen; and later updated in 2019. Its intent is to help ensure the quality of developed activities; to align these with the science practices of NGSS; and to provide a standardized template and format. The complete document is shown in Appendix D along with the review protocol.

Table 7
Active QuarkNet Centers: Workshop Held in Program Years 2018-2019 and 2019-2020[a]

Center	Status		Center	Status	
	2018-19	2019-20		2018-19	2019-20
Black Hills State University	Active	Active	University of California at Riverside	--	--
Boston Area (Brown & Northeastern Universities)	Active	Active	University of California at Santa Cruz	--	Active
Brookhaven National Laboratory/Stony Brook University	Active	Active	University of Cincinnati	Active	Active
The Catholic University of America	Active	Active	University of Florida	Active	Active
Chicago State University/ University of Illinois/Chicago	Active	Active	University of Hawai'i	Active	Active
Colorado State University	Active	Active	University of Houston/ Rice University	Active	Active
Fermilab/University of Chicago	Active	Active	University of Illinois at Chicago/Chicago State University	Active	Active
Florida Institute of Technology	--	Active	University of Iowa/Iowa State	Active	Active
Florida International University	--	Active	University of Kansas	Active	Active
Florida State University	Active	Active	University of Minnesota	Active	Active
Idaho State University	Active	Active	University of Mississippi	Active	Active
Johns Hopkins University	Active	Active	University of New Mexico	Active	Active
Kansas State University	Active	Active	University of Notre Dame	Active	Active
Lawrence Berkeley National Laboratory	Active	Active	University of Oklahoma	Active	Active
Northern Illinois University	Active	Active	University of Oregon	Active	Active
Oklahoma State University	Active	Active	University of Pennsylvania	--	--
Purdue University	--	Active	University of Puerto Rico at Mayaguez	Active	Active
Purdue University Northwest	Active	Active	University of Rochester	--	--
Queensborough Community College	--	Active	University of Tennessee, Knoxville	Active	--
Rice University – (with University of Houston)	Active	Active	University of Washington	Active	Active
Rutgers University	Active	Active	University of Wisconsin – Madison	--	Active
Southern Methodist University	Active	Active	Vanderbilt University	Active	Active
Syracuse University	Active	Active	Virginia Center (Hampton, George Mason, William & Mary Universities)	Active	Active
Texas Tech University	Active	Active	Virginia Tech	Active	Active
University at Buffalo – SUNY	Active	Active	Virtual Center	Active	Active
			Wayne State University	--	--

Program Year 2018-19: June 2018 through May 2019; 2019-20: June 1, 2019 through May 31, 2020 (as of August 2020)
[a]Because of COVID-19 some centers have delayed the scheduling of their workshops but are marked as active nonetheless.

Over the course of the QuarkNet program, the development (and review) of activities in the Data Activities Portfolio has been a dynamic process. This has included making sure that all activities, in particular older activities, were reviewed or re-reviewed before 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 (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. In addition, over the past two years, curriculum topics were created to help teachers envision and plan for sequencing lessons (and helping to sure that their students develop the required skills-set). This effort revealed possible gaps in student skills-sets; thus, additional activities were created to help fill these gaps.

Current on-going efforts include the re-review of previously posted activities; filling in gaps for improved sequencing; developing neutrino materials; and creating activities at level 4. A brief history of the Data Activities Portfolio is highlighted in Appendix E.

Data Activities Portfolio: Activities, Masterclasses and e-Labs

Table 8 provides a list of the current activities in the Data Activities Portfolio; there are a total of 30 activities. This represents: 7 activities at Level 0; 10 activities at Level 1; 11 activities at Level 3; and 2 activities at Level 3. In comparison during the 2012-2017 program contract years where a focused effort to expand the number and quality of activities in the Data Activities Portfolio occurred, there were 10 activities at Levels 0-2 at the conclusion of the 2017 program year (not including masterclasses) (Beal & Young, 2017).

Each of the current 30 instructional materials 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 activities. Activities can be searched by 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 (0-3 and soon to be 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); information on technology requirements; and estimated class time to implement are also provided.

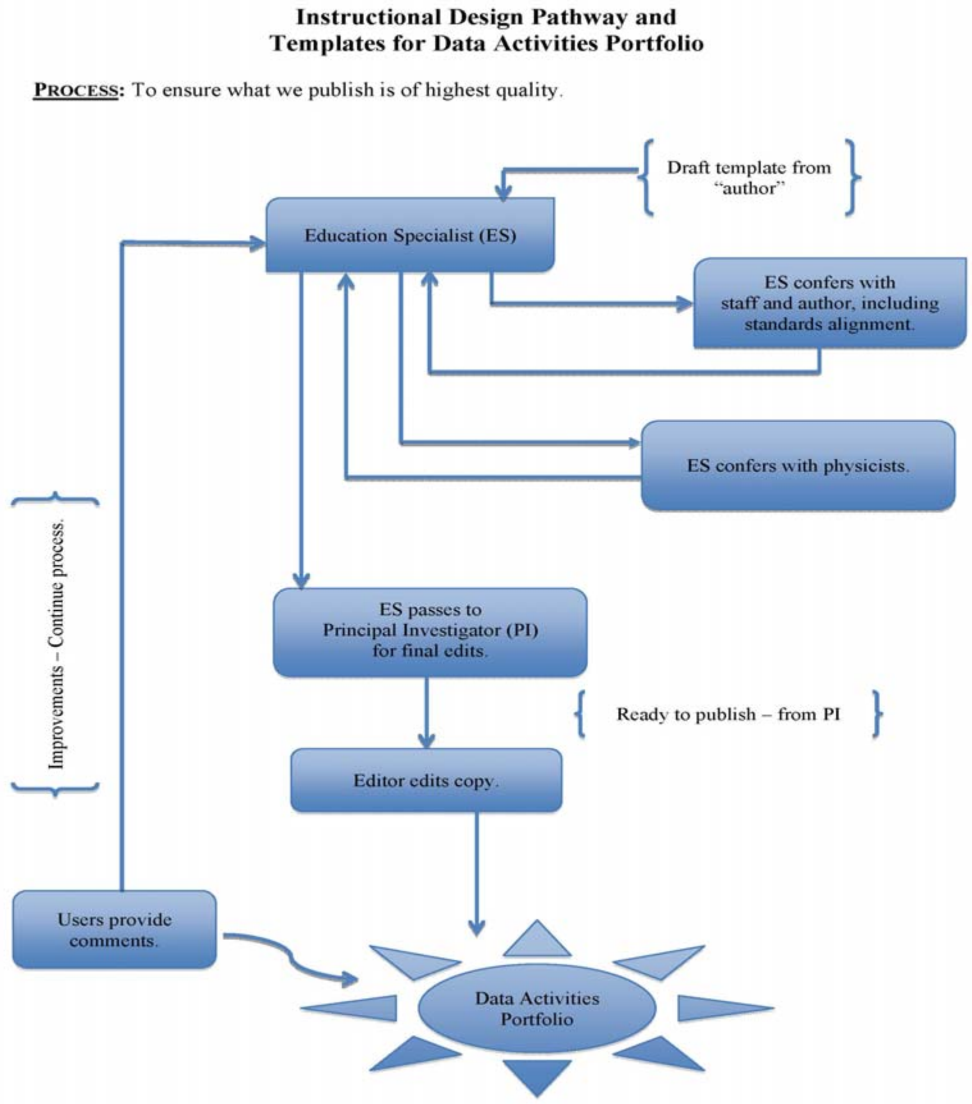


Figure 2. Instructional Design Pathway for Data Activities Portfolio (created by Young, Roudebush & Bardeen)

Table 8
Instructional Materials in the Data Activities Portfolio

Level	Activity	Data Strand	NGSS Practices
0	Mass of U. S. Pennies	Cosmic Ray, LHC	1,3,4,7
0	Quark Workbench 2D/3D	Cosmic Ray, LHC	2,6
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	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
1	What Heisenberg Knew	Neutrino	2,4,5,6,7,8
1	The Case of the Hidden Neutrino	LHC, Neutrino	4,5,6,7
1	Making it 'Round the Bend – Qualitative	LHC	4,5,7
1	Rolling with Rutherford	Cosmic Ray, LHC	1,3,4,7
1	Calculate the Z Mass	LHC	1,4,5,7
1	Calculate the Top Quark Mass	Cosmic Ray, LHC	1,4,5,7
1	Signal and Noise: Cosmic Muons	Cosmic Ray	4,5,6,7,8
1	Mean Lifetime Part 1: Dice	Cosmic Ray, LHC	4,5
1	Histograms: Uncertainty	Cosmic Ray, LHC, Neutrino	4,5
1	Energy, Momentum, and Mass	Cosmic Ray, LHC, Neutrino	2,4,5,7
2	Making it 'Round the Bend – Quantitative	LHC	4,5,6,7
2	Cosmic Rays and the Sun	Cosmic Ray	3,4,6,7
2	CMS Data Express	LHC	4,5,8
2	TOTEM Data Express	LHC	4,5,8
2	ATLAS Z-path Masterclass	LHC	1,3,4,5,6,7,8
2	CMS Masterclass WZH-path	LHC	1,3,4,5,6,7,8
2	Mean Lifetime Part 2: Cosmic Muons	Cosmic Ray	2,3,4,5
2	Mean Lifetime Part 3: MINVERvA	Cosmic Ray, Neutrino	2,3,4,6,7
2	ATLAS Data Express	LHC	4,5,8
2	ATLAS W-path Masterclass	LHC	1,3,4,5,6,7,8
2	CMS Masterclass J/Psi	LHC	1,2,4,5,6,7,8
3	Cosmic Ray e-Lab	Cosmic Ray	1,3,4,6
3	CMS e-Lab	LHC	1,3,4,6

Note: List of activities taken from QuarkNet website https://quarknet.org/data-portfolio. (As of 6/13/2020)
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.

It should be noted that there are three activities that are not included in the above table that were developed through a partnership with STEP UP focused on Diversity and Inclusion. These activities are: QuarkNet: Changing the Culture (Level 0); QuarkNet STEP UP: Careers in Physics (Level 1); and QuarkNet STEP UP Women in Physics (Level 2).

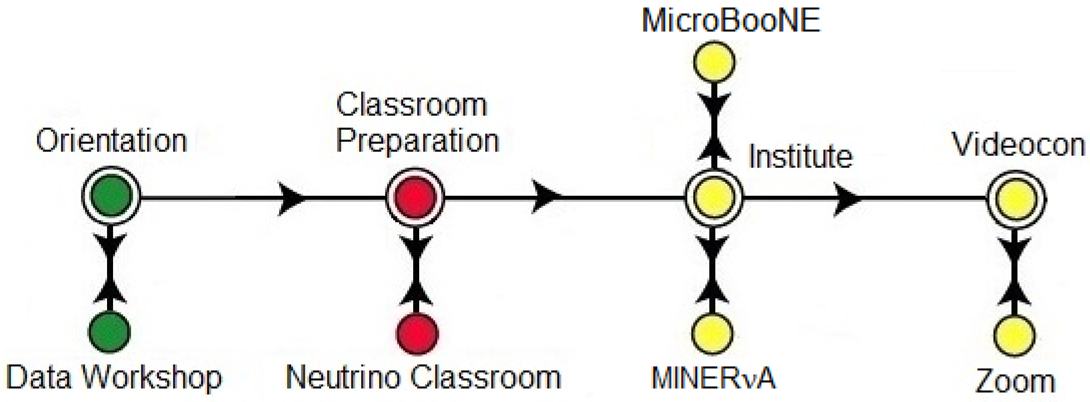


Figure 3. Neutrino Masterclass Project Map 2019 (developed by Cecire, Bilow and Wood; https://quarknet.org/content/neutrino-masterclass-project-map-2020).

Level 3 instructional materials, which are contained in the Data Activities Portfolio, are supported with 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.

An example of a Project Map is shown in Figure 3. As noted on the website, The Project Map "is arranged in the typical chronological order in which a masterclass is prepared and then carried out. The order is more descriptive than prescriptive. This Project Map has 4 'metro stops' plus associated branches. The main metro stops are: **Orientation** explains orienting of teachers and physicists to run a masterclass and provides schedule information. **Classroom Preparation** details how teachers get their students ready for the masterclass. **Institute** and **Videocon** with their branches cover the main elements of the masterclass day. These make up the heart of the Project Map."

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.

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

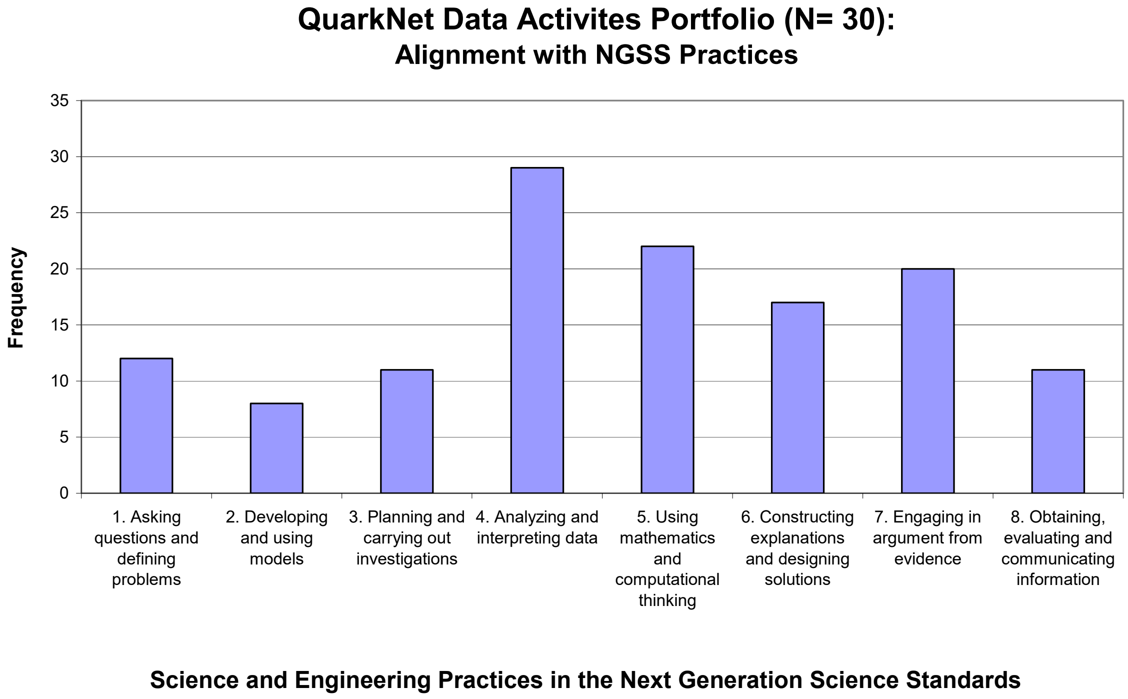


Figure 4. Alignment of Data Activities Portfolio activities with NGSS Practices

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).

Aligning Activities with the Next Generation Science Standard Practices

Two points seem evident from the distribution shown in Figure 4. First, at the program level a strength of the instructional materials in the Data Activities Portfolio is how well these collectively align with the Next Generation Science Standards, Science and Engineering Practices especially 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 Level 2 and 3 activities require analyzing and interpreting data (Practice #4). And, of importance it should be noted this engagement is based on authentic data, often using large data sets involving cutting-edge physics, especially for higher level 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.

The Program's Website

As already suggested, with or without a user account (a guest user account is available) a visitor to the QuarkNet website (https://quarknet.org/) can access all of the instructional materials that have been just described (Data Activities Portfolio, Masterclasses, and e-Labs) along with supportive documents and resources. There are also listings and links to QuarkNet centers.

Groups have been created, using the website to share center-wide information for a specific center (such as agendas, annual reports) or, to provide information to satisfy a specific need or activity (e.g., Planning the Masterclass 2019). Expectations for mentors are provided; as well as a summary of award support; 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 stakeholder; 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.

For example, a summary of server interactions for logged-in users for e-Labs from October 2016 through September 2017 (conducted by Joel Griffith, IT staff, and described in an October 6, 2017 email) suggested the following usage levels. [A server interaction included logins, analyses, saving and accessing plots and posters among other usages.] Based on logged-in users, Griffith reported an estimated 700 users of the e-Lab site (based on unique teacher-ids, eliminating obvious duplicate accounts and staff member usage). This usage-data covered over 4,000 research groups -- reasonably reaching an estimated 4,000 student groups – and which may sum to an estimated 10,000 students reached for this 1-year period.

Based on postings in monthly reports prepared by a QuarkNet PI and staff during May 2019 through March 2020, uploads totaled 5,071 for e-lab studies, where 461 plots and 29 cosmic ray posters were created. And, from late May through the end of June there were an additional 923 cosmic ray uploads, 31 cosmic ray plots and 1 cosmic poster.

Implementation of QuarkNet:
2018-2019 and 2019-2020 Program Years

As usual in the planning of the 2019-2020 program, centers were asked to complete a short RFP, requesting contact information (individual's name, email address, and center name); plans for workshops in the 2019 program year; expected number of days; anticipated dates; expected number of teachers; and additional information as needed (https://quarknet.org/content/summer-2019-rfp). Staff teachers then followed up with centers via emails and/or phone calls as a reminder and/or to help clarify any questions. 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 track 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 repeated for the 2020-2021 program year starting with an email blast distributed on February 3, 2020 again with a link to support information (https://quarknet.org/content summer-2020-rfp). We will discuss the potential impact of COVID-19 pandemic may have on the implementation of summer 2020 workshops later in this report.

With the start of the 2019-2020 program year and throughout this current award period, annually each center can apply for a budgeted 30 teacher-days (through the RFP process just described). As noted in an email blast (in January 18, 2019; and again in February 3, 2020), this could mean, for example, 6 teachers for 5 days or 15 teacher-days for 2 days. The budget for merged centers (two or more) was set at 45 teacher-days (personal communication, email). To help centers plan for a given program year (with most activity starting in the summer), centers are given a list of national workshop opportunities along with a sample agenda to aid in planning and implementation https://quarknet.org/page/ /summer-workshop-opportunities-quarknet-centers) as well as a staff-member representative list (https://quarknet.org/content/quarknet-center-staff-assignments-january-2020).

2018- 2019 Program Year

A list of QuarkNet Workshops held during the 2018-2019 program year by QuarkNet staff is shown in Table 9. Data Camp was implemented at Fermilab from July 16-20, 2018. These are considered nationally-run workshops.

Table 10 lists the meetings and workshops held at QuarkNet Centers and led by the *individual centers*. Together for both tables, this represents a total of 55 centers (50 centers in year 3+ of the program); 1 virtual center; and 4 sabbatical centers (based on emails from S. Wood, K. Cecire; M. Bardeen, June 21, 2019). (As already mentioned, see Table 7 for a list of the centers and the status of each.)

Table 9

2018-2019 QuarkNet-staff Held Workshops

QuarkNet Center	**Workshop Type (e.g., Cosmic, Data, CMS e-Lab)**	**Workshop Dates (Chronological Order)**	**Staff/Fellow Leading Workshop**
Kansas State University	LIGO	June 4-5	Shane Wood
Kansas State University	Cosmic	June 6-8	Martin Shaffer
University of Minnesota	Neutrino Prototype	June 13-14	Shane Wood/Ken Cecire
Texas Tech University	Cosmic	June 13-14	Martin Shaffer
Rice University/ University of Houston	CMS Data	June 25-26	Shane Wood
Rice University/ University of Houston	Neutrino Prototype	June 27-28	Shane Wood
University of Iowa/Iowa State University	CMS e-Lab	July 9-10	Marla Glover
Black Hills State University	Neutrino Prototype	July 18-19	Shane Wood
Fermilab/University of Chicago	LIGO	July 18-19	Shane Wood
Johns Hopkins University	LIGO	July 25-26	Marla Glover
Virginia Center	Neutrino Prototype	August 6-7	Shane Wood
Colorado State University	LIGO	August 8-10	Ken Cecire
University of Washington	ATLAS Data	August 17-19	Shane Wood
University of Florida	Neutrino Prototype	August 25-26	Ken Cecire

[a] Hampton, George Mason and W&M Universities

A breakdown of annual participants (2018-2019 and 2019-2020 program years) is provided in the annual NSF report submitted by the PIs and program staff, respectively.

Program Year 2019-2020

With the roll-out 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 be (and have been) modified for the workshops led by individual centers, if desired. During nationally-led workshops, indeed these agendas are often modified in real time providing a straightforward way of documenting content and noting changes. Once a workshop was completed, the updated agenda memorialized 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 make it easier for centers to complete their annual reports; with details regarding the workshop or meeting captured in one or both of these documents.

Table 10

2018-2019 QuarkNet Center-led Meetings and Workshops

Center	**2018** Meeting Dates (All days)	Center	**2018** Meeting Dates (All days)
Black Hills State University	July 10-14	University of California, Riverside	
Boston area	August 14-15	University of California, Santa Cruz	
Brookhaven National Laboratory	June 25-29	University of Cincinnati	Summer (no dates specified in annual report)
Catholic University of America	August 13-17, plus 3 days in fall	University of Florida	August 25-26
Colorado State University	August 8-10	University of Hawaii	June 2-3
Fermilab/University of Chicago	July 18-19	U of Illinois Chicago/Chicago State University	June 25-29
Florida Institute of Technology		University of Iowa/Iowa State	July 9-13
Florida International University		University of Kansas	June 11-13
Florida State University	August 1-2	University of Minnesota	June 12-14
Idaho State University	July 9-13	University of Mississippi	June 25-26
Johns Hopkins University	July 23-27	University of New Mexico	May 4 and one fall day
Kansas State University	June 4-8	University of Notre Dame	July 30 - Aug 3
Lawrence Berkeley National Laboratory/ Stony Brook University	June 18-22	University of Oregon	June 20-21
Northern Illinois University	June 25-29	University of Pennsylvania	
Oklahoma State University/University of Oklahoma	July 24-27	University of Puerto Rico-Mayaguez	Dec. 8-9; April 6, 2019
Purdue University		University of Rochester	
Purdue University Northwest	June 18-22	University of Tennessee, Knoxville	
Queensborough Community College		University of Washington	August 17-19
Rice University/University of Houston	June 25-29	University of Wisconsin-Madison	
Rutgers University	July 9-13	Vanderbilt University	June 25-29
Southern Methodist University	Aug 6-10	Virginia Center (Hampton, George Mason and William and Mary Universities)	Aug 6-8
Syracuse University	Aug 8-10	Virginia Tech University	July 23-26
Texas Tech University	June 13-15	Virtual Center	July 11-14
University at Buffalo	Aug 21-22	Wayne State University	

Nationally-led workshops were 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 using cosmic ray detectors, or machine learning. Often, a tour of local laboratories and research centers is 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). It should be noted that 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 to major in physics.)

Of particular importance, activities from the Data Activities Portfolio (DAP) included in the workshops were documented, too. It is evident from Table 11, especially for nationally-led workshops, that activities from the DAP are a frequent and integral part of the workshop. This focus – and its documentation – coincides with the improved quality and robust increase in the number of activities included in the DAP (since 2017). By design, the embedded DAP activities align with the content of the workshop, often at multiple student-skills levels (Level 0, 1, 2, and 3). Teachers engaged in these activities as active learners – as students -- and, at times, can select from examples of provided activities during the workshop 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 how they may comprehend the content. This is compatible with effective teacher professional development practices outlined by Darling-Hammond, et al., (2017). To that end, teachers are often given the time to reflect on how they might use these activities in their classroom – a primary purpose of the DAP -- and incorporate these into their implementation plans.

As noted in Table 11, among the most frequently used DAP activities were: *Shuffling the Deck* (Level 0); *What Heisenberg Knew* (Level 1); *Rolling with Rutherford* (Level 1); and *Calculating the Z Mass* (Level 1); but other activities related to Mean Life and MINERvA measurement were evident as well.

In the next several sections, we take a look at the development of evaluation measures and the evaluation plan along with preliminary results from the Teacher Survey administered during the 2018-2019 program year; and early results from the Center Feedback Template.

Table 11

2019-2020 QuarkNet Workshops and Meetings: National- and Center-led

Center	**2019 Dates (All days)**	**Workshop/Meeting**	**Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
Black Hills State University	No activity		
Boston area	August 14-15	**Neutrino Workshop** (co-led by Center)	Mean Life Part 3: Minerva (2) Mean Life Part 2: Cosmic Muons (2) What Heisenberg Knew (1) MINERvA masterclass measurement
Brookhaven National Laboratory/ Stony Brook University	July 3	**MINVERvA Neutrino Masterclass**	MINERvA Neutrino measurement (2)
The Catholic University of America	August 5-7	CMS and Cosmics **(CMS Data Workshop)**	Shuffling the Particle Deck (0) Rolling with Rutherford (1) Calculate the Z Mass (1)
Colorado State University	July 29-31	**Neutrino Data Workshop**	Mean Lifetime Part 1: Dice (1) Mean Lifetime Part 2: Cosmic Muons (2) Shuffling the Particle Deck (0) What Heisenberg Knew (1) The Case of the Hidden Neutrino (1) Histograms: Uncertainty (1) Mean Lifetime Part 3: MINERvA (2) Implementation Plans
Fermilab/University of Chicago	July 24-26	**Neutrino Data Workshop & Student Presentations**	Shuffling the Particle Deck (0) The Case of the Hidden Neutrino (1) Mean Lifetime Part 1: Dice (1) Mean Lifetime Part 3: MINERvA (2) MINERvA Masterclass measurement (2) Histograms: The Basics (0) Histograms: Uncertainty (1) What Heisenberg Knew (1) Implementation Plans
Florida Institute of Technology	No activity		

Note. National-led QuarkNet workshops are in a bold-face font.

Information compiled from the workshop agenda posted on individual center pages on QuarkNet website.

Table 11

2019-2020 QuarkNet Workshops and Meetings: National- and Center-led (con't.)

Center	**2019 Dates (All days)**	**Workshop/Meeting**	**Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
Florida International University	August 5-7	**CMS Workshop**	Shuffling the Particle Deck (0) Rolling with Rutherford (1) Calculate the Z Mass (1)
Florida State University	July 31- August 2	**CMS Workshop**	Shuffling the Particle Deck (0) Rolling with Rutherford (1) Calculate the Z Mass (1) Making it Round the Bend (Qualitative) (1) Making it Round the Bend (Quantitative) (2) CMS Masterclass Measurement (2)
Idaho State University Pocatello (co-conducted workshop with the University of Cinncinnati)	June 17-20	Cosmic Ray Muon Detectors (CRMD) **Neutrino Masterclass**	Assemble a complete CRMD Neutrino Masterclass
Johns Hopkins University	July 22-26	JHU Workshop	Create videos for use in the classroom Develop lesson plan/approach based on transcribed lecture recorded from a theoretical physicist
Kansas State University	March 2 April 5	Masterclass Orientation Masterclass	
	May 28-31	Cosmic Ray Workshop	Configure a cosmic ray detector Identify and describe cosmic ray e-Lab tools Create, organize and interpret a data plot Develop a plan to increase current use of data by students
Lawrence Berkeley National Laboratory	June 24-28	Physics in and through the Cosmology	The Case of the Hidden Neutrino (1) What Heisenberg Knew (1) Shuffling the Particle Deck (0) MINERvA Masterclass Measurement (2)
Northeastern University	No activity		
Northern Illinois University	June 24	Cosmic Ray Workshop	Mean Lifetime Part 1: Dice (1) Mean Lifetime Part 2: Cosmic Muons (2)

Note. National-led QuarkNet workshops are in a bold-face font.
Information compiled from the workshop agenda posted on individual center pages on QuarkNet website.

Table 11

2019-2020 QuarkNet Workshops and Meetings: National- and Center-led (con't.)

Center	**2019 Dates (All days)**	**Workshop/Meeting**	**Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
Purdue University	No activity		
Purdue University Northwest	June 13	CMS Masterclass Mini-Workshop	CMS Masterclass Measurement
Queensborough Community College		No workshop	CMS tracking detection and GPS data postings
Rice University/University of Houston	June 17-21	**CMS Data Workshop**	Shuffling the Particle Deck (0) Histograms: Uncertainty (1) TOTEM Data Express (2) Making it Round the Bend (Qualitative) (1) Making it Round the Bend (Quantitative) (2) Calculate the Z Mass (1) or Calculate the Top Quark Mass (1) CMS WWDD Measurement
Rutgers University	No date specified	Summer Research Program and 1-day Workshop	Focus on transferring summer-research material into their classrooms
Southern Methodist University	July 29-31	**Neutrino Data Workshop** (July 29-30) Center-led Workshop (July 31)	Shuffling the Particle Deck (0) The Case of the Hidden Neutrino (1) Mean Lifetime Part 1: Dice (1) Mean Lifetime Part 3: MINERvA (2) Histograms: The Basics (0) Histograms: Uncertainity (1) What Heisenberg Knew (1) MINERvA Masterclass Measurement (2)
Syracuse University	August 15-16	**Workshop with STEP UP**	Mean Lifetime Part 1: Dice (1) Mean Lifetime Part 3: MINERvA (2) New York Science Learning Standards 3D e-Lab (North County 3D Café)

Note. National-led QuarkNet workshops are in a bold-face font.

Information compiled from the workshop agenda posted on individual center pages on QuarkNet website.

Table 11

2019-2020 QuarkNet Workshops and Meetings: National- and Center-led (con't.)

Center	**2019 Dates (All days)**	**Workshop/Meeting**	**Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
Texas Tech University	June 3-7	Summer Workshop (first 3 days) **CMS Workshop** (last 2 days)	Rolling with Rutherford (1) Shuffling the Particle Deck (1) or Quark Workbench 2D/3D (1) Calculate the Z Mass (1) CMS Masterclass Measurement (2) Exploration of Level 3 DAP (CMS e-lab)
University of Buffalo, SUNY	March 30	**CMS Masterclass**	
	August 19-20	CMS Workshop	Several new ideas for cosmic data analysis with e-Lab were presented.
University of California, Riverside	No activity		
University of California, Santa Cruz	No activity		
University of Cincinnati (Workshop co-conducted with Idaho State Pocatello)	March 8	**LCHb Masterclass**	
	June 19-20	**Neutrino Data Workshop** (2 days) 1-day Workshop	Shuffling the Particle Deck (Level 0) What Heisenberg Knew (Level 1) The Case of the Hidden Neutrino (Level 1) Mean LifeTime Part 3: MINERvA (Level 2) MINERvA Masterclass Measurement (Level 2) During 1-day Workshop (and LCHb Masterclass): Rolling with Rutherford (Level 1) Marking it 'Round the Bend QuarkBench Workbench 2D/3D (Level 0) Calculate the Z Mass (Level 1) Implementation Plans
University of Florida	No activity		
University of Hawaii	No activity		
University of Illinois at Chicago/ Chicago State University	July 8-12	**CMS Workshop**	Rolling with Rutherford (1) Two separate studies (the speed of muons and the rate of multiple muons in cosmic ray air showers)
University of Iowa/Iowa State University	No activity		

Note. National-led QuarkNet workshops are in a bold-face font.

Information compiled from the workshop agenda posted on individual center pages on QuarkNet website.

Table 11

2019-2020 QuarkNet Workshops and Meetings: National- and Center-led (con't.)

Center	**2019 Dates (All days)**	**Workshop/Meeting**	**Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
University of Kansas	June 12-14	Computing in the Physics Classroom	Construct lesson plan Each group constructs student computing exercises Try out student computing exercise on other groups Groups report out on classroom exercise
University of Minnesota	April 6	**Neutrino Masterclass**	MINERvA Analysis
	June 12-14	**Minnesota Workshop: Neutrinos, CMS & e-Labs**	Histograms: Uncertainty (1) What Heisenberg Knew (1)
University of Mississippi	No activity		
University of New Mexico	September 7	Tour	Technical and historical tour of scientific heritage sites of Los Alamos, NM.
University of Notre Dame	Summer Weekly Meetings Special Events	**Weekly Teacher Meetings** **Summer Research** **QuarkNet Week** **ATLAS Masterclass** (March 15)	Discussions about physics and teaching ATLAS Masterclass.
University of Oklahoma/Oklahoma State	July 17-19	Workshop ATLAS Masterclass	Discussed QuarkNet materials in the classroom Conducted a masterclass for teachers and demonstrated how they can use a masterclass with their students.
University of Oregon	June 20-21	**ATLAS Data Workshop**	Rolling with Rutherford (1) Quark Workbench (1) or Shuffling the Particle Deck (1) Calculate the Z Mass (1) Mass of US Pennies (0) Atlas Z-path Masterclass Measurement
University of Pennsylvania	No activity		
University of Puerto Rico	November 2-3	Cosmic Ray	
University of Rochester	No activity		

Note. National-led QuarkNet workshops are in a bold-face font.
Information compiled from the workshop agenda posted on individual center pages on QuarkNet website.

Table 11

2019-2020 QuarkNet Workshops and Meetings: National- and Center-led (con't.)

Center	**2019 Dates (All days)**	**Workshop/Meeting**	**Data Activities Portfolio (Level)** [and/or classroom use/implementation plans]
University of Tennessee, Knoxville	July 12-13	**MicroBooNE Masterclass Development Workshop**	Neutrino Masterclass Status μβ Masterclass
University of Washington	No activity		
University of Wisconsin Madison	No activity		
University of Wisconsin River Falls	No activity		
Vanderbilt University	June 24-28	CMS Workshop	Using CRMD and e-lab facilities. Set up a standard CRMD in telescope configuration.
Virginia Center (College of William and Mary, Hampton University, and George Mason University)	March 9 April 6 August 5-7	**CMS Masterclass** **Neutrino Masterclass** **Workshop: Theme Data Analysis CMS**	Histograms: Uncertainty (1) Making it Round the Bend (Qualitative) (1) Making it Round the Bend (Quantitative) (2) What Heisenberg Knew (1) Energy, Momentum, and Mass (1) TOTEM Data Express (2) CMS Masterclass Measurement (2) Signal & Noise Reflections and Brainstorming
Virginia Tech	August 5-7	Catching Gravitational Waves	LIGO e-Labs Create lesson plans for e-Labs incorporated into classrooms.
Virtual Center	August 12-13	CMS Analysis and Step UP	CMS Masterclass Measurement
Wayne State	No activity		
National Program held at Fermilab	July 15-19, 2019	**Data Camp**	Rolling with Rutherford (1) Shuffling the Particle Deck (0) QuarkNet Workbench 2D/3D (0) Mass of U.S. Pennies (0) Calculate the Top Quark Mass (1)

Note. National-led QuarkNet workshops are in a bold-face font.

Information compiled from the workshop agenda posted on individual center pages on QuarkNet website (February 15, 2020)

Development of Evaluation Measures and Evaluation Plan

The first goal of the evaluation has been completed, that is, the (1) Development of a Program Theory Model (PTM). Although the PTM will be reviewed and may be revised, as needed during this award period, the lion share of this model is completed.

To fulfill the remaining two evaluation goals: (2) Assessment of program outcomes at the national and center levels through teacher-level outcomes; and, (3) Assessment of the sustainability of program centers, based on center-level and sustainability outcomes, two evaluation measures were designed; that is, a Teacher Survey and a Center Feedback Template. As a reminder, the new evaluation efforts began in September 2018 to coincide with the 2018-2019 program year. Most QuarkNet workshops and meetings at participating centers occur over the summer (as already noted in previous tables). The Teacher Survey was rolled out to coincide with these summer 2019 activities. (This aligns with Goal 2: assessment of teacher-level outcomes). A pilot test of the Center Feedback Template began in November 2019 and has been extended during the 2019-2020 program year. This coincides with assessment of center-level outcomes (Goal 3) and will serve to provide a context for teacher-level responses.

An UPDATE: Teacher Survey has been integrated into the process starting in spring 2020. Program operations data, gathered from the Center Feedback Template, and other sources will be linked to teacher-level evaluation data when possible to assess outcomes relative to program engagement at the individual level (by teacher) and at the center level (teachers embedded or nested by center).

QuarkNet staff teachers (Wood, Cecire) and the education specialist (Roudebush) posted on the QuarkNet website a *Guide to Teacher Implementation Plan Development*. In the planning for the 2020-2021 program year, this will be a required activity for all nationally-led workshops and strongly recommended for center-run workshops. It will augment evaluation attempts to use teacher implementation plans as evidence for workshop teacher-level outcomes and will help link teacher-level information obtained from the UPDATE: Teacher Survey. Finally, interviews and classroom observations may be used, based on specific sampling as feasible.

We first describe the evaluation measures themselves; then, present preliminary results based on the implementation of these methods and measures.

Assessment of Program Outcomes at the National and Center Levels: Teacher Survey

The Teacher Survey was developed to assess teacher-level program outcomes at the national and center levels as perceived by participating teachers. As implied, the unit of measure is the individual teacher (see Table 12). The full survey is shown in Appendix F (in a PDF format). Teachers participate in the survey electronically through a SurveyMonkey link. Teachers are encouraged to complete the survey using their own

Table 12
Teacher Survey: Teacher Perceptions of Exposure to Program Core Strategies and Assessment of Program Outcomes

Core Strategies	Outcomes	Evaluation Measure
Provide opportunities for teachers to be exposed to: • Instructional strategies that model active, guided-inquiry learning (see NGSS science practices). • Big Idea(s) in Science (cutting-edge research) and Enduring Understandings (in particle physics).	***Teachers:*** *Translate their experiences into instructional strategies, which reflect guided inquiry and NGSS science and engineering practice and other science standards as applicable. Specifically:* • Discuss and explain concepts in particle physics. • Engage in scientific practices and discourse. • Use particle physics examples, including authentic data, when teaching subjects such as momentum and energy. • Review and use instructional materials from the Data Activities Portfolio, selecting lessons guided by the suggested pathways. • Facilitate student investigations that incorporate scientific practices. • Use active, guided-inquiry instructional practices in their classrooms that align with NGSS and other science standards. • Use instructional practices that model scientific research. • Illustrate how scientists make discoveries. • Use, analyze and interpret authentic data; draw conclusions based on these data. • Become more comfortable teaching inquiry-based science. • Use resources (including QuarkNet resources) to supplement their knowledge and instructional materials and practices. • Increase their science proficiency. • Develop collegial relationships with scientists and other teachers. • Are life-long learners. ***(And their) Students will be able to:*** • Discuss and explain particle physics content. • Discuss and explain how scientists develop knowledge. • Engage in scientific practices and discourse. • Use, analyze and interpret authentic data; draw conclusions based on these data. • Become more comfortable with inquiry-based science.	The Teacher Survey is intended to assess teachers' perceptions related to their exposure to core strategies (as *implemented*); and, their perceptions regarding teacher and student outcomes. (See Appendix F for a copy of the survey.) The unit of measure for this survey is the individual teacher; it is conducted via SurveyMonkey. The intent is for teachers to complete the survey during their on-site program engagement. This is an annual event. Teachers are asked to complete a much shorter survey (Update) the following year they complete the full survey; it is focused on use of activities in the Data Activities Portfolio in their classroom; teacher-level and student-level outcomes. (See Appendix G.)
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.		
Local Centers (Each center seeks to foster lasting relationship through collaboration at the local level and through engagement with the national program.) *In addition, through sustained engagement provide opportunities for teachers and mentors to:* • Interact with other scientists and collaborate with each other. • Build a local (or regional) learning community.		

electronic device, although the use of their personal cell phone is not recommended.

Through this survey, teachers are asked to provide information about themselves (e.g., *How many years have you been teaching?*) brief information about their school (e.g., *What best describes the location of your school?);* as well as the nature and extent of their participation in QuarkNet (e.g., Which *QuarkNet Workshops or Programs have you participated in*?). The central thesis of the survey incorporates questions related to the core program strategies, and teacher-level program outcomes articulated in the PTM.

A detailed description of strategies and program outcomes covered in this survey is shown in Table 12. Specifically, teachers are asked their perspectives on the degree to which they were exposed to or engaged in the program strategies listed in the table (and reflected in the PTM) (e.g., *QuarkNet provides opportunities for me to: a. Engage as an active learner, as a student.*). Then, teachers are asked their perceptions as to how (or if) they have applied what they have experienced or learned through their QuarkNet participation in their classrooms (e.g., *Demonstrate how to use, analyze and interpret authentic data*). Also, they are asked to reflect on the degree to which they think QuarkNet has influenced these behaviors. Finally, teachers are asked to reflect on student-level outcomes based on perceived student classroom engagement and the degree to which QuarkNet has influences these behaviors as well (e.g., *Discuss and explain concepts in particle physics*).

Throughout the survey there is a full array of response options; with many opportunities for open-ended responses. A 5-point, Likert-like scale is used to gather teacher perspectives on questions related to exposure to core program strategies (Poor, Fair, Average, Good or Excellent); teacher program outcomes that are event-based in the classroom (Almost Always, Very Often, Sometimes, Not Very Often, or Rarely); and, student classroom engagement (Very High, High, Moderate, Low or Very Low). When used, a "Not Applicable" option carried a value of zero. These responses were coded such that the higher the value, the more positive the response.

In support of the Teacher Survey, an email blast was sent in early spring (2019) to active centers to underscore the importance of evaluation efforts prior to the planned summer (2019) workshops. Evaluation requests were also included on their "must do" list (which included information for teachers to receive their stipend). Mentors, fellows and facilitators were asked to include the participation of the survey in the agenda of the event as well (and to include the SurveyMonkey link). Teachers were encouraged to self-identify on the survey to facilitate the linking of this survey information to program participation levels. Thus, evaluation requests and requirements were embedded along with other program announcements and actions.

The first administration of the Teacher Survey occurred during QuarkNet workshops and programs implemented during the 2019-2020 program year. Teachers were asked to complete the survey during their at-site QuarkNet event. Time to complete the survey was incorporated into most workshop agendas and many workshop facilitators announced and emphasized the importance of survey participation. According to Survey Monkey, it took (and will take) an estimated 18 minutes to complete it.

The full survey is a planned annual event; however, a given teacher is asked to complete this survey only once during this grant period. Starting in spring 2020, if a teacher has completed the full Teacher Survey, he or she will be asked to complete the short UPDATE: Teacher Survey (see Appendix G). The update focuses on the use (or planned use) of activities in the Data Activities Portfolio in the classroom; teacher level outcomes and their perceptions about (their) student outcomes. The update has been rolled out to coincide with the 2020-2021 program year. Teachers access it through a SurveyMonkey link with an estimated 6-minute completion time (time to complete is also incorporated into the agenda).

Assessment of the Sustainability of Program Centers: Based on Center-level and Sustainability Outcomes – Center Feedback Template

Given that most teachers experience the QuarkNet program through their engagement of the program at a specific center, the center provides an important context in which the teachers experience the program and at the same time, centers are a source of outcomes in their own right. To this end, the Center Feedback Template was designed to assess this program context; assess center-level outcomes (see Table 13); and, gather information on success factors as a means to assess sustainability outcomes (see Table 14).

The Center Feedback Template is a 4-page form (see Appendix H). It is divided into four sections. Section I requests information about the Center (who is participating in this effort and who is completing this form). Section II asks about program events over the past two years. Section III gathers information about center-level outcomes (described in Table 13); and Section IV is focused on the Success Factors listed in Table 14).

Given that this template is more complicated than a survey per se, we have used the following protocol. First, relying on the help of QuarkNet staff teachers, centers are selected on a rolling basis (we have selected four centers initially starting in September 2019 and then six more centers in spring 2020). To help ease the task, a draft of Section II is completed by the evaluator based on information gathered from existing annual reports and agenda for a given center over the past two years, for example, 2019 and 2018 program years. This draft summary is reviewed by QuarkNet staff teachers who have direct knowledge about a given center and is revised as needed. (Figure 5 shows a blank Section II.) Then, the mentor is sent an email suggesting that an initial conference call is necessary to help the center fulfill this request. In practice, this conference call has run about an hour and typically has included a staff teacher, the mentor and lead teachers and the evaluator. During discussion, Section II is reviewed but the focus of the call is on helping the center complete Sections III and IV after the call is complete (see Figures 6 and 7). An agreed upon completion deadline is then set. Once the center completes the form a short summary of teacher survey responses (from their center) is emailed to them.

Table 13
Center Feedback Template: Linking Core Strategies and Center-level Outcomes

Core Strategies	Outcomes	Evaluation Measure
Provide opportunities for teachers to be exposed to: Instructional strategies that model active, guided-inquiry learning (see NGSS science 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 (for science) and designing solutions (for engineering) 7. Engaging in argument from evidence 8. Obtaining, evaluating, and communicating information.	**Local Centers** • Model active, guided-inquiry instructional practices that align with NGSS and other science standards that model scientific research. *Through engagement in local centers* ***Teachers as Leaders:*** • Act in leadership roles in local centers and in their school (and school districts) and within the science education community. • Attend and/or participate in regional and national professional conferences sharing their ideas and experiences. ***Mentors:*** Become the nexus of a community that can improve their teaching, enrich their research and provide broader impacts for their university. ***Teachers and Mentors:*** Form lasting collegial relationships through interactions and collaborations at the local level and through engagement with the national program.	The Center Feedback Template is intended to serve as a guide or protocol to capture center-level information related to *implemented* program strategies and well as key center-level outcomes. (See Appendix H for a copy of this protocol.) The unit of measure for this evaluation effort is the center. The narrative of this report explains the plan for how this template is and will be distributed and in what ways centers are offered assistance in completing it based on staff teacher aid and/or assistance from the evaluator. This template also addresses sustainability outcomes, which are presented in Table 14.
*Program provides opportunities for a **strong mentor**.* (Mentor provides leadership skills mainly of content and/or technical expertise; understands education and professional development -- working with teacher leaders as needed; models research.)		
Local Centers: *In addition, through sustained engagement provide opportunities for teachers and mentors to:* • Interact with other scientists and collaborate with each other. • Build a local (or regional) learning community		

In addition to serving the evaluation needs that have been described, we hope that this information will be of value to the centers – as a means to reflect on program engagement (past or present) – as well as helpful to QuarkNet staff as they think about current or future needs of the center. We also hope that this process offers a summary of broader impacts of the program for centers to use for other purposes.

As mentioned, we plan on linking teacher responses from the survey to program participation data captured through the Center Feedback Template, as well as other program operations data so that teacher and center responses can be understood in the context of the degree and type of program engagement.

Table 14

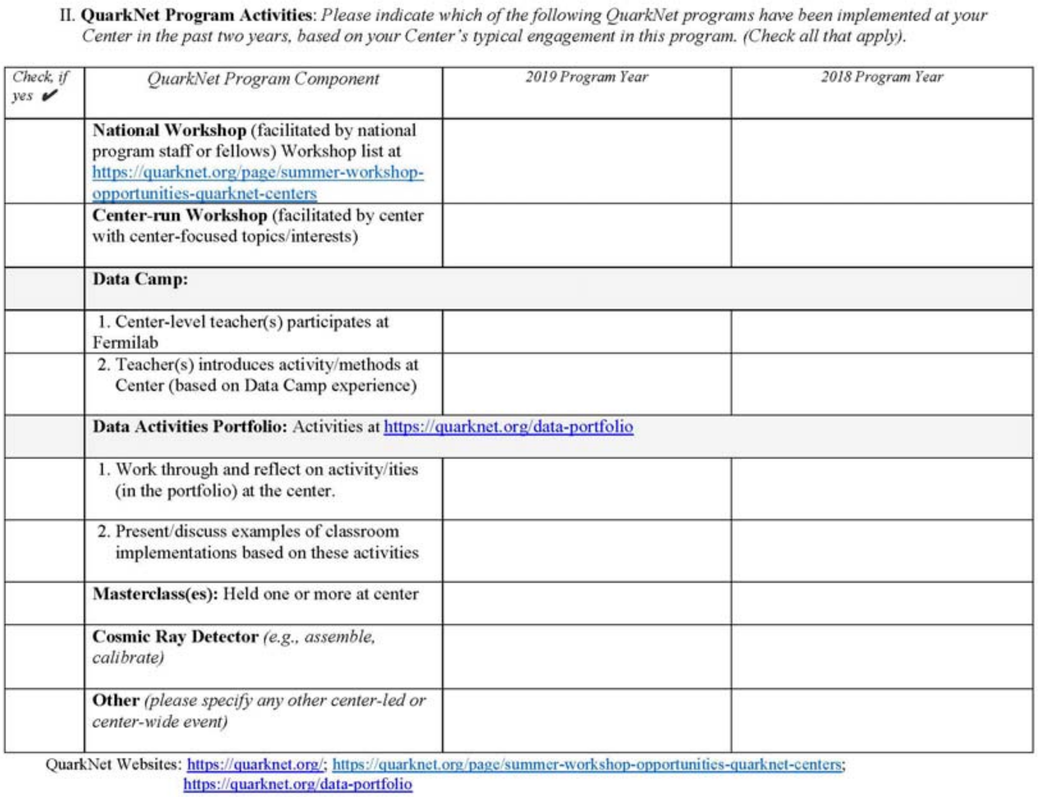
Center Feedback Template: Sustainability Outcomes and Success Factors[a]

Sustainability Outcomes[b]	Success Factors[a]
1. Program components or strategies are continued (sustained fidelity in full or in part). 2. Benefits or outcomes for target audience(s) are continued. 3. Local/Center-level partnerships are maintained.[c] 4. Organizational practices, procedures and policies in support of program are maintained. 5. Commitment/attention to the center-level program and its purpose is sustained.[c] 6. Program diffusion, replication (in other sites) and/or classroom adaptation occur.[c]	1. *Program provides opportunities for a **strong teacher leader**.* (Teacher provides leadership in areas of content and/or is a technical expert; models exemplary pedagogical skills; able to provide organizational skills. These characteristics may be present in one or a team of teacher leaders.) 2. *Program provides opportunities for a **strong mentor**.* (Mentor provides leadership skills mainly of content and/or technical expertise; understands education and professional development -- working with teacher leaders as needed; models research.) 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.) 4. *Meaningful activities* (The standard for meaningful activities is focusing topics in modern physics, discussing how to implement this content in classrooms, conducting research and discussing scientific inquiry methods; using Data Activities Portfolio instructional materials.) 5. *Directly addresses classroom implementation of instructional materials for all teachers.* (Time for teachers to discuss Data Activities Portfolio instructional materials and pathways; to consider NGSS, AP, IB or other science standards; presentation(s) from veteran teachers on classroom implementation experiences or similar engagement.) *6. Program is able to provide regular contact and support with teachers.* (Specific support and or follow up from staff; staff teachers are available and/or volunteers who support teachers, especially related to classroom implementation.) *7. Money for additional activities or additional grants.* (Seeking additional funding to fulfill the mission/ objectives of the center; providing supplemental or complementary support for QuarkNet e.g., providing transportation, lodging, buying equipment; providing food.) *8. Stable participant base.*(A stable participant base can provide an expert group that can help other teachers, support outreach, and provide organizational leadership.) *9. Addresses teacher professionalism.* (The standard is to provide opportunities for at least a few teachers to attend professional meetings; support teachers taking leadership roles in their school, school districts, outreach, and highlight PD opportunities for continuing development.) *10. Establish a learning community.* (The standard is forming a cohesive group where teachers learn from one another; engage with mentors and other scientists; provide outreach to other teachers.)

[a] M.J. Young & Associates (2017, September). *QuarkNet: Matrix of Effective Practices*

[b] This framework is based on the work of Scheirer and Dearing (2011); adopting their definition of sustainability, as well: “Sustainability is the continued use of program components and activities for the continued achievement of desirable program and population outcomes” (p. 2060). The language has been modified slightly to better fit the QuarkNet program.

[c] The language of this characteristic was modified to better fit the QuarkNet program.

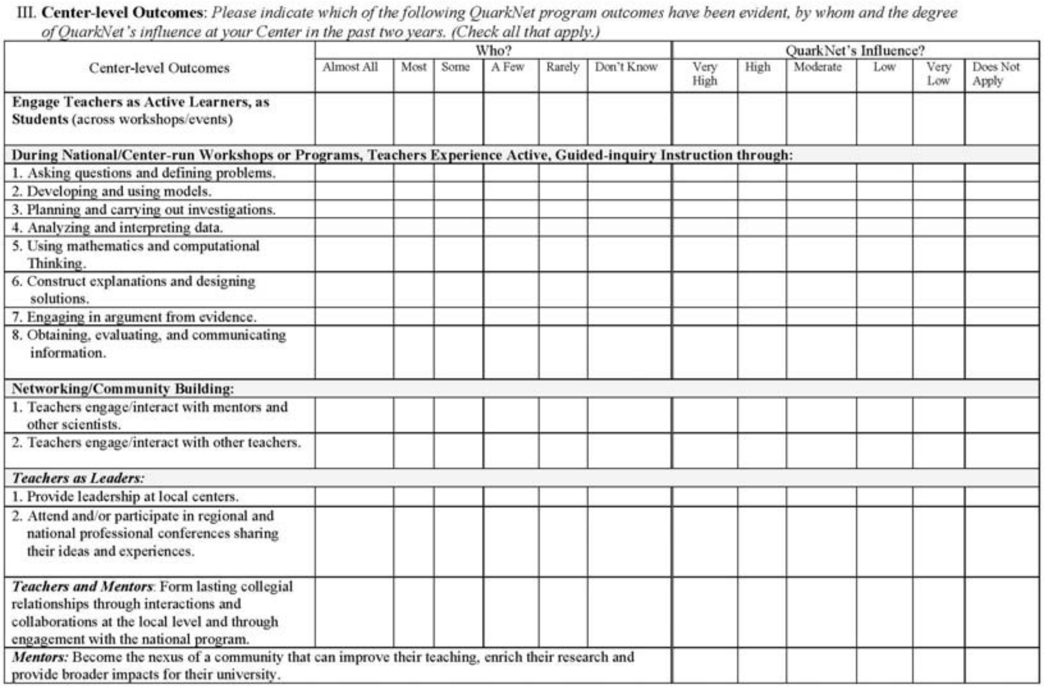


II. **QuarkNet Program Activities**: *Please indicate which of the following QuarkNet programs have been implemented at your Center in the past two years, based on your Center's typical engagement in this program. (Check all that apply).*

Check, if yes ✔	*QuarkNet Program Component*	*2019 Program Year*	*2018 Program Year*
	National Workshop (facilitated by national program staff or fellows) Workshop list at https://quarknet.org/page/summer-workshop-opportunities-quarknet-centers		
	Center-run Workshop (facilitated by center with center-focused topics/interests)		
	Data Camp:		
	1. Center-level teacher(s) participates at Fermilab		
	2. Teacher(s) introduces activity/methods at Center (based on Data Camp experience)		
	Data Activities Portfolio: Activities at https://quarknet.org/data-portfolio		
	1. Work through and reflect on activity/ities (in the portfolio) at the center.		
	2. Present/discuss examples of classroom implementations based on these activities		
	Masterclass(es): Held one or more at center		
	Cosmic Ray Detector *(e.g., assemble, calibrate)*		
	Other *(please specify any other center-led or center-wide event)*		

QuarkNet Websites: https://quarknet.org/; https://quarknet.org/page/summer-workshop-opportunities-quarknet-centers; https://quarknet.org/data-portfolio

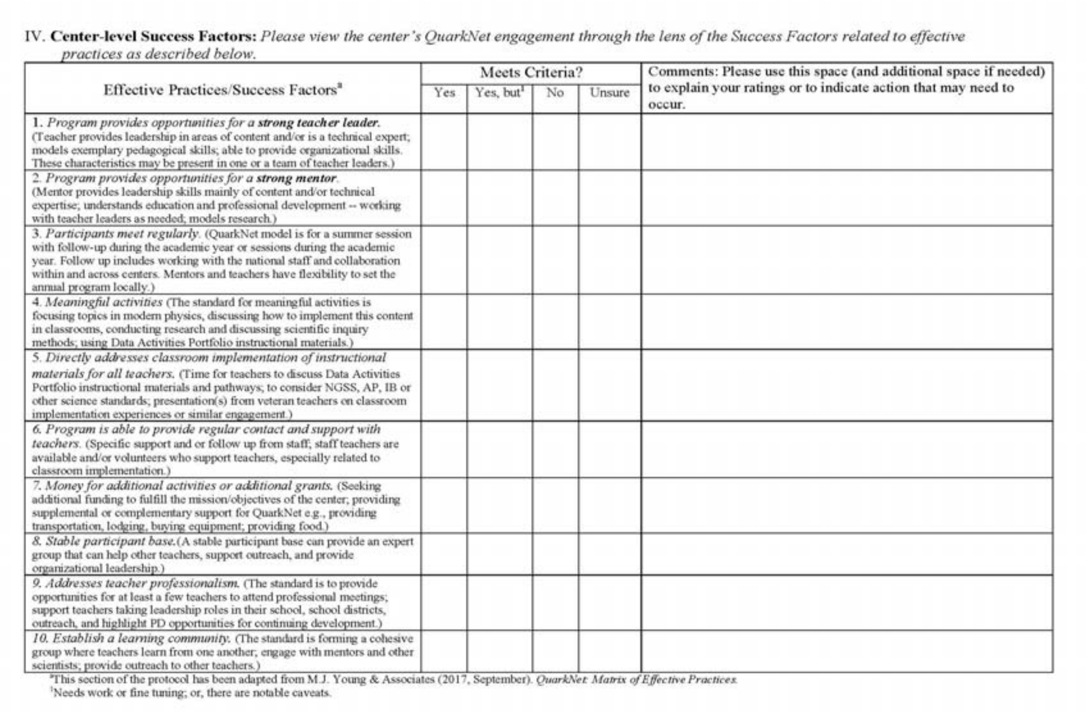
Figure 5. Section II of the Center Feedback Template



III. **Center-level Outcomes**: *Please indicate which of the following QuarkNet program outcomes have been evident, by whom and the degree of QuarkNet's influence at your Center in the past two years. (Check all that apply.)*

Center-level Outcomes	Who?						QuarkNet's Influence?					
	Almost All	Most	Some	A Few	Rarely	Don't Know	Very High	High	Moderate	Low	Very Low	Does Not Apply
Engage Teachers as Active Learners, as Students (across workshops/events)												
During National/Center-run Workshops or Programs, Teachers Experience Active, Guided-inquiry Instruction through:												
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. Construct explanations and designing solutions.												
7. Engaging in argument from evidence.												
8. Obtaining, evaluating, and communicating information.												
Networking/Community Building:												
1. Teachers engage/interact with mentors and other scientists.												
2. Teachers engage/interact with other teachers.												
Teachers as Leaders:												
1. Provide leadership at local centers.												
2. Attend and/or participate in regional and national professional conferences sharing their ideas and experiences.												
Teachers and Mentors: Form lasting collegial relationships through interactions and collaborations at the local level and through engagement with the national program.												
Mentors: Become the nexus of a community that can improve their teaching, enrich their research and provide broader impacts for their university.												

Figure 6. Section III of the Center Feedback Template.



IV. **Center-level Success Factors:** *Please view the center's QuarkNet engagement through the lens of the Success Factors related to effective practices as described below.*

Effective Practices/Success Factors[a]	Meets Criteria?				Comments: Please use this space (and additional space if needed) to explain your ratings or to indicate action that may need to occur.
	Yes	Yes, but[1]	No	Unsure	
1. *Program provides opportunities for a* ***strong teacher leader.*** (Teacher provides leadership in areas of content and/or is a technical expert; models exemplary pedagogical skills; able to provide organizational skills. These characteristics may be present in one or a team of teacher leaders.)					
2. *Program provides opportunities for a* ***strong mentor***. (Mentor provides leadership skills mainly of content and/or technical expertise; understands education and professional development -- working with teacher leaders as needed; models research.)					
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.)					
4. *Meaningful activities* (The standard for meaningful activities is focusing topics in modern physics, discussing how to implement this content in classrooms, conducting research and discussing scientific inquiry methods; using Data Activities Portfolio instructional materials.)					
5. *Directly addresses classroom implementation of instructional materials for all teachers.* (Time for teachers to discuss Data Activities Portfolio instructional materials and pathways; to consider NGSS, AP, IB or other science standards; presentation(s) from veteran teachers on classroom implementation experiences or similar engagement.)					
6. *Program is able to provide regular contact and support with teachers.* (Specific support and or follow up from staff; staff teachers are available and/or volunteers who support teachers, especially related to classroom implementation.)					
7. *Money for additional activities or additional grants.* (Seeking additional funding to fulfill the mission/objectives of the center; providing supplemental or complementary support for QuarkNet e.g., providing transportation, lodging, buying equipment; providing food.)					
8. *Stable participant base.*(A stable participant base can provide an expert group that can help other teachers, support outreach, and provide organizational leadership.)					
9. *Addresses teacher professionalism.* (The standard is to provide opportunities for at least a few teachers to attend professional meetings; support teachers taking leadership roles in their school, school districts, outreach, and highlight PD opportunities for continuing development.)					
10. *Establish a learning community.* (The standard is forming a cohesive group where teachers learn from one another; engage with mentors and other scientists; provide outreach to other teachers.)					

[a] This section of the protocol has been adapted from M.J. Young & Associates (2017, September). *QuarkNet: Matrix of Effective Practices.*

[1] Needs work or fine tuning; or, there are notable caveats.

Figure 7. Section IV of the Center Feedback Template.

QuarkNet Participant: 2019 Teacher Survey

The response rate for the 2019 Teacher Survey was 78% (based on a total of 243 surveys from teachers who participated in the 2019-2020 program year -- 243 out of 311). An additional 78 teachers (who participated in QuarkNet in 2018-2019 *but not* in 2019-2020) were contacted via email and asked to participate in the survey. A total of 22 of these teachers completed the survey for a response rate of 28%. Thus, a total of 265 teachers responded to the survey. We believe the reason behind the high response rate for 2019-2020 participating teachers was the administration of the survey -- face-to-face -- during workshops and programs. The credit, here, is due to QuarkNet facilitators' commitment to the survey and we are thankful for it.

Raw Data

Survey Monkey estimated a 96% completion rate (meaning most participating teachers answered most or all of the questions). Raw data were downloaded from Survey Monkey via an Excel spreadsheet and exported to SPSS for subsequent analyses. Although the survey is accessible by a link, the raw data are only accessible via a specific Survey Monkey account.

Data were reviewed, cleaned, and when necessary new variables were created to facilitate data analysis. These data manipulations are described in the analyses sections of this report, as needed.

Table 15
Teacher Survey: Gender of QuarkNet Teachers

Gender	Number	Percent
Male	161	60.8
Female	103	38.9
Not specified	1	0.3
Total	265	100.0

Demographics

A total of 265 teachers participated in the Teacher Survey in 2019 as already mentioned. Before teacher-level (and their students) outcomes are explored, a brief look is provided as to who are these teachers. To begin, as can be seen in Table 15, a total of 161 (60.8%) are male and 103 (38.9%) are female.

Teaching experience, number of years at the current school and participation in QuarkNet are well correlated. The correlation between years teaching and years at current school was high (r = .66); as well as years teaching and QuarkNet experience (r = .50); and, years at current school and QuarkNet experience (r = .53). The number of years that teachers participated in QuarkNet ranged from 0 (his/her first time) up to 20 years.

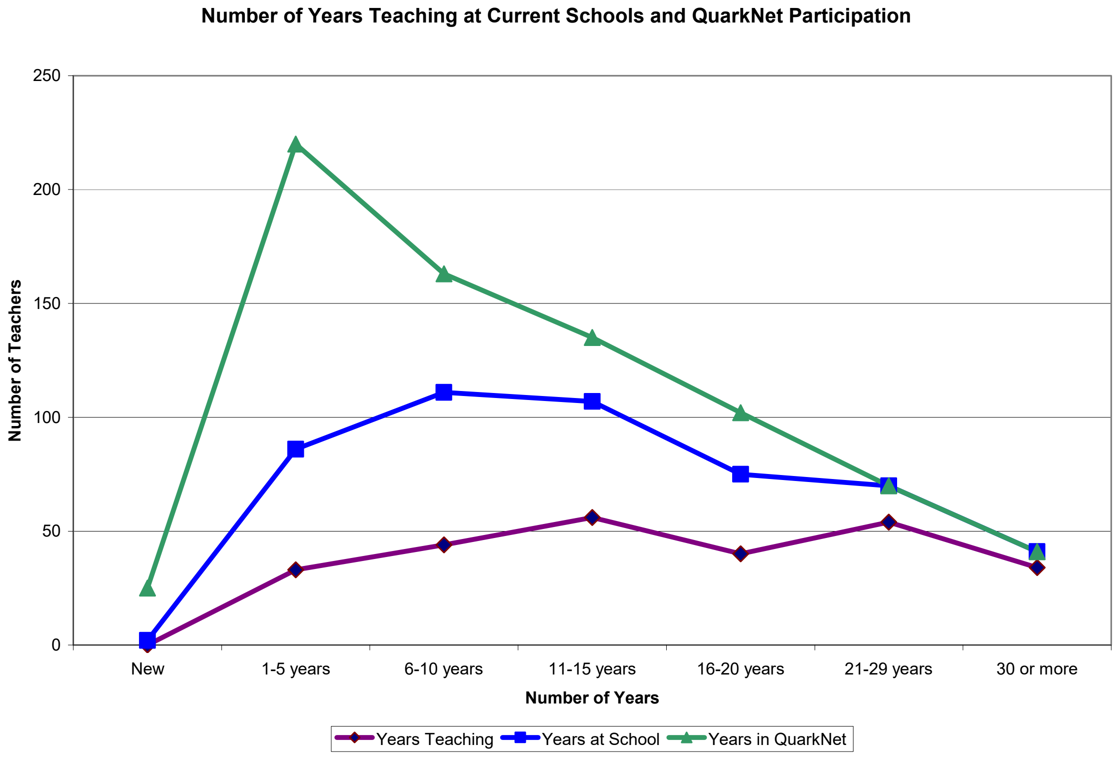


Figure Set 8. Comparison of the number of years: Teaching; at current School; and, participating in QuarkNet.

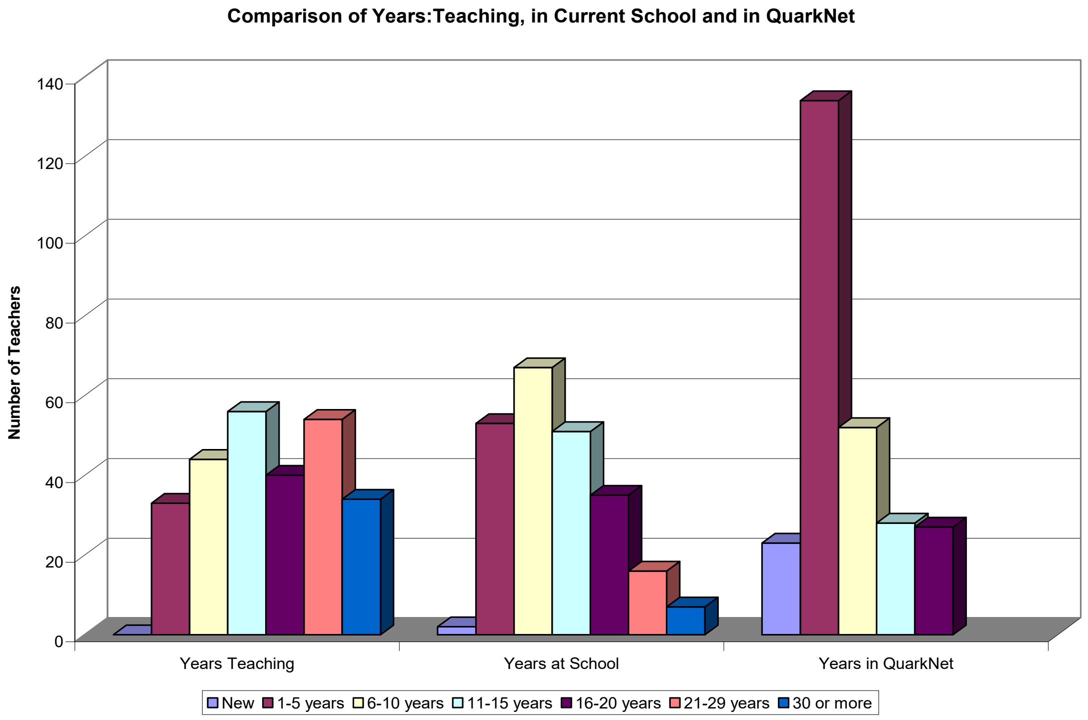


Figure Set 8 (con't). Comparison of the number of years: Teaching; at current School; and participating in QuarkNet.

Shown in Figure Set 8 (starting on previous page), many participants were new to QuarkNet or had participated in the program for just a few years; however, the number of long-term participants is noteworthy as well that is, -- the mean number of years was 6.26 years, with a median of 4 years (50th percentile). Collectively, these teachers had a mean number of years teaching of 17 years (median 15 years); a mean of 10.5 years at his/her school (8.5 median years); with a few teachers who are retired.

There were noted statistically significant differences in this profile, however, when responses from male and female teacher were compared. Regarding number of years participating in QuarkNet, the mean number of years was 6.97 (SD = 5.87) for male teachers versus 5.12 (SD = 4.84) for female teachers [$t_{(245.49)} = 2.67$, $p < .01$ equal variance not assumed]. The same held true for the reported number of years teaching; the mean number of years was 18.49 (SD = 10.72) for male teachers versus 15.27 (SD = 9.15) for female teachers [$t_{(258.)} = 2.49$, $p < .02$]. And, this difference was statistically significant for number of years at current school, a mean number of years was 11.40 (SD=8.12) for male teachers versus 9.03 (SD = 7.39) for female teachers [$t_{(253.)} = 2.35$, $p < .02$].

As shown in Table 16, most often participating teachers represented schools in suburban areas (128 or 48%); followed by rural and urban locations (each at 51 or 19%). The type of "best descriptor" for location of school was not related to whether the teacher is male or female.

Table 16
Description of School Location and Teaching Physics

	Number	Percent
Best Describe Location of School		
Rural	51	19
Suburban	128	48
Urban	51	19
Urban, Central City	30	11
Not Specified	5	2
Total	265	100
Teaching Physics?		
Yes	228	86
No*	34	13
Not Specified	3	1
Total	265	100

*Responses were explained as for example: Taught in the past; will teach soon by not this year; general science; physic tutor.

Most participating teachers indicated that he or she is teaching physics (228 or 86%). There was a statistical association by gender, however, as to whether or not a teacher taught (is teaching) physics. That is, slightly more female teachers reported that they were *not* teaching physics; and, slightly more male teachers reported that they were teaching physics [$\chi^2_{(1, 261)} = 6.13$, p <.02].

Table 17
Which Workshop or Program?

Workshop/Program	Num. Teachers	Workshop/Program	Num. Teachers
Data Camp	111	Cosmic Ray e-Lab Ad.	25
ATLAS	23	Neutrino Data Workshop	69
CMS Data Workshop	68	ATLAS Masterclass	38
CMS e-Lab Workshop	58	CMS Masterclass	77
Cosmic Ray e-Lab Intro	124	Neutrino Masterclass	31

Note. Multiple responses were allowed.

QuarkNet Participation

Teachers were asked to select the QuarkNet workshops or programs where they were participants. These responses are summarized in Table 17. (Multiple responses were allowed.) Teachers also mentioned the CERN Summer Program (36); World Wide Data Day (13); International Cosmic Day (23); and International Muon Week (26).

Overview of Analyses Related to Teacher (and their Students) Outcomes

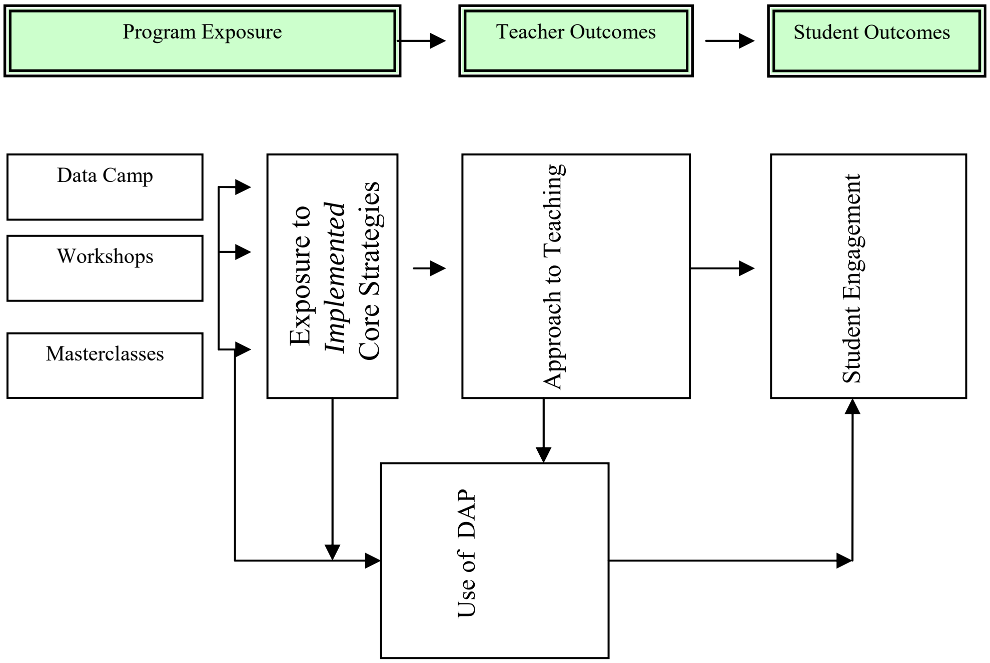


Figure 9. Overview of analyses related to Teacher (and their Students) Outcomes.

To begin analyses related to outcomes, we explored the relationship between engagement in QuarkNet and exposure to core program strategies; and, subsequently the potential impact this involvement has on teacher outcomes and student engagement outcomes. 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 a model toward understanding teachers' approach to teaching and use of activities in the Data Activities Portfolio. Because of this complexity, Figure 9 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

Please keep in mind 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; and, exposure to core strategies and expected outcomes as described below. We reserve judgment as to the best model to use at this time because these analyses are preliminary -- in part because we need to gather information on center-level engagement in QuarkNet to provide a context to better understand how this engagement and subsequent outcomes are related; and to analyze center-level engagement in its own right.

Program Fidelity:
Perspective of Teachers on Exposure to Program Core Strategies

Given the logically links between articulated core program strategies and expected program outcomes as suggested by the PTM, teachers were asked about their exposure to such strategies during their QuarkNet program engagement. This is seen as a measure of the fidelity of the *implemented* program as compared to the program as *designed*. To this end, in the Teacher Survey, teachers were asked to reflect on their exposure to core program strategies; the instructions were:

> *Please rate the following strategies based on your current QuarkNet program experience and, if applicable, on your previous involvement in QuarkNet programs to date. If you have participated in QuarkNet for many years, please respond based on what you think the cumulative effect of this participation has been over the past two years.*

Table 18
Items Used to Form a **Core Strategies** Scale based on Teacher Responses

Exposure to QuarkNet Strategies
QuarkNet provides opportunities for me to:
21a. Engage as an active learner as a student.
b. Do science the way scientists do science.
c. Engage in authentic particle physics investigations.
d. Engage in authentic data analysis experiments using large data sets.
e. Develop explanations of particle physics content.
f. Discuss the concept of uncertainty in particle physics.
QuarkNet provides opportunities for me to:
22a. Engage in project-based learning that models guided-inquiry strategies.
b. Share ideas related to content and pedagogy.
c. Review and select particle physics examples from the Data Activities Portfolio instructional materials.
d. Use the pathways, suggested by the Data Activities Portfolio, to help design classroom instructional plan(s).
e. Construct classroom implementation plan(s) incorporating experience(s) and Data Activities Portfolio instructional materials.
f. Become aware of resources beyond my classroom.

The items in Table 18 (Q21 and 22 from the survey) align with the core program strategies presented in Table 8 and from the PTM. As previously described, these items were rated on a 5-point, Likert-like scale from (1= Poor, 2 = Fair, 3= Average, 4 = Good, and 5= Excellent). For analysis purposes, items were summed to create a **Core Strategies** scale, with *the higher the scale score, the more positive the response.* Descriptive statistics based on actual scores from this 12-item scale, based on an N=255, ranged from 12 to 60, with a Mean = 54.18 (SD = 7.26); and an alpha = 0.87 (reliability coefficient).

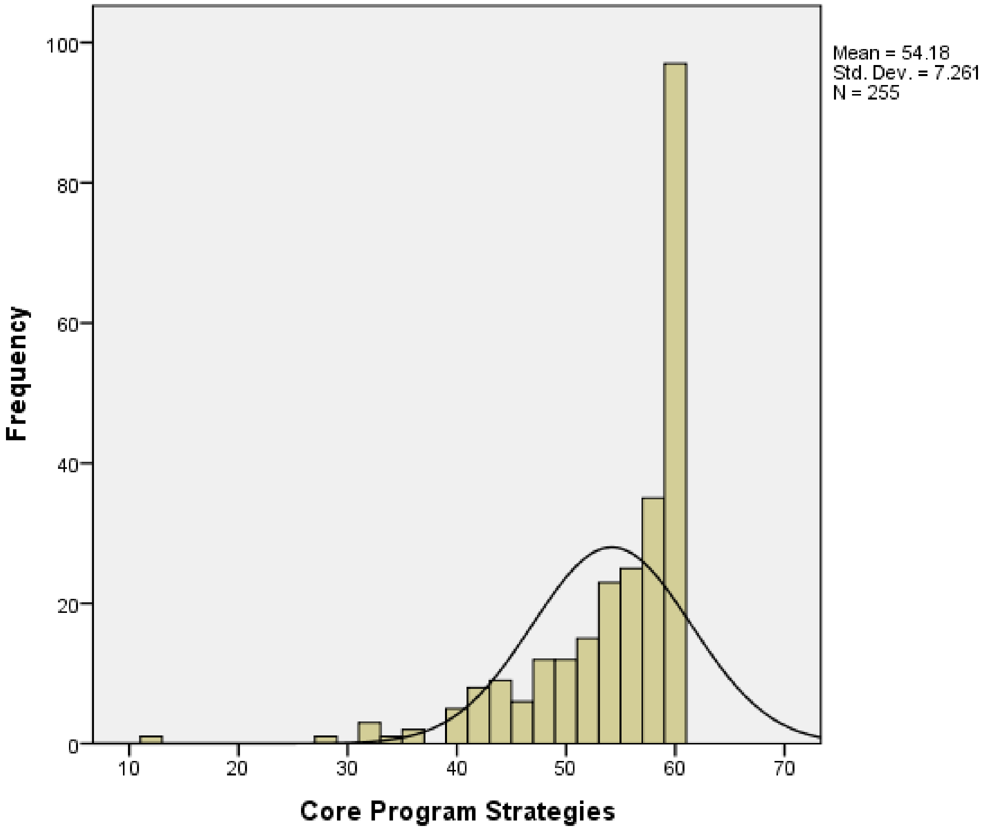


Figure 10. Distribution of Core Program Strategies scale scores.

These statistics suggest that this scale can be used as a measure of program fidelity, with a skewed distribution as shown in Figure10. These data suggest that participating teachers were exposed to a high level of core program strategies (based on their perceived experiences).

Exposure to QuarkNet Core Program Strategies Related to Type of Engagement

As measured by these scores, we ask three questions, *Does perceived exposure to QuarkNet core program strategies differ for participating teachers, who:*

1. Did or did not participate in Data Camp?
2. Engaged in a variety of workshops (e.g., CMS Workshop, ATLAS Workshop, Neutrino Workshop)?
3. Did or did not participate in a Masterclass?

And, a fourth question,

4. Is perceived exposure to QuarkNet core program strategies related to reported use of activities from the Data Activity Portfolio in the classroom?

Table 19
Perceived Exposure to QuarkNet **Core Program Strategies** Compared to
Type and Variety of Program Engagement and Use of Data Activities Portfolio

Comparison	N	Mean	SD^a	Analysis Results
Data Camp				
Yes	109	55.55	5.02	$t_{(241.98)}{}^{b} = 2.82, p < .01$
No	146	53.16	8.44	
Variety of Workshops^c				
No workshops	76	51.58	9.30	$F_{(2, 252)} = 8.13, p < .001$
One workshop^c	80	54.56	6.32	
Two or more^c	99	55.88	5.48	
Masterclasses				
None	144	53.02	8.02	$t_{(252.18)}{}^{b} = 3.08, p < .01$
One or More	111	55.69	5.83	
Used DAP Activities				
Yes	130	56.65	4.66	$\chi^2_{(1, 250)} = 36.13, p < .001$ $^{\mathbf{d}}$
No	120	51.46	8.61	

[a] Standard deviation

[b] Equal variance not assumed; independent t-test.

[c] This variable refers to the variety of workshops not the total number of events.

[d] Based on a binary, logistic regression analysis.

These data are summarized in Table 19. As can be seen, participating teachers reported higher scores on the **Core Strategies** scale based on degree of program engagement. This is evident for teachers who participated in Data Camp (as compared to teachers who did not); for teachers who engaged in a variety of workshops (the more varied the higher the score, on average); and, for those teachers who participated in one or more Masterclasses (compared to teachers who did not). It is important to note that these analyses are conducted, not to pit a type of QuarkNet engagement against each other but rather, to explore whether a Core Strategies measure supports a common sense idea that more engagement in the QuarkNet program (*as implemented*) is related to higher exposure to program strategies (as perceived by teachers); strategies deemed core to the program as identified by the PTM. Further, these analyses are not intended to imply causality but do suggest that program engagement and measurement of Core Strategies are related in a meaningful way and speaks to the fidelity of the implemented program as compared to the program as designed as perceived by participating teachers.

Finally and important as well, those teachers who used activities from the Data Activities Portfolio (DAP) tended to report higher Core Strategies scores than those teachers who have not used these instructional materials in their classrooms (although the R^2 value was modest, estimated at 0.18).

Program Outcomes: Approach to Teaching and QuarkNet's Perceived Influence

Several scales were created from questions in the Teacher Survey related to teacher (and their students) outcomes and the perceived influence of QuarkNet on these behaviors. The first of these scales was **Approach to Teaching**, directed toward teacher-outcomes articulated in the PTM. To this end, in the Teacher Survey, teachers were asked to reflect on classroom instruction, as follows:

> *In thinking about your approach to teaching, please rate the frequency in which you engage in each of the following in your classroom.*

Table 20
Items Used to Form an **Approach to Teaching**
Scale based on Teacher Responses

Approach to Teaching Outcomes

27a. Discuss and explain concepts in particle physics.
  b. Engage in scientific practices and discourse.
  c. Use physics examples including authentic data when teaching subjects such as momentum and energy.
  d. Review and use instructional materials from the Data Activities Portfolio.
  e. Selecting these lessons guided by the suggested pathways.
  f. Facilitate student investigations that incorporate scientific practices.
29a. Use active guided-inquiry instructional practices that align with science practices standards (NGSS and other standards).
  b. Use instructional practices that model scientific research.
  c. Illustrate how scientists make discoveries.
  d. Demonstrate how to use, analyze and interpret authentic data.
  e. Demonstrate how to draw conclusions based on these data.
  f. Become more comfortable teaching inquiry-based science.

The items in Table 20 (Q27 and 29 from the survey) were rated on a 5-point, Likert-like event scale from (5= Almost Always, 4 = Very Often, 3= Sometimes, 2= Not Very Often, and 1= Rarely. (A "Not Applicable" option was scored as zero.) Similarly, for analysis purposes, items were summed to create an **Approach to Teaching** scale, with *the higher the scale score, the more positive the response.* Descriptive statistics based on actual scores from this 12-item scale, based on an N=250, ranged from 14 to 60, with a Mean of 43.11 (SD = 8.61); and an alpha of 0.88 (reliability coefficient). Figure 11 shows the distribution of these scores, suggesting an approximate normal distribution. We conclude that this scale can be used as a measure in subsequent analyses (either as an outcome or a predictor).

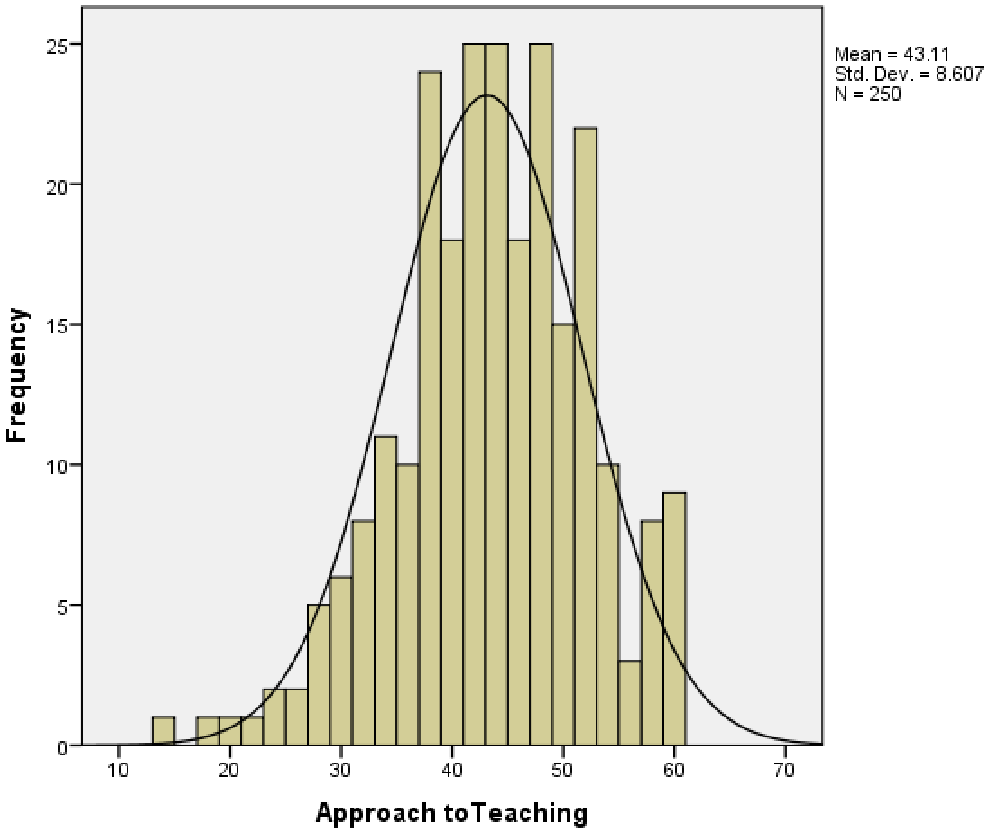


Figure 11. Distribution of Approach to Teaching scale scores.

As measured by these scores, we ask three questions, *Do Approach to Teaching scores differ for participating teachers, who:*

1. Did or did not participate in Data Camp?
2. Engaged in a variety of workshops (e.g., CMS Workshop, ATLAS Workshop, Neutrino Workshop)?
3. Did or did not participate in a Masterclass?

And, a fourth question,

4. Are Approach to Teaching scores related to reported use of activities from the Data Activity Portfolio in the classroom?

These data are summarized in Table 21. As can be seen, participating teachers reported higher scores on the **Approach to Teaching** scale based on type of program engagement. This is evident for teachers who participated in Data Camp (as compared to teachers who did not); for teachers who engaged in a variety of workshops (the more varied the higher the score, on average); and, for those teachers who participated in one or more Masterclasses (compared to teachers who did not). Approach to Teaching scores were

Table 21
Approach to Teaching Outcome Related to
Type and Variety of Program Engagement and Use of Data Activities Portfolio

Comparison	N	Mean	SD[a]	Analysis Results
Data Camp				
Yes	108	44.86	7.95	$t_{(248)} = 2.85, p < .01$
No	142	41.77	8.87	
Variety of Workshops[b]				
No workshops	74	40.93	8.42	$F_{(2,\ 247)} = 7.94, p < .001$
One workshop[b]	79	41.95	9.14	
Two or more[b]	97	45.71	7.67	
Masterclasses				
None	140	41.67	8.47	$t_{(248)} = 3.03, p < .01$
One or More	110	44.94	8.48	
Used DAP Activities				
Yes	128	46.29	7.54	$\chi^2_{(2, 244)} = 41.52, p <.001$ [c]
No	117	39.50	8.36	

[a] Standard deviation

[b] This variable refers to the variety of workshops not the total number of events.

[c] Based on binary, logistic regression (including Core Strategies and Approach to Teaching scale scores as independent variables).

also related to use of activities in the Data Activities Portfolio. Although single-variable analyses are helpful; for example, in suggesting that these measures are "behaving" in expected and meaningful ways, more variables need to be added into the mix. And with this, more complicated analyses are warranted and may be more illustrative of these relationships.

QuarkNet's Influence on Approach to Teaching

In the Teacher Survey, teachers were asked:

> *Now, indicate the degree to which you think QuarkNet has contributed to your implementation of these instructional strategies in your classroom.*

The items in Table 20 (now Q28 and 30) were repeated but this time these items were rated on a 5-point, Likert-like scale from (5= Very High, 4 = High, 3= Moderate, 2 = Low, 1= Very Low) measuring the perceived QuarkNet influence on these behaviors. (A "Not Applicable" option was scored as zero.) As done for previous scales, items were summed to create a **QuarkNet's Influence on Approach to Teaching** score, with *the higher the score, the more positive the response.* Descriptive statistics based on actual scores from this 12-item scale, based on an N= 227, ranged from 12 to 60, with a Mean of 48.15 (SD = 9.46); and an alpha of 0.92 (reliability coefficient). (See Figure 12.)

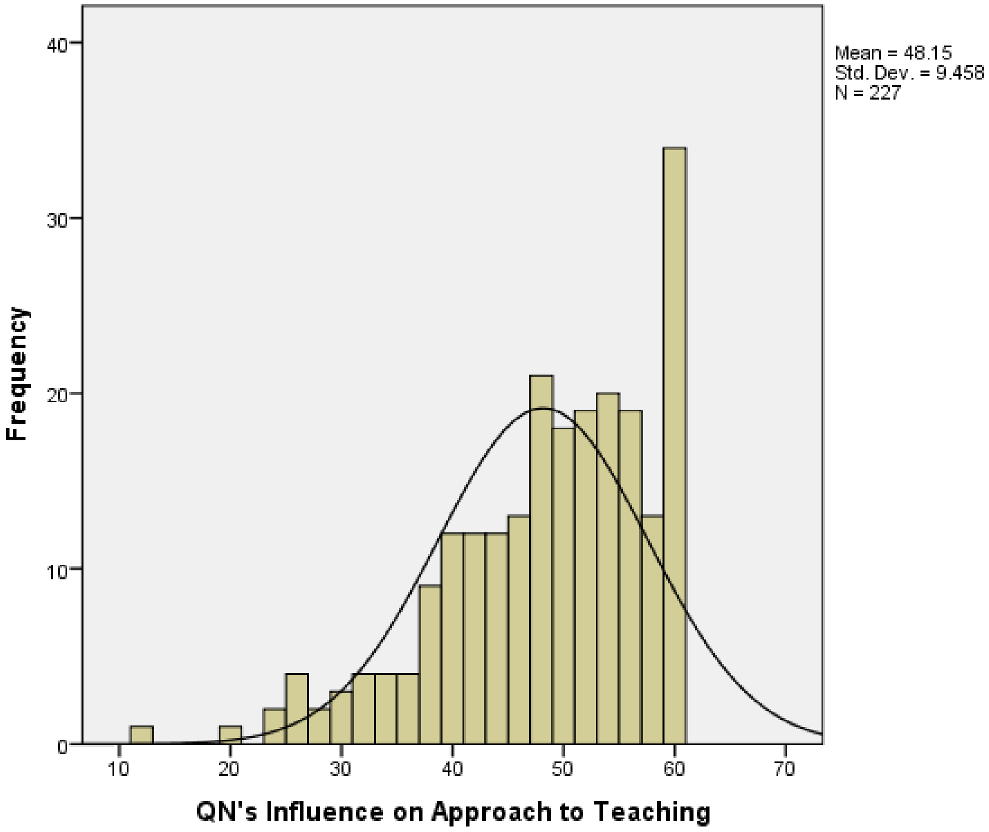


Figure 12. Distribution of QN's Influence on Approach to Teaching scale scores.

*How is QuarkNet Engagement Related to **Approach to Teaching**?*

In a combined analysis -- Engagement in: Data Camp, Variety of Workshops, Master-classes; and, perceived exposure to Core Strategies, perceived QuarkNet's Influence on Teaching, and Use of Activities in the Data Activities Portfolio – were investigated simultaneously in a stepwise, multiple regression analysis with Approach to Teaching as the dependent variable. This analysis suggests that perceived QuarkNet's Influence (entered first); and, Use of DAP activities (added second) are related to **Approach to Teaching** as measured [$F_{(2,\ 218)} = 80.66$, $p < .001$, with an $R^2 = .42$]. The summary statistics from this analysis are shown in Table 22. Additional variables did not improve the model (that is, were not statistically significant).

*So, What's Related to **Used DAP** Activities in the Classroom?*

To understand what's related to **Used DAP** activities in the classroom, a binary logistic regression analysis was conducted with Used DAP as the dependent variable and the following variables seen as "predictors," these are: perceived exposure to Core Strategies,

Table 22
Approach to Teaching: Summary Statistics and Related Variables

Model Summary[a]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
Final	.652[b]	.425	.420	6.33

Coefficients[b]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
QN’s Influence on Teaching	.508	.047	.576	10.749	<.0001
Used DAP	3.061	.901	.182	3.399	<.001

[a] Predictors: (Constant), QuarkNet Influence on Teaching, Used DAP
[b] Dependent Variable: Approach to Teaching

Approach to Teaching, QuarkNet’s Influence on Teaching, and engagement in Data Camp, Variety of Workshops, and Masterclasses. Based on this analysis, all variables were statistically related to **Used DAP** except QuarkNet’s Influence. Core Strategies was added first, Approach to Teaching (added second), followed by all of the types of QuarkNet program engagement [$\chi^2_{(5, 221)} = 6.73$, $p <.001$, estimated $R^2 = .38$].

To summarize, **Approach to Teaching** was shown to be related to *perceived* QuarkNet’s Influence on Teaching, and the use of activities from the Data Activities Portfolio in the classroom as reported by teachers. **Use of DAP** activity was shown to be related to exposure to Core Strategies, Approach to Teaching, and all of the types of QuarkNet program events (Data Camp, Variety of Workshops, and Masterclass engagement). At this stage of preliminary analyses, we have not pursued an exploration of which among these models are the best or the most parsimonious. The weight of these analyses, however, suggests that there is a relationship between engagement in QuarkNet and exposure to core program strategies; and, that the type and degree of program engagement is related to teacher outcomes (Approach to Teaching) and, of importance, the use of activities from the Data Activities Portfolio in the classroom.

Student Engagement

In the Teacher Survey, teachers were asked to assess perceptions of their Student Engagement in their classrooms, and their judgment as to QuarkNet’s Influence on this engagement. Accordingly, teachers were instructed:

> *This last set of questions asks about your students' classroom engagement and how QuarkNet may have influenced (through your participation and/or your students) this engagement. In your judgment, please indicate ...*

Table 23
Items Used to Form a **Student Engagement**
Scale based on Teachers' Perceptions

Student Engagement (*My students are able to …*)
32a. Discuss and explain concepts in particle physics.
  b. Discuss and explain how scientists develop knowledge.
  c. Engage in scientific practices and discourse.
  d. Use, analyze and interpret authentic data.
  e. Draw conclusions based on these data.

The items in Table 23 (Q32 from the survey) were rated on a 5-point, Likert-like scale from (5= Almost Always, 4 = Very Often, 3= Sometimes, 2= Not Very Often, and 1= Rarely. (A "Not Applicable" option was scored as zero.) Again, for analysis purposes, items were summed to create a **Student Engagement** scale, with *the higher the scale score, the more positive the response.* Descriptive statistics based on actual scores from this 5-item scale, based on an N=240, ranged from 4 to 25, with a Mean of 18.87 (SD = 3.45); and an alpha of 0.84 (reliability coefficient). Figure 13 shows the distribution of these scores, suggesting a measure with natural variability that is approaching a normal distribution.

The items in Table 23 (now Q33) were repeated but this time these items were rated on a 5-point, Likert-like scale from (5= Very High, 4 = High, 3= Moderate, 2 = Low, 1= Very Low) measuring the perceived QuarkNet influence on these behaviors. (A "Not Applicable" option was scored as zero.) As done for previous scales, items were summed to create a **QuarkNet's Influence on Student Engagement** score, with *the higher the score, the more positive the response.* Descriptive statistics based on actual scores from this 5-item scale, based on an N= 213, ranged from 5 to 25, with a Mean of 20.04 (SD = 3.85); and an alpha of 0.91 (reliability coefficient). (See Figure 14.)

How is QuarkNet related to perceived Student Engagement?

When all variables are placed in a stepwise, multiple regression analysis: Core Strategies, Approach to Teaching, QuarkNet's Influence on Student Engagement, Data Camp, Variety of Workshops, Masterclasses, and Use of DAP activities (predictors) to explore the relationship to **Student Engagement** (dependent measure), two variables emerge as statistically related. That is, QuarkNet's Influence on Student Engagement (entered first) as perceived by teachers, and Approach to Teaching were statistically related to **Student Engagement,** [$F_{(2, 204)} = 86.56$, $p < .001$, with an $R^2 = .46$]. Additional variables did not improve this model. (See Table 24 for the summary statistics of this analysis.)

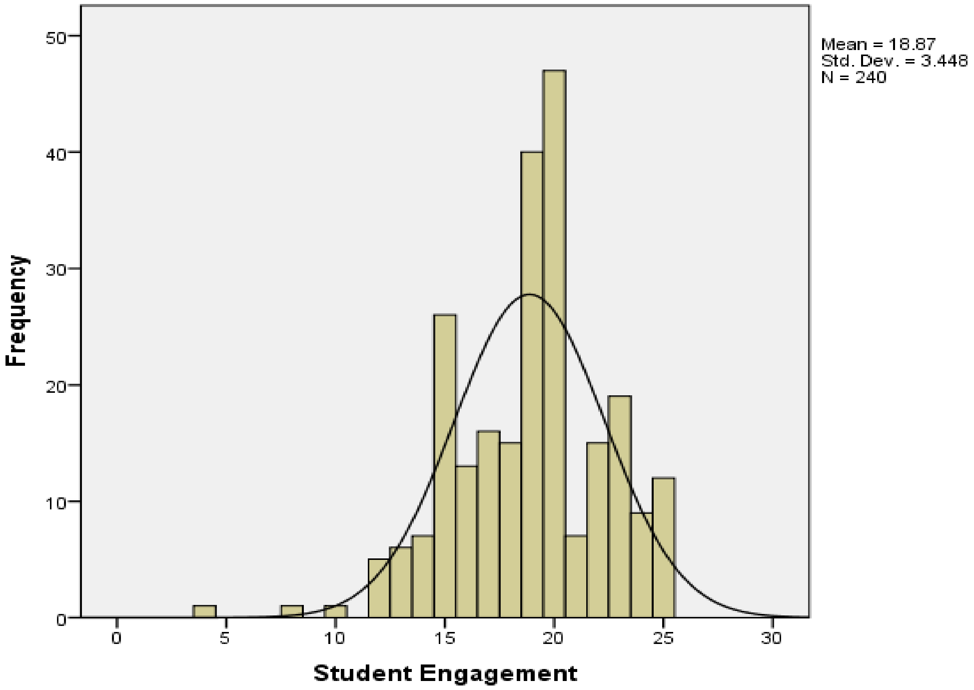


Figure 13. Distribution of Student Engagement scale scores.

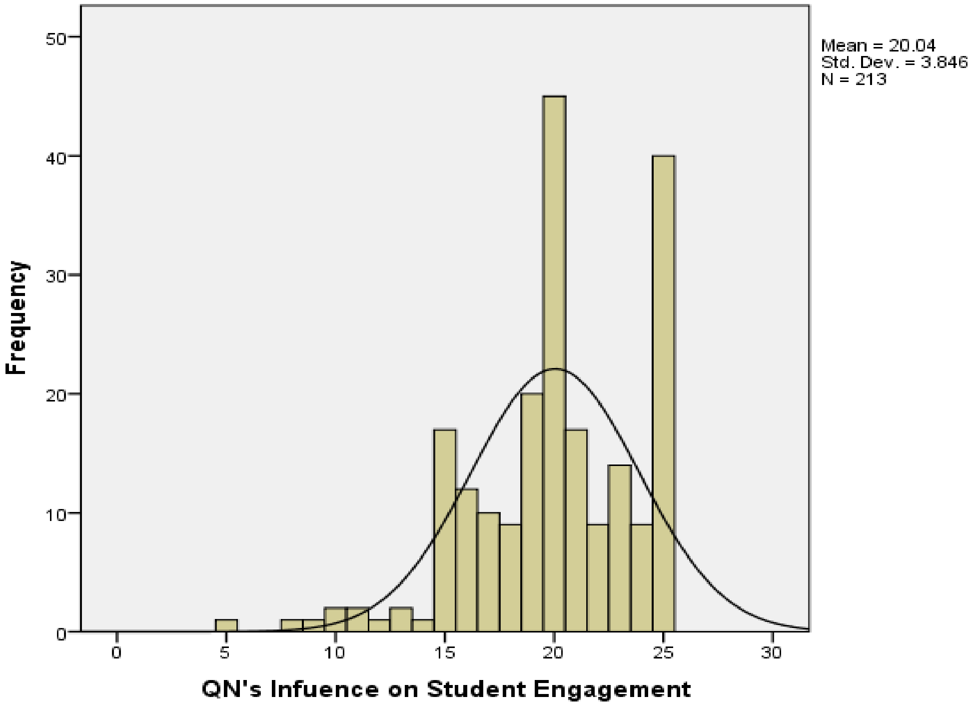


Figure 14. Distribution of QuarkNet's Influence on Student Engagement

Table 24
Student Engagement: Summary Statistics and Related Variables

Model Summary[a]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
Final	.678	.459	.454	2.441

[a]Predictors: (Constant), QuarkNet's Influence on Student Engagement, Approach to Teaching,

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	4.899	1.108		4.42	<.001
QNet's Influence on Student Engagement	.375	.049	.437	7.72	<.001
Approach to Teaching	.154	.024	.368	6.52	<.001

[a]Dependent Variable: Student Engagement

It is important to note that there were no statistically significant differences based on teacher's gender for type of QuarkNet engagement (Data Camp, Variety of Workshop or Masterclass participation); and there were no differences by gender based on Core Strategies, Approach to Teaching, QuarkNet's Influence on Teaching, Student Engagement, and QuarkNet's Influence on Student Engagement.

To emphasize, these analyses are preliminary and do not infer causality. Of importance, the involvement of Center-level engagement in QuarkNet – as measured through the Center Feedback Template will be added to the mix of these analyses in an attempt to offer a more complete picture of these relationships.

Implementing the Center Feedback Template an Early Look: How it will Inform These and Other Analyses

We began obtaining feedback from participating QuarkNet centers with a pilot test of the process starting in November 2019 for four centers. Six additional centers were rolled out in Spring 2020. All ten centers have completed this process (see Table 25).

As already noted, these centers were selected based on conversations with staff teachers and the evaluator. For each of these centers, Section II was completed by the evaluator (and reviewed by the Staff Teachers) before it was distributed. One lesson gleaned from this process is that Section II offers a succinct summary of programs and events at a

Table 25
QuarkNet Centers with Completed Feedback Templates

Center	Completion Date	Center	Completion Date
Pilot Test		Added in Spring 2020	
Catholic University	November 2019	University of Cincinnati	April 6, 2020
Fermilab/University of Chicago	February 2020	Boston Area/Brown University	May 19, 2020
Rice University/ University of Houston	March 2020	University of Kansas	May 21, 2020
Colorado State University	July 2020	Virginia Center	May 21, 2020
		Kansas State University	June 24, 2020
		University of Minnesota	June 29, 2020

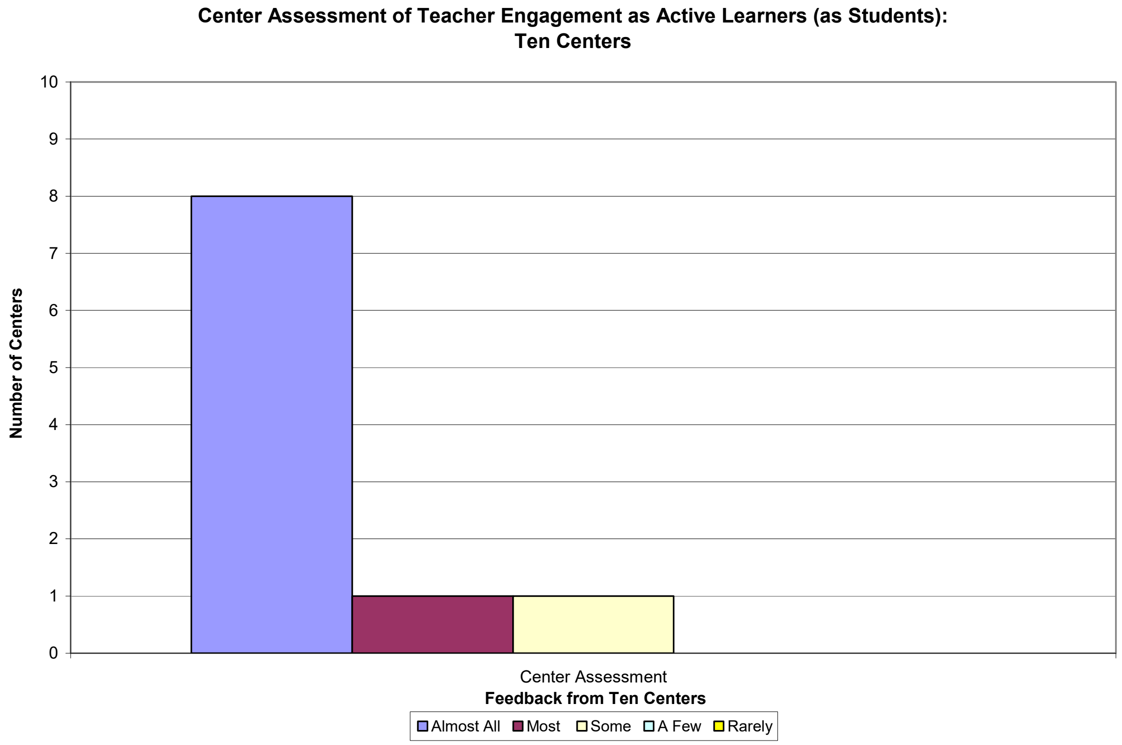
particular center (an easy reference of two years of agenda and annual reports). Early feedback from centers suggests that this is a helpful process for them and staff teachers have noted that it is of value as well.

Very Early Results: Center-Level Outcomes

As the number of centers who participate and complete their Center Feedback Template increases, we will conduct more complicated analyses. At this very early stage, we provide a few descriptive analyses to give a sense as to how center-level outcomes and teacher-level outcomes will be compared in the future.

To begin, Figure Set 15 presents responses to the question about the opportunity for QuarkNet teachers to be engaged as active learners (as students). The first graph, in this set, shows the responses from the ten centers who participated in the Center Feedback Template so far. As indicated, eight out of the ten centers indicated that *"Almost All"* of their teachers were engaged as active learners (as students) during the workshops held at their center. The second graph reflects responses by individual teachers who were asked the degree to which QuarkNet provided them with an opportunity to engage as an active learner (as a student). As shown, most teachers rated the opportunity to engage as active learners, as students as *"Excellent"* for participating teachers from these centers; for teachers from other centers; and for all teachers who responded to the Teacher Survey.

In Figure Set 16, we look at the degree to which QuarkNet activities and engagement in workshops expose participating teachers to NGSS practices at the program level. This is assessed by activities from the Data Activities Portfolio *as designed* (based on the upper two graphs) and then for *implemented* workshops (based on the two lower graphs). Specifically, the first graph in the upper-left hand corner shows the alignment of these practices across all DAP activities (a graph that was presented earlier in this report). The graph in the upper-right hand corner breaks down this same alignment based on the student skill-set levels of these activities.



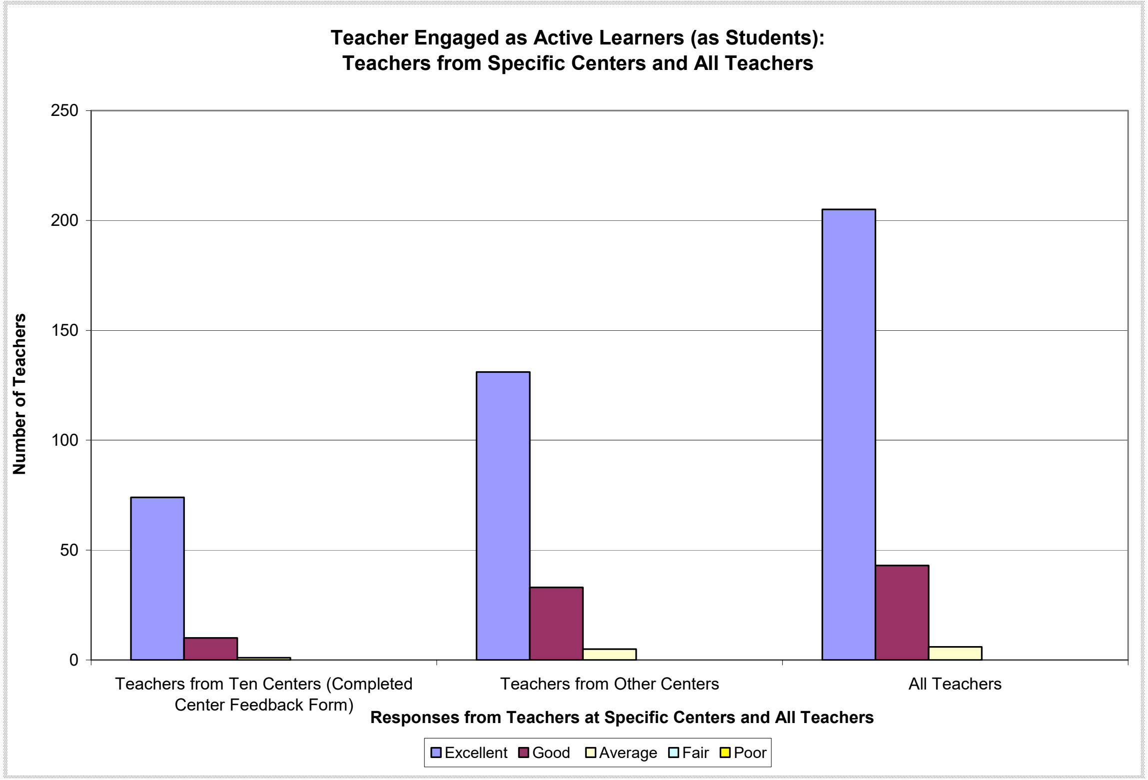


Figure Set 15. Centers' Assessment of Teachers Engagement as Active Learners compared to teacher perspectives of this opportunity.

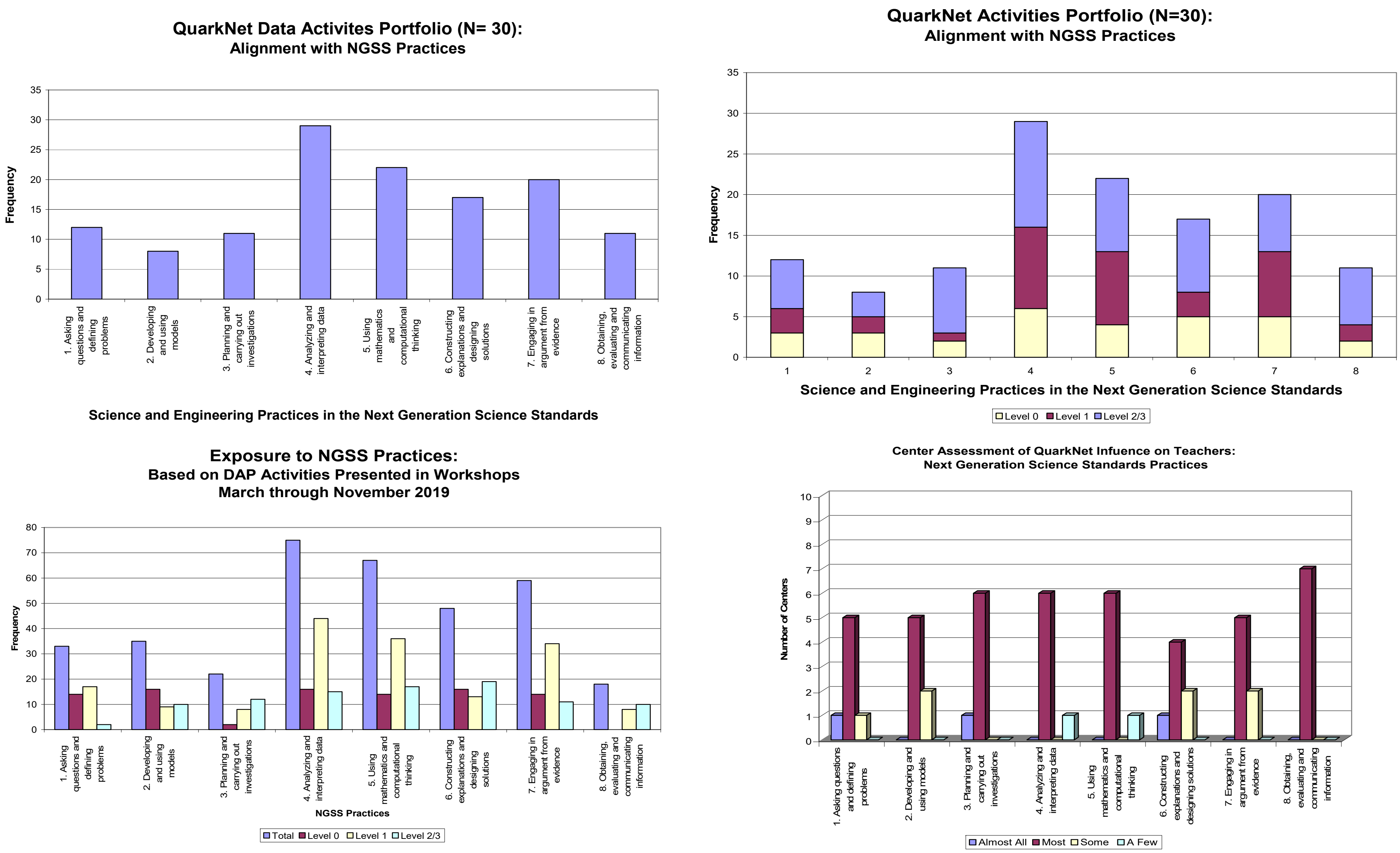


Figure Set 16. Alignment of NGSS Practices and the activities from the Data Activities Portfolio by activity, by activity level, based on activities presented in 2019 QuarkNet workshops, and center assessment of teacher engagement in these practices during QuarkNet workshops.

The graph in the bottom left-hand shows the alignment of these practices across all of the DAP activities that were presented during workshops in the 2019 program year (from March to November 2019, based on workshop agendas). Together these three graphs suggest that at the overall program level, *as designed and as implemented*, participating QuarkNet teachers are engaged in scientific endeavors that align with these practices, especially analyzing and interpreting data (practice 4); use mathematics and computational thinking (practice 5); engaging in argument from evidence (practice 7); and obtaining, evaluating and communicating information (practice 8). *But what does the experience of the individual teacher look like?* Although an early picture, the fourth graph (lower right-hand corner) suggests that the individual-teacher engagement at the center level aligns well with these NGSS practices, with "*Most*" or *Almost All*" teachers engaged in scientific endeavors that align with each of these practices. (For this graph, this engagement in scientific endeavors is based on two years of workshops for these centers, engagement in DAP activities as well as other endeavors that are part of QuarkNet workshops and programs.)

The Impact of COVID-19

The full impact that coronavirus (COVID-19) has had on the United States may not be known for many years. As each of us cope with learning and applying safe practices during this pandemic, the QuarkNet program has responded in many ways starting in March 2020. An overview of these efforts was submitted to NSF on May 1, 2020 and is shared in Appendix I. Also as a reminder, QuarkNet staff hold weekly meetings on the program overall; tech needs; and instructional material needs and development where many of these modifications were discussed. We highlight these modifications as follows.

Teacher Support

The QuarkNet online teacher support includes:

- Resources for teaching physics online (including remote online simulations and online lessons)
- Resources for online Cosmic Ray analyses (using data from cosmic ray detectors remotely)
- Comments on adapting data activities to teaching these online.
- *Friday Flyer* (weekly) shifted content to reminding teachers of available support and new online options.
- QuarkNet Wednesday Webinars on particle physics-related topics (May 6 through June 10, 2020)

In addition, six Notre Dame Zoom channels were opened up for videoconferencing. IT Infrastructure Support was already working remotely and the University of Notre Dame has provided support in setting up webinars and explaining Zoom capabilities as needed.

Programs

Program modifications were made to help adapt these to online teaching venues:

Cosmic Ray Studies

- CMS e-lab (using CERN's LHC data from physics research projects remotely)
- A few detectors continue to upload data; and a staff member moved one of the Fermilab detectors to his home to provide an updated standard data set for e-Lab.

Masterclasses

- The current CMS masterclass was modified for remote learning – The Big Analysis of Muons in CMS (BAMC).
- One BAMC was held in April and another in May.

Staff also built a support infrastructure with student and teacher pages on the QuarkNet website; Zoom Q& A sessions for teachers; an April 15 webinar on the Standard Model and CMS (conducted by a Kansas State University particle physicist); tables for recording results online in the CMS Instrument for Masterclass Analysis; and an April 17 webinar to discuss the data with particle physicists.

Fellows Workshop

- A virtual workshop was held on May 15-17; its primary purpose for participating fellows was to develop online workshops to be offered during summer 2020.

Data Camp

- Two virtual data camp events are planned for summer 2020 that emphasize the use of coding skills as these pertain to physics in general and particle physics in particular.

STEP UP

- QuarkNet Ambassador Training (virtual) planned for June 19-20 focused on how to use STEP UP activities and training on workshop best practices.

Summer 2020 Workshops at Centers

At this point in time, many centers remain uncertain as to what each will do. Centers have been encouraged to consider these options:

- Reschedule workshops for late summer or fall in hopes that face-to-face meetings would be possible at that time.

- Offer a virtual workshop – where at least a portion of their workshop time would be conducted remotely.
- Cancel a 2020 workshop with a plan to meet again in 2021.
- Other options.

Virtual summer meetings may also allow teachers to share successful strategies and tools with each other in teaching in a virtual setting.

As plans for summer workshops emerge, there are several centers that have scheduled summer workshops as virtual events; with discussions about events during the school year to supplement these actions. The full extent of the implementation of workshops in summer 2020, of course, will become more evident with the full rolling out of 2020-2021 program year. Early opportunities to conduct workshops in a virtual environment suggest the need for focused content; the importance of break-out groups; offline work (in-between on-line sessions); frequent breaks; and managing group size to keep all engaged.

Evaluation

Continue to involve centers in completing the Center Feedback Template. The most recent of these conversations have lent themselves to a discussion on what virtual opportunities might look like and how these may support, for example, in-school year events as well as summer events. As needed, we will "observe" virtual workshops and work to help QuarkNet systematically engage teachers in the development of classroom implementation plans as part of these events; and, to document and include these efforts as an evaluation measure intended to assess the influence of QuarkNet on classroom instruction and materials. Formative evaluation assessment may be added into the mix if the delivery of workshops in a virtual environment suggests a paradigm shift in program content. We will remain, however, focused on the assessment of outcomes as suggested by the PTM whether workshops are held face-to-face or in a virtual environment.

Preliminary Summary and Recommendations

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

This report is a prototype of the final evaluation report of this program that will be submitted at the end of this award period; as such, it presents a draft of the final evaluation report (although as an interim report it is final). In serving as a prototype, the present report and its review demonstrate the shift in evaluation efforts that has occurred from formative (and summative) assessment to an outcomes-based evaluation. In providing this early look, it is hoped that this will provide opportunities to help QuarkNet program staff members better understand this shift. It will also allow opportunities for staff to identify principal needs and concerns that the evaluation may be able to be responsive to; and to give the evaluator time to adjust to these needs and suggestions proposed by staff to help aid in the usefulness of evaluation findings and recommendations.

With the onset of a new external evaluator, we have proposed a new direction for the evaluation focused on the following, that is, the: (1) Development of a Program Theory Model (PTM); (2) Assessment of program outcomes at the national and center levels through teacher-level outcomes; and, (3) Assessment of the sustainability of program centers, based on center-level and sustainability outcomes.

The fully-articulated PTM is complete. The process used to create the PTM has been described in this report and the model has been described in detailed. Ideally, a program theory model offers a cohesive and representative picture of the program, "an approximate fit" of the program as *designed*. We have sought consensus on the representativeness of this model with key stakeholders and will revisit the PTM over the course of the award period, as this is needed.

To a large extent the PTM 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).

The development of a PTM and a Theory of Change is consistent with common guidelines proffered by the Institute of Education Sciences, U.S. Department of Education and the National Science Foundation (2013). Weiss (1995) noted that grounding evaluation in theories of change means integrating theory with practice. She postulated further that making assumptions explicit and reaching consensus with stakeholders about what they are trying to do, and why, and how, may ultimately be more valuable than eventual findings (Weiss, 1995), having more influence on policy and popular opinion (Rallis, 2013).

We have used the PTM to direct the development of evaluation measures and methods designed to address the remaining two goals. A Teacher Survey and a Center Feedback template have been designed to measure the teacher-level and center-level outcomes articulated in the PTM, respectively. Each of these has been developed, the first administration of the Teacher Survey coincided with the start of summer workshops that occurred in 2019; and the roll-out of the Center Feedback template began in September 2019. To coincide with the 2020-2021 program year, we have added an Update: Teacher Survey to continue to capture information from participating teachers and to focus on classroom implementation of QuarkNet content and instructional materials.

A total of 265 teachers (a response rate of 78%) participated in the Teacher Survey. A profile of participating teachers has been provided in the narrative of this report. Our approach to analysis has been to explore, preliminarily, teacher perspectives as to their exposure to core program strategies, perceived approach to teaching, student engagement, the potential influence QuarkNet has had on teachers' approach to teaching and student engagement as well as self-reported use of activities from the Data Activity Portfolio.

In preliminary analyses ….

Regarding **Core Strategies**, program engagement and measurement of exposure to core program strategies were shown to be related in a meaningful way (that is, more engagement by type of event, the higher the perceived exposure to core strategies; and more reported use of activities from the Data Activities Portfolio in the classroom); and speaks to the fidelity of the *implemented* program as compared to the program as *designed* as perceived by participating teachers who completed the Teacher Survey. Regarding, **Approach to Teaching,** teaching outcomes were shown to be related to *perceived* QuarkNet's Influence and the use of activities from the Data Activities Portfolio in the classroom as reported by participating teachers. **Use of DAP** activity was shown to be related to exposure to Core Strategies, Approach to Teaching, and all of the types of QuarkNet program events (Data Camp, Variety of Workshops, and Masterclass engagement).

Regarding, **Student Engagement,** QuarkNet's Influence on Student Engagement and Approach to Teaching were related perceived student engagement in inquiry-based science based on the perceptions of their participating teachers.

Although preliminary, the weight of these analyses suggests that there is a relationship between engagement in QuarkNet and exposure to core program strategies; and, that the type and degree of program engagement is related to teacher outcomes (Approach to Teaching) the use of activities from the Data Activities Portfolio in the classroom, and teachers' perceptions of Student Engagement in inquiry-based science that aligns with the NGSS Science and Engineering practices.

In assessment of the process of conducting center-level information through the Center Feedback Template, results from the pilot test and a second round of outreach suggest that this process has been helpful for QuarkNet staff teachers, the centers themselves (mentors and lead teachers), and the evaluation. Based on review of very early results, both centers (based on ten centers at this point) and teachers indicated that the program offers the opportunity ("all or most teachers" for centers and "excellent" ratings by participating teachers) for teachers to engage as active learners, as students, as part of their QuarkNet workshop participation. Also, review of center-level and teacher-level assessments suggests that QuarkNet workshop participation aligns well with the NGSS Science and Engineering practices based on DAP activity alignment and the engagement of these activities by participating teachers during QuarkNet workshops and programs.

Program Summary and Recommendations

The full impact that coronavirus (COVID-19) has had or will have on QuarkNet remains to be determined for the 2020-2021 program year and beyond. Currently, QuarkNet staff has actively sought to plan and conduct workshops, which previously were held face-to-face, in virtual environment(s). This has included modifying the content by focusing on core concepts as well as the delivery of the workshop or program, such as half-day sessions with small-group breakout sessions, separate off-line time to work on specific tasks, and breaks built into the agenda.

The following program summary and recommendations are proffered:

1. The program has had a long-standing practice of holding regularly-scheduled staff meetings. One of these is staff-wide; one is specific to IT concerns; and, one is specific to program content and development. The evaluator has been invited to attend these weekly meetings, and she has regularly attended the staff-wide meeting. Of importance, these weekly meetings have been especially helpful in discussing and planning program content and delivery modifications as a result of coronavirus, COVID-19. Continue to hold these meetings as determined by the feasibility of everyone’s schedule.
2. During the 2019-2020 program year, there has been a concerted effort to help nationally- and center-led workshops document the content of their workshops through the development and use of agenda templates; which are posted on-line. This is a simple and pragmatic step that has been very valuable. First, these agendas can and have been modified and used by QuarkNet centers. In many cases, agenda are modified during the event which memorializes the program in a just-in-time fashion.
3. The documenting of program content through workshop agendas has improved our ability to identify which (and how) activities from the Data Activities Portfolio (DAP) have been incorporated into workshops, especially nationally-led workshops and to a lesser extent but still notable for center-led workshops. This (along with item 2) may help centers prepare their annual reports, which each participating center is asked to do.
4. DAP activities, collectively, have been shown to align well with Next Generation Science Standards Science and Engineering Practices. Of importance, these activities are a bridge for teachers to implement QuarkNet content and materials into their classrooms. Continue to maximize the use of Data Portfolio Activities by teachers at center-led and nationally-led QuarkNet workshops and meetings.
5. Starting with the 2020-2021 program year, staff created a guide to help teachers reflect on and develop implementation plans that can be incorporated into their classrooms using QuarkNet content and instructional materials. Staff members have mandated this discussion in nationally-led workshops and they have strongly encouraged its use in center-run 2020-2021 workshops.

6. As articulated in item 5, continue support of the development by teachers of implementation plans and the subsequent use of these plans by teachers, QuarkNet program staff, and the evaluator.
7. The number (and the quality) of activities in the DAP has increased dramatically from 2017 (the end of the past grant period) to the new program-award period. 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 work-load for their development and eventual use.
8. Consider adding a Project Coordinator position to QuarkNet staff, if not now, in the future. This person could help the education specialist with DAP activity development as well as have other responsibilities such as helping to track participation related to registration, updating teacher profiles on the QuarkNet website; and subsequent stipend payment.
9. 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 program.
10. Continue to support the evaluation and its efforts as reasonable; and continue to work with the evaluator, as planned, to help embed evaluation efforts and requirements within the structure and delivery of the program.

Evaluation Summary and Recommendations

The following evaluation summary and recommendations are proffered:

1. The response rate for the Teacher Survey was 78% during the 2019-2020 program year. This successful return rate 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.
2. Working with QuarkNet staff, the Update Teacher Survey dovetails well with the guidelines for teachers in the development of classroom implementation plans. We think that this will facilitate a meaningful way for participating teachers to reflect and build these plans as well as, hopefully, provide a pathway for documenting and incorporating this information into the evaluation.
3. Initial efforts to distribute and collect center-level information through the Center Feedback Template suggest that this process has been helpful for QuarkNet staff, Center level mentors and lead teachers, and the evaluation.
4. Preliminary analyses from the Teacher Survey suggest that there is a meaningful link between exposure to program strategies and program engagement; and that this engagement is related to teacher outcomes, perceived student engagement, and use of activities from the Data Activities Portfolio in the classroom of participating teachers.
5. Very early data analyses suggest agreement between center-level perceptions and teacher-level perceptions on teachers experiencing activities as active learners (as students) and exposure to instructional materials (and their delivery) that align with the Next Generation Science Standards Engineering and Science Practices.

6. As more centers participate in the Center Feedback Template process, integrate these center-level outcomes data with analysis of teacher-level perceptions and outcomes. Add sustainability outcomes into the mix as the number of participating centers grows.
7. 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.
8. As recommended by the Advisory Board in December 2019 and to the extent possible, extend external evaluation efforts to incorporate QuarkNet’s international outreach efforts.
9. Continue to be mindful of the many responsibilities that program staff, mentors and teachers have. 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.
10. 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, participating teachers, NSF and others who may be interested in QuarkNet.

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Briefly History of Program

After the cancellation of the Superconducting Super Collider, which occurred in 1993, a concerted effort by a group of physicists was undertaken to help avert what might have resulted in an "impending demise of particle physics research in the U.S." (https://www.nd.edu/stories/causality-principle). This included physicists Randy Ruchti, from Norte Dame; Oliver Baker, from Hampton University; and Michael Barnett, from the Lawrence Berkeley National Laboratory); and, Marge Bardeen an educator (Fermilab educator now emeritus) as well as a commitment from the National Science Foundation and the Department of Energy to support the Large Hadron Collider (LHC) and LHC experiments (QuarkNet proposal, 2018).

In 1999, the National Science Foundation (NSF) affirmed its interest in developing an education and outreach national program across the physics centers in the United States in anticipation of the development of the LHC and to coincide with its support of the LHC and LHC experiments. [The LHC has become the world's largest and most powerful particle collider as part of CERN's (Conseil Européen pour la Recherche Nucléaire) accelerator complex at the European Center for Nuclear Research, with its first started up in September 2008.] In broad terms, the vision for this proposed education and outreach program was to mirror the experience and success of the MarsQuest program (Dusenberry & Lee, 1998), a program started to coincide with an up and coming decade of the exploration of the planet Mars, co-funded by NSF and NASA.

To begin, QuarkNet program stakeholders surveyed as many as 60 research centers to learn what educational and outreach efforts were implemented at these centers, at that time. Results indicated that efforts varied considerably across these centers further underscoring the need for a concerted national effort. From its beginning, QuarkNet focused on bringing teachers into the particle physics research community providing program continuity to participating centers by offering a national network of structured workshops and programs grounded in core program strategies (personal communication, M. Baredeen, September 18, 2018).

Development of the QuarkNet Program Theory Model

In sync with the start of the current award period, the evaluation began with the development of a Program Theory Model (PTM). The complexity of the program and its network of partners as well as its longevity suggested that the development of such a model was warranted. Thus at this stage of the program, the creation of a program theory model largely involved making key program components and strategies -- that have evolved and been implemented over time -- explicit and served to help link these to an outcomes-based evaluation.

Accordingly, we drew on a variety of information sources in its development, including relevant literature on effective professional development; the Next Generation Science Standards (and other relevant standards); and, structured interviews with key program stakeholders. And as discussed in the full narrative of the report, we have included a framework that adds program sustainability strategies and outcomes into the mix.

The narrative of the evaluation report describes in detail the three program anchors:

1. Drawing from the Literature: Effective Professional Development
2. Program Alignment with the Next Generation Science Standards
3. Program's Use of the Concept of Guided Inquiry

of the PTM and will not be repeated in this appendix.

Initial Interviews with Key Program Stakeholders

An important part of the information-gathering step in creating the PTM was the conduct of a structured interview with key program stakeholders, including the Principal Investigators and staff, and the two past evaluators. To guide these interviews, a written protocol was developed; then, reviewed and revised based on suggestions from the Principal Investigators (PIs). The protocol and the list of stakeholders and evaluators who participated in this interview process are shown at the end of this appendix. Each interview was conducted over the phone and most lasted between 1 to 1 ½ hours. As necessary, a second interview was scheduled to complete the information covered in the protocol. All interviews were conducted from September 18, 2018 through October 11, 2018.

There were five general themes discussed during these interviews, to obtain: 1. A general picture of the individual's role and responsibilities in the program; 2. Individual perceptions about program development and implementation; 3. Program strategies that the individual thought essential; 4. Program outcomes for teachers, their students, centers, and others; and, 5. Sustainability issues and concerns for the centers and the national program.

Each interview was digitally recorded, consent of this was verbally obtained, and each individual was given the option of stopping the recording at any time during the interview. These interviews were transcribed, with information extracted with an eye toward informing the PTM and did not necessarily represent a verbatim account of these discussions.

Meeting with Past Evaluators

In addition to these interviews, a face-to-face meeting was conducted with M. Jean Young and Ginny Beal, the two past evaluators, on October 2, 2018 in Tucson, AZ. along with the current evaluator. This was a day-long meeting where past evaluation efforts were discussed as well as plans for future evaluation efforts. Moreover, previous evaluation measures were reviewed and discussed as relevant. Although the purpose of this meeting was not solely focused on the development of the PTM, this discussion did inform the model relevant to QuarkNet's program evolution, its structure and core strategies as well as program outcomes related to teachers, centers, and sustainability efforts.

Information from these sources were culled into drafts of the PTM; and, shared and revised during iterative meetings with the PIs and key stakeholders until agreement was reached on the content of its component parts. Once the narrative of the PTM was agreed upon, a graphic presentation of it was created.

QuarkNet: Initial Interview Protocol

After a brief background question, I would like to discuss five main themes with you. These are: 1) your role in this project; 2) your perceptions about program development and implementation; 3) program strategies that you think essential; 4) program outcomes for teachers, students, centers and others; and, 5) sustainability issues and concerns for the centers and the national program. My purpose in our conversation is to use this information, along with other relevant resources, to build a program theory model of QuarkNet and to focus evaluation efforts around core program strategies and program outcomes including long-term sustainability of the program.

It is expected that our conversation will take about 1 to 1 ½ hours and unless you object I will digitally record our conversation for note taking purposes only. At any time, you may ask that I stop recording and I will comply with your request. I will extract information for this and other interviews to form the basis of a program theory model to identify program strategies and suggest logical links to program and long-term outcomes. No responses by individuals will be identified by name unless specific permission to do so is obtained.

I have sought to ask a standard set of questions to get a sense of the varying degrees of stakeholder knowledge about the program. Thus at times, I may ask a question that you may have some or little background information about; at other times a particular question likely will generate a great deal of discussion. Please feel free to proffer ideas or recommendations not asked if you think these are germane or critical to QuarkNet.

Background

I want to start with a few quick background questions.

Please give a brief professional sketch of yourself (as this pertains to your involvement in *QuarkNet*).

Organizationally, how does *QuarkNet* relate to, interconnect or fit within your institution?

Your Role

What is your role in *QuarkNet*? What are your main responsibilities in this program?

Program

Development/Historical Perspective

What ideas, resources, and/or materials were initially used to develop this program? Who was involved in the initial planning of this program?

How or in what ways has *QuarkNet* changed or evolved over the past several years? If relevant please talk about the process as to how this change occurred.

Target Audience/Recruitment

Who do you see as the target audience(s) (in terms of teachers, students, centers, others) of *QuarkNet*?

How are new centers added to *QuarkNet*? What process is or has been used to recruit teachers for in this program? What criteria are used? Is the program reaching the "right" teachers; others?

Program Components

Briefly describe the program strategies or core activities that you think are essential to *QuarkNet*. (Reference either the national program or center-level program or both.) Which of these do you think are most important? Are there program strategies that are not used during the implementation of the program or that could/should be strengthened?

Program Outcomes

I'd like to talk about your perceptions regarding program outcomes for participating teachers, students and participating centers?

What program outcomes do you believe are the most important for teachers to gain from this program? What are the long-term outcomes you believe would result from program participation by teachers? How do identified program outcomes link to core program components?

What outcomes do you believe are the most important to gain for the national program?
What outcomes do you believe are the most important for participating centers? How about students? Any others?

What level of evidence of program impact do you and/or your institution need to sustain your involvement in the program?

Partnership/Sustainability

What are the barriers or challenges to an institution's participation in *QuarkNet*? What program or infrastructure components do you think need to be put in place in order for an institution to sustain its participation in this program within the 5-year grant period or beyond?

What criteria or measures do you think we should used to gauge program sustainability among program centers? For the national program?

What do you think the program can do to help assist centers in their efforts to sustain *QuarkNet* through their own funding efforts?

Is there anything else that you want to share regarding the program or your involvement?

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.

Diversity – Women and Minorities: QuarkNet partners with other STEM organizations to reach more students underrepresented in STEM, either through their teachers or directly. Recent partners are *Step Up 4 Women,* an American Physical Society program to increase the representation of women amongst physics bachelor’s degrees and *STEAM Workshop at NACA,* a program of the Native American Community Academy, Albuquerque, in which students create visual stories using projection art about ideas in Western science and indigenous culture. An example of being nimble to respond to opportunities is the *i.am. Angel Foundation,* transforming lives through education inspiration and thinking. Also, some centers partner with other organizations to reach beyond QuarkNet schools to students traditionally underrepresented in STEM.

Advisory Board: Seven or eight 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+.

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.

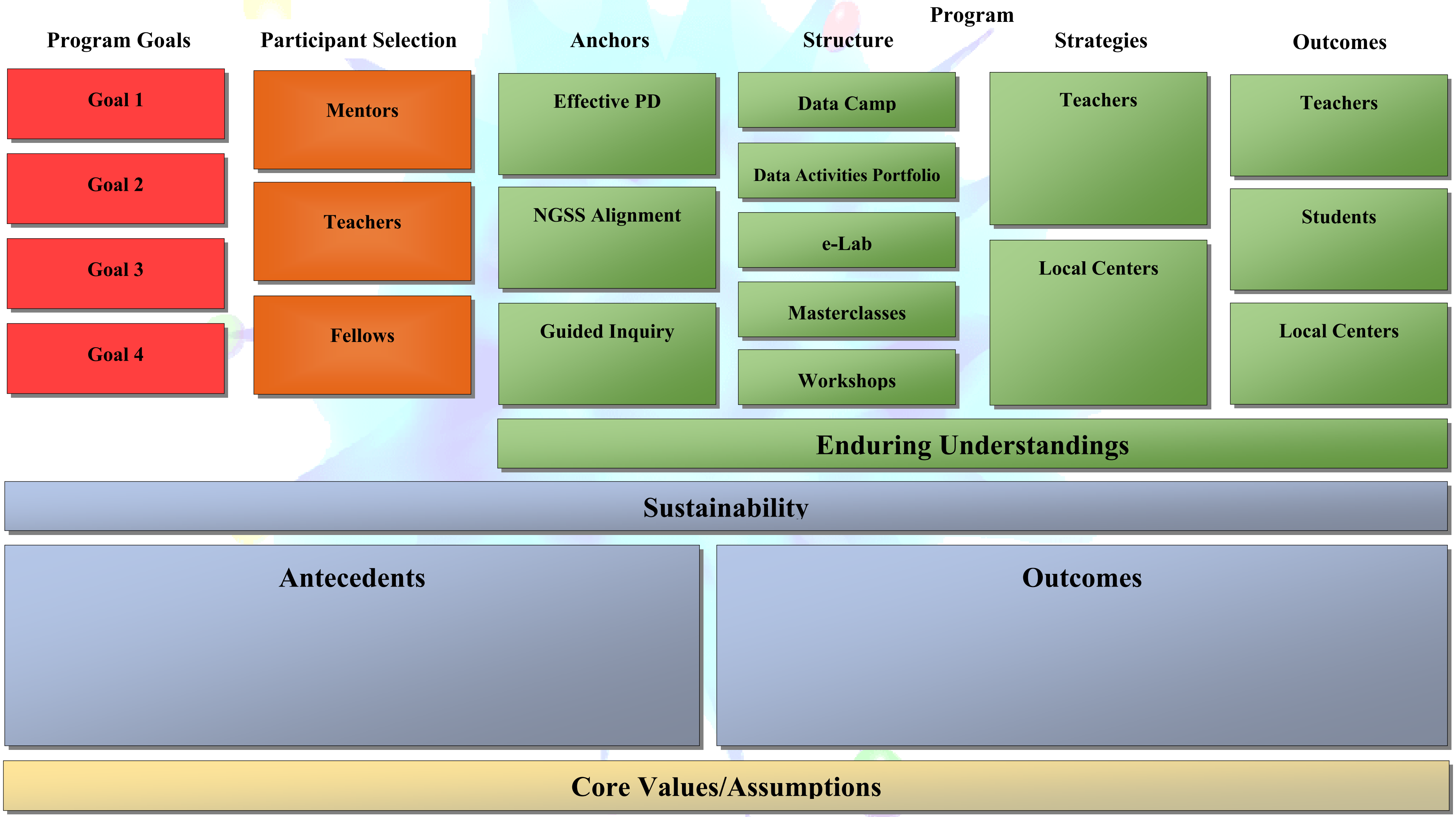
Broader Impacts and Community Outreach: QuarkNet efforts extend beyond the program. Often, centers integrate QuarkNet in other community outreach and broader impact efforts. QuarkNet has led in facilitating the public use of large particle physics databases. QuarkNet staff and teachers attend and present at meetings of the American Association of Physics Teachers and the American Physical Society. At International Particle Physics Outreach Group (IPPOG) meetings QuarkNet presentations have highlighted how QuarkNet works, e-Labs, the Data Activities Portfolio and scientific discovery for students. QuarkNet has developed and coordinated the CMS masterclass, led the global cosmic ray studies project, and provided a wealth of information for other IPPOG members to consider in their own education and outreach programs.

QuarkNet

QuarkNet Program Theory Model

Program Statement: 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.

Centers: QuarkNet delivers its professional development program in partnership with local centers.



QuarkNet Program Theory Model

Program Statement: 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 classroom.

QuarkNet delivers its professional development program in partnership with local centers.
QuarkNet Centers: Centers both form the essential backbone of and are partners in QuarkNet. A center is housed at a university or laboratory, serving primarily teachers who live within reasonable commuting distances. An online center, the Virtual Center, provides a home for teachers who no longer live close to a particle physics research group. At the center, program leaders include one or two particle 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.

Program Goals

Measurable professional development (PD) goals are:
Goal 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.

Goal 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.

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

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

Participant Selection

Teachers: High school physics/physical science teachers who express interest in QuarkNet and/or who are invited to participate through staff, fellows, or mentors/ center teachers. Mentors may know high school teachers who would be good additions to their research team and/or who may become associate teachers at the center.

Mentors: Particle physics researchers working at a university or laboratory who have expressed interest in participating in QuarkNet. Mentors propose a research project, identify a mentor team, and describe previous outreach experience. Staff and PIs approve before adding the mentors/centers to the QuarkNet network.

Fellows: QuarkNet teachers who are invited by staff to become fellows based on participants' experiences working with a local center or on national programs such as Data Camp.

Program Anchors

Characteristics of Effective Professional Development[1]
- Is content focused
- Incorporates active learning utilizing adult learning theory
- Supports collaboration, typically in job-embedded contexts
- Uses models and modeling of effective practice
- Provides coaching and expert support
- Offers opportunities for feedback and reflection
- Is of sustained duration

[1] Darling-Hammond, L., Hyler, M.E., & Gardner, M. (2017, June). Effective teacher professional development. Palo Alto, CA: Learning Policy Institute.

Pedagogical and Instructional Best Practices
Aligns with the **Science and Engineering Practices** of the NGSS. APPENDIX F – Science and Engineering Practices in the NGSS (2013, April). As suggested, these practices are intended to better specify what is meant by inquiry in science.
https://www.nextgenscience.org

1. Asking questions (for science) and defining problems (for engineering)
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 (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Content addresses **Disciplinary Core Ideas and Crosscutting Concepts** (NGSS):

1. Patterns
2. Cause and Effect
3. Scale, Proportion and Quantity
4. Systems and System Models
5. Energy and Matter in Systems
6. Structure and Function
7. Stability and Change of Systems

Guided Inquiry
Guided inquiry (teacher provides problem or question) and Structured inquiry (where teacher provides problem and procedure) [Herron, M.D. (1971). The nature of scientific enquiry. *School Review, 79*(2), 171- 212.] **Guided Inquiry** - The **solution is not already existing/known in advance** and could vary from student to student. **Students EITHER investigate a teacher-presented question** (usually open-ended) **using student designed/selected procedures OR investigate questions that are student formulated** (usually open-ended) **through a prescribed procedure** (some parts of the procedure may be student designed/selected). (2007 Jan-Marie Kellow)

Program Structure

Data Camp: A 1-week program offered annually in the summer at Fermilab. It 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 the teachers are expected to engage as students as active learners of a challenging topic they may initially have known very little about. In the beginning of the week, teachers receive an authentic CMS dataset and work in small groups to analyze the dataset. Groups use these data 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 data. Then, teachers explore various instructional materials in the Data Activities Portfolio that offer them help in incorporating particle physics concepts into their everyday lessons and propose an implementation plan for their classrooms. Throughout the week, teachers take tours (e.g., LINAC tunnel, MINOS experiment) and participate in seminars held by theoretical and experimental physics.

Data Activities Portfolio: An online compendium of particle physics classroom instructional materials organized by data strand and expected level of student engagement. These materials are based on authentic experimental data used by teachers to give students an opportunity to learn how scientists make discoveries. Strands include LHC, CMS, Cosmic Ray Studies, and neutrino data. Activities increase in complexity, sophistication and expected student engagement from Levels 0 to 4. Pathways provide guidance for teachers to develop a sequence of lessons or activities appropriate for their students. Draft instructional materials are reviewed based on specified instructional design guidelines and are aligned with NGSS, IB, and AP science standards (Physics 1 and Physics 2) as relevant.

Through guidance from teachers, students are provided the opportunity such that:
Level 0 – Students build background skills and knowledge needed to do a Level 1 activity. Students analyze one variable or they determine patterns, organize data into a table or graphical representation and draw qualitative conclusions based on the representation of these data.
Level 1 – Students use the background skills developed in Level 0. They calculate descriptive statistics, seek patterns, identify outliers, confounding variables, and perform calculations to reach findings; they may also create graphical representations of the data. Datasets are small in size. The data models come from particle physics experimentation.
Level 2 – Students use the skills from Level 1 but must apply a greater level of interpretation. The analysis tasks are directed toward specific investigations. Datasets are large enough that hand calculation is not practical, and the use of statistics becomes central to understanding the physics. They perform many of the same analysis tasks but must apply a greater level of interpretation.
Level 3 – Students use the skills from Level 2. They develop and implement a research plan utilizing large datasets. They have choices about which analyses they do and which data they use; they plan their own investigations. The level and complexity of the Level 3 investigations is generally higher than in Level 2.
Level 4 – Students use the skills from Level 3. They identify datasets and develop code for computational analysis tools for the investigation of their own research plan.

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

Masterclass, U.S. Model: A one-day event in which students become "particle physicists for a day." Teachers and mentors participate in an orientation by QuarkNet staff or fellows. Teachers implement about 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 explain the measurements they will make using authentic particle physics data. Working in pairs, students are expected to analyze the data in visual event displays; to characterize the events; pool their data with peers; and draw conclusions, helped by one or more particle physicists and their teacher. 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 or CERN. Some masterclasses take place at school with teachers providing the particle physics and measurement information. U.S. Masterclasses are part of a larger program, International Masterclasses.

Workshops: The primary vehicle through which participating QuarkNet teachers receive professional development.

Center-run Workshop: A center's second year involves new associate teachers in a multi-week experience that focuses on a research scenario prepared by their mentor(s) with support from lead teacher(s). The mentor models research, similar to Data Camp, where teachers, as students and active learners, have an opportunity to engage in an experiment, receive and analyze data, and present results. Then teachers have time to create a plan to share their experiences with their students and often use instructional materials from the Data Activities Portfolio in this planning.

During a center's third year and after, lead teacher(s) and mentor(s) have flexibility to organize 4-to-5 day workshops to meet local needs and interests. These workshops vary in content and structure. Centers may meet only during the summer, only during the school year or both during the summer and school year. Some centers meet even more frequently depending upon interest and availability of teachers. These workshops may include a national workshop[3] and offer a learning-community environment with opportunities for teachers to interact with scientists, and learn and share ideas related to content and pedagogy.

[3] **National Workshop:** On request, QuarkNet staff and/or fellows conduct workshops held at local centers. These workshops typically occur during the summer and can vary in length from several days to a week period. Content includes, for example, cosmic ray studies, LHC or neutrino data, and related instructional materials from the Data Activities Portfolio. National workshops support opportunities for teachers to work in a learning-community environment, learn and share ideas related to content and pedagogy, and develop classroom implementation plans.

Program Strategies

QuarkNet is not static but evolves to reflect changes in particle physics and the education context in which it operates.

Teachers

Provide opportunities for teachers to be exposed to:

- Instructional strategies that model active, guided-inquiry learning (see NGSS science practices).
- Big Idea(s) in Science (cutting-edge research) and Enduring Understandings (in particle physics).

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.

Local Centers

Each center seeks to foster lasting relationships through collaboration at the local level and through engagement with the national program.

In addition, through sustained engagement provide opportunities for teachers and mentors to:

- Interact with other scientists and collaborate with each other.
- Build a local (or regional) learning community.

Program Outcomes

Teachers

Translate their experiences into instructional strategies, which reflect guided inquiry and NGSS science and engineering practice and other science standards as applicable.[4, 5] *Specifically:*

- Discuss and explain concepts in particle physics.
- Engage in scientific practices and discourse.
- Use particle physics examples, including authentic data, when teaching subjects such as momentum and energy.
- Review and use instructional materials from the Data Activities Portfolio, selecting lessons guided by the suggested pathways.
- Facilitate student investigations that incorporate scientific practices.
- Use active, guided-inquiry instructional practices in their classrooms that align with NGSS and other science standards.
- Use instructional practices that model scientific research.
- Illustrate how scientists make discoveries.
- Use, analyze and interpret authentic data; draw conclusions based on these data.
- Become more comfortable teaching inquiry-based science.
- Use resources (including QuarkNet resources) to supplement their knowledge and instructional materials and practices.
- Increase their science proficiency.
- Develop collegial relationships with scientists and other teachers.
- Are lifelong learners.

(And their) Students will be able to:

- Discuss and explain particle physics content.
- Discuss and explain how scientists develop knowledge.
- Engage in scientific practices and discourse.
- Use, analyze and interpret authentic data; draw conclusions based on these data.
- Become more comfortable with inquiry-based science.

Local Centers

- Model active, guided-inquiry instructional practices that align with NGSS and other science standards that model scientific research.

Through engagement in local centers

Teachers as Leaders:

- Act in leadership roles in local centers and in their schools (and school districts) and within the science education community.
- Attend and/or participate in regional and national professional conferences sharing their ideas and experiences.

Mentors:

- Become the nexus of a community that can improve their teaching, enrich their research and provide broader impacts for their university.

Teachers and Mentors:

- Form lasting collegial relationships through interactions and collaborations at the local level and through engagement with the national program.

Enduring Understandings (See last page.)

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[4] College Board Advanced Placement science standards and practice; and AP Physics; International Baccalaureate Science standards and practices.

[5] To the extent possible in their school setting.

Sustainability[a]

Antecedents

Characteristics of the Specific Program

1. Fidelity to PTM core strategies as implemented (national or center level)[b]
2. Evidence of flexibility/adaptability at the center level (if/as needed)
3. Evidence of effectiveness

Organizational Setting at the Center-level Program[c]

1. (Good) fit of program with host's organization and operations
2. Presence of an internal champion(s) to advocate for the program
3. Existing capacity and leadership of the organization to support program
4. Program's key staff or clients believe in the program (believe it to be beneficial)

Specific Factors Related to the Center-level Program

1. Existing supportive partnerships of local organizations (beyond internal staff)
2. Potentially available/existing funders or funding
3. Manageable costs (resources and personal; supported by volunteers)[d]

Outcomes

1. Program components or strategies are continued (sustained fidelity in full or in part).[e]
2. Benefits or outcomes for target audience(s) are continued.[e]
3. Local/center-level partnerships are maintained.[f]
4. Organizational practices, procedures and policies in support of program are maintained.
5. Commitment/attention to the center-level program and its purpose is sustained.[f]
6. Program diffusion, replication (in other sites) and/or classroom adaptation occur.[f]

Core Values/Assumptions

QuarkNet provides opportunities:

1. That seek to meet the needs and interests of participating teachers.
2. For participating teachers and mentors to form collegial relationships that are an integral part of the QuarkNet experience.
3. Where participating teachers are professionals.
4. For teachers to get together to discuss physics and to form learning communities.
5. Where QuarkNet centers are central to building a national program and are an effective way to do outreach.
6. Where QuarkNet fellows are integral in helping the program reach teachers.
7. To help keep high school physics teachers interested and motivated in teaching and to help teachers avoid burnout.
8. Where a diversity of ideas is brought into the program to help the long-term commitment by teachers/mentors to the program.
9. To help build and improve science literacy in teachers and their students.
10. To help teachers build confidence and comfort in teaching guided-inquiry physics.

The program is based on the premise that:

11. All students are capable of learning science.
12. Science is public, especially in physics where many researchers collaborate together on the same experiments.
13. The program should strive to achieve equity in language and behavior relative to race, ethnicity and gender.
14. Through the program, teachers are able to go back to their classroom with enthusiasm and with ideas that they can use to appeal to the imagination of their students.
15. Master teachers as staff are effective PD facilitators and center contacts.

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[a] This framework is based on the work of Scheirer and Dearing (2011); adopting their definition of sustainability, as well: "Sustainability is the continued use of program components and activities for the continued achievement of desirable program and population outcomes" (p. 2060). The QuarkNet Sustainability framework has been modified to better reflect the QuarkNet program (as recommended by Scheirer, et al., 2017). (See notes below.)

[b] Program fidelity, as *implemented*, has been added as a program characteristic.

[c] The language used to describe these organizational characteristics has been modified slightly to better fit the *QuarkNet* program.

[d] This cost component was moved to environmental or contextual concerns of the specific program.

[e] The order of these two outcomes are reversed from the original.

[f] The language of this characteristic was modified to better fit the QuarkNet program.

Enduring Understandings of Particle Physics

1. Scientists make a claim based on data that comprise the evidence for the claim.
2. Scientists use models to make predictions about and explain natural phenomena.
3. Scientists can use data to develop models based on patterns in the data.
4. Indirect evidence provides data to study phenomena that cannot be directly observed.
5. Scientists can analyze data more effectively when they are properly organized; charts and histograms provide methods of finding patterns in large datasets.
6. Scientists form and refine research questions, experiments and models using observed patterns in large data sets.
7. The Standard Model[6] provides a framework for our understanding of matter at its most fundamental level.
8. The fundamental particles are organized according to their characteristics in the Standard Model.
9. Particle physicists use conservation of energy and momentum to measure the mass of fundamental particles.
10. Fundamental particles display both wave and particle properties, and both must be taken into account to fully understand them.
11. Particle physicists continuously check the performance of their instruments by performing calibration runs using particles with well-known characteristics.
12. Well-understood particle properties such as charge, mass, momentum and energy provide data to calibrate detectors.
13. 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.
14. Particle physicists must identify and subtract background events in order to identify the signal of interest.

Developed by Young, Roudebush, Smith & Wayne, 2019

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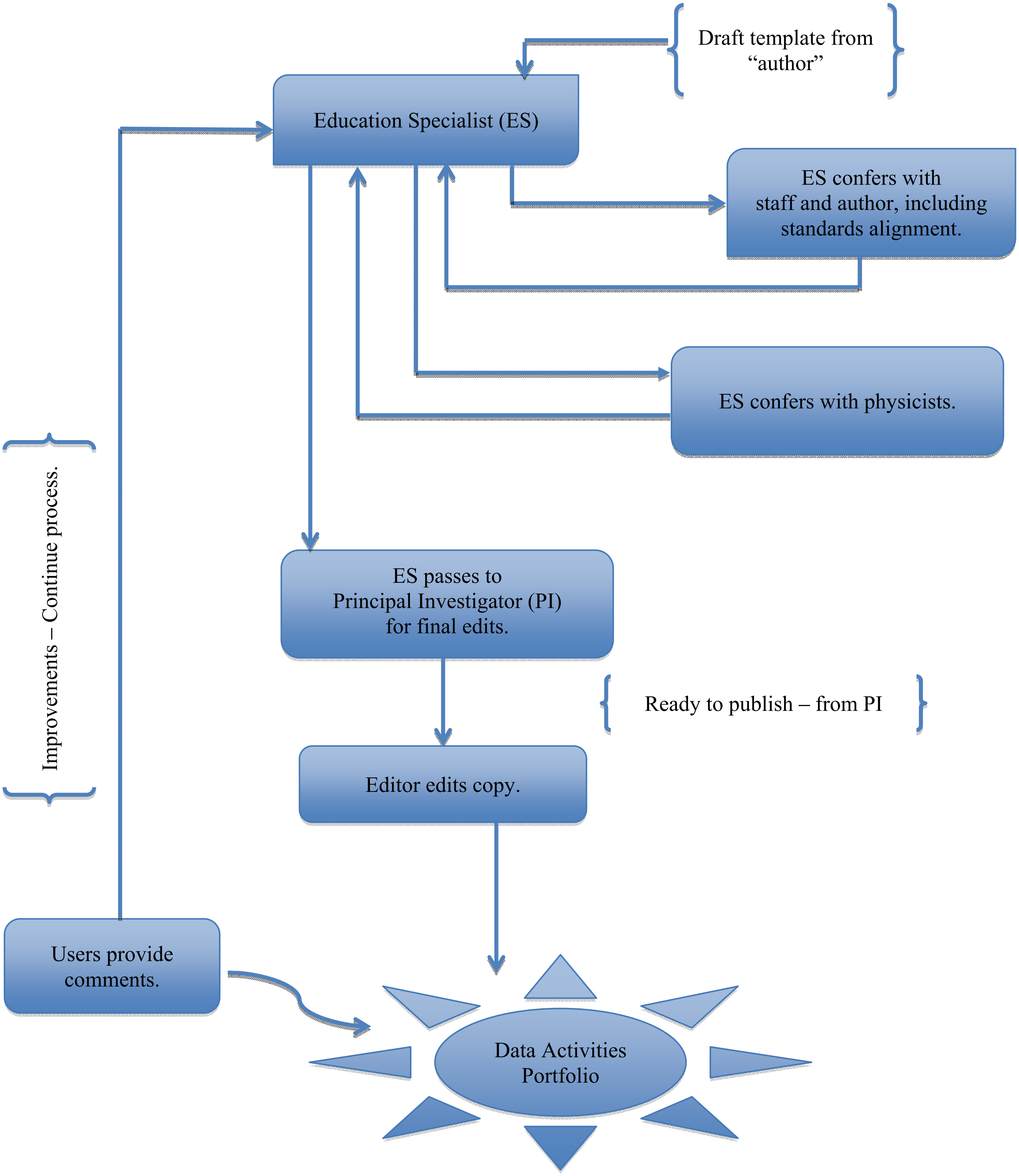
[6] The Standard Model of Particle Physics: the current theoretical framework that describes elementary particles and their forces (six leptons, six quarks and four force carriers). Physicists (and other scientists) can understand every phenomenon observed in nature by the interplay of the elementary particles and forces of the Standard Model. The search beyond the Standard Model of Particle Physics may lead to a larger, more elegant "theory of everything." (http://www.fnal.gov/pub/science/inquiring/matter/ww_discoveries/index.html)

Instructional Design Pathway and Templates for Data Activities Portfolio

<u>PROCESS</u>: To ensure what we publish is of highest quality.



CRITERIA USED AT INSTRUCTIONAL DESIGN STAGE – ANNOTATED

In line with the NGSS Framework*

Exemplars:

1. Includes a question to address and/or problem to solve; could be developing a model to explain a phenomenon or test a model. – Science Practices
2. Students gather data and/or test solutions; provide claims, evidence and reasoning. – Science Practices
3. Addresses crosscutting concept(s) and disciplinary core ideas

In line with the Common Core Literacy Standards**

Reading Exemplars:

1. 9-12.4 Determine the meaning of symbols, key terms . . .
2. 9-12.7 Translate quantitative or technical information . . .

In line with the Common Core Mathematics Standards**

Exemplars:

1. MP2. Reason abstractly and quantitatively.
2. MP5. Use appropriate tools strategically.
3. MP6. Attend to precision.

In line with AP Physics 1 Curriculum Framework Standards***

Exemplars:

1. EK 3.A.2: Forces are described by vectors.
2. EK 3.B.1: If an object of interest interacts with several other objects . . .
3. EK 3.C.3: A magnetic force results from the interaction of a moving . . .

In line with AP Physics 2 Curriculum Framework Standards****

Exemplars

1. EK 1.E.6.a: Magnetic dipole moment is a fundamental source . . .
2. EK 3.A.2: Forces are described by vectors.
3. EK 3.C.3: A magnetic force results from the interaction of a moving . . .

In line with IB Physics Standards*****

Standard 1: Measurement and Uncertainty
Standard 5: Electricity and Magnetism

**A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, National Research Council, 2012. https://www.nextgenscience.org/

**The Common Core State Standards for English Language Arts & Literacy in History/Social Studies, Science, and Technical Subjects, Council of Chief State School Officers (CCSSO) and the National Governors Association (NGA), 2019. http://www.corestandards.org/read-the-standards/

***AP Physics 1: Algebra-Based Course and Exam Description, College Board, 2017. https://secure-media.collegeboard.org/digitalServices/pdf/ap/ap-physics-1-course-and-exam-description.pdf

****AP Physics 2: Algebra-Based Course and Exam Description, College Board, 2017. https://secure-media.collegeboard.org/digitalServices/pdf/ap/ap-physics-2-course-and-exam-description.pdf

*****International Baccalaureate Physics (SL) Standards, IB Diploma Programme, 2016. https://www.ibo.org/globalassets/publications/recognition/physicssl2016englishw.pdf

International Baccalaureate Physics (HL) Standards, IB Diploma Programme, 2016. https://www.ibo.org/globalassets/publications/recognition/physicshl2016englishw.pdf

Macro Design

1. Activity addresses a ‘big idea’ (core idea); sub-ideas support the big idea (can be concepts and/or principles).

   Often, this is the same as or similar to the enduring understanding. A core idea can be as basic as “calibration,” a classic physics concept such as “momentum,” or a principle (law) such as $E = mc^2$. Research indicates that students come away from a well-structured lesson/activity with an understanding that they maintain even through life (it “endures”). Over time they lose the details but not the enduring understanding.

2. Students apply science process skills and/or design technology.

   There are a variety of skills that students learn in *doing* science. These include all the ways students use data as well as thinking/reasoning skills such as compare/contrast, infer/predict. Design technology means the process of design-develop-test-redesign-redevelop-retest . . . i.e., engineering.

3. Format is guided inquiry.

   Over the years, QuarkNet teachers have developed the understanding that in doing particle physics, students and teachers can learn best facilitated by guided, not open, inquiry. While leading/facilitating is important, such as asking clarifying questions, learning particle physics depends on difficult concepts, principles and procedures that need more guidance than some other science fields.

4. The conceptual framework is from simple to complex and supports activities that can include an “enrichment” or follow-on section.

   The conceptual framework is embodied in the Data Activities Portfolio (DAP). The DAP organizes activities by data strand, pathway and level of student engagement. Activities differ in complexity and sophistication—tasks in Level 0 are designed to build skills needed for higher levels. Level 1 activities are simpler than those in Levels 2 and 3. While each level can be explored individually, students who start in one level and progress to more complex levels experience increasingly challenging tasks. Pathways suggest activity sequences designed to develop understanding of a particular concept. Also, teachers can select activities to offer a learning experience of an appropriate length and level for their students.

Level Definitions

Level 0 Students builds background skill and knowledge needed to do a Level 1 activity. Students analyze one variable or they determine patterns, organize data into a table or graphical representation and perform simple calculations.

Level 1 Students use background skills developed in Level 0. They calculate descriptive statistics, seek patterns, identify outliers, confounding variables, and perform calculations to reach findings; they may also create graphical representations of the data. Datasets are small in size. The data models come from particle physics experimentation.

Level 2 Students use skills from Level 1. They perform many of the same analysis tasks but must apply a greater level of interpretation in order to distinguish between signal and background. Datasets are medium in size so that mathematical calculations are too large to be done using pencil and paper.

Level 3 Students use the skills from Level 2. They develop and implement a research plan utilizing large datasets. They make decisions in their analysis by taking into consideration complications such as background, signal to noise, and instrumentation effects.

Level 4 Students use the skills from Level 3. They identify datasets and develop analysis tools for the investigation of their own research plan.

Micro Design

1. There are behavioral objectives.

   The objectives start with a verb (what you want students to know and be able to do) and/or the action (behavior) is implicit in the objective. The objectives should ALL be measurable since they will drive what is in the assessment: Did students learn what you wanted them to know? Did they exhibit the skill you wanted them to learn?

2. There are connections to the real world such as awareness of scientific exploration, contemporary physics research, the skills that scientists use, and the importance of scientific literacy.

   Since one of the QuarkNet goals is for students to become more scientifically literate, it is important that the activities help them better understand what doing science actually involves and how scientists pursue science. This may include statements such as "This is what they do at CERN" or "This is how scientists do . . ." to ensure these data are useable/reliable/accurate."

3. Students analyze data to come up with a hypothesis/solution/explanation; they apply reasoning including critiquing their ideas; e.g., identify flaws in their argument.

   A main focus of the NGSS, Common Core, AP Physics 1, AP Physics 2, and IB is for students to be able to make a claim based on evidence and reasoning. Often, the final "reasoning" part is missing. They can describe the evidence, but they fail to make the logical reasoning to connect the data with the conclusion they draw. Students must be able to back up their conclusion with an evaluation of the extent to which their data is "good" evidence to support the conclusion.

4. Evaluation/assessment is based on whether or not the objectives are achieved; questions refer directly to the objectives. There are no distractions or extraneous ideas.

   Several activities will have a student report sheet. This could be used as the summative assessment if the objectives are aligned with the report sheet. Learning a skill, such as developing a histogram, can be a formative assessment that may or may not become part of the report sheet but is nonetheless assessed. Formative assessment may be just checking student work informally. If there is more that can be added to the activity, there might be an enrichment section. Adding extra ideas at the assessment stage, distractions and extraneous ideas, confuses the students about what you want them to know and be able to do.

   A sample template for an activity follows; this sample shows font size, type and other formatting that your activity must follow.

TITLE (*TIMES NEW ROMAN, 18*)
TEACHER NOTES (*TIMES NEW ROMAN, 16*)

(*TIMES NEW ROMAN, 12*)

DESCRIPTION (**THIS TYPE OF STYLE CAN BE FOUND UNDER *FORMAT, FONT, SMALL CAPS*.**)

Briefly provide an overview and purpose of the activity. *For example:* From where do cosmic rays come? Can they be from the sun? Or are they from elsewhere but blocked by the sun? Students search for a specific data file in the Cosmic Ray e-Lab and look for evidence of the passage of the sun in the flux measurements derived from this file. Many people new to studying cosmic rays initially *think* that cosmic rays originate in our sun. This activity allows students to investigate this idea and study evidence that can confirm or refute their original understanding. An e-Lab user collected data with the detector in a configuration that allowed the detector's axis to sweep across the sun at local solar noon including data before and after the sun's transit. Data collected at the beginning and end of the sweep provide the "control" or no effect from the sun, while solar noon provides data on effect of the sun. (*Layout, after, 5 pt* between paragraphs)

STANDARDS ADDRESSED (**FILL IN AS APPROPRIATE. THIS LIST SHOWS FORMAT.**)

Next Generation Science Standards
- Science and Engineering Practices
  - 4. Analyzing and interpreting data
  - 5. Using mathematics and analytical thinking
- Crosscutting Concepts
  - 1. Observed patterns

Common Core Literacy Standards
- Reading
  - 9-12.4 Determine the meaning of symbols, key terms . . .
  - 9-12.7 Translate quantitative or technical information . . .

Common Core Mathematics Standards
- MP2. Reason abstractly and quantitatively.

AP Physics 1 Standards
- Exemplars

AP Physics 2 Standards
- Exemplars

IB Physics Standards
- Exemplars

ENDURING UNDERSTANDINGS

- One EU per activity

Choose from one of the following:

1. Scientists make a claim based on data that comprise the evidence for the claim.
2. Scientists use models to make predictions about and explain natural phenomena.
3. Scientists can use data to develop models based on patterns in the data.
4. Indirect evidence provides data to study phenomena that cannot be directly observed.
5. Scientists can analyze data more effectively when they are properly organized; charts and histograms provide methods of finding patterns in large data sets.
6. Scientists form and refine research questions, experiments and models using observed patterns in large data sets.

7. The Standard Model provides a framework for our understanding of matter at its most fundamental level.
8. The fundamental particles are organized according to their characteristics in the Standard Model.
9. Particle physicists use conservation of energy and momentum to measure the mass of fundamental particles.
10. Fundamental particles display both wave and particle properties, and both must be taken into account to fully understand them.
11. Particle physicists continuously check the performance of their instruments by performing calibration runs using particles with well-known characteristics.
12. Well-understood particle properties such as charge, mass, momentum and energy provide data to calibrate detectors.
13. 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.
14. Particle physicists must identify and subtract background events in order to identify the signal of interest.

LEARNING OBJECTIVES (BEGIN WITH VERB THAT CAN BE MEASURED.)

As a result of this activity, students will know and be able to:

- xxx

PRIOR KNOWLEDGE

What students should probably know before they engage in this activity

BACKGROUND MATERIAL

This is content information for the teacher, often including links for where to get more information.

RESOURCES/MATERIALS

IMPLEMENTATION

Guidelines for the teachers, activity sequence; basically, write-up of the activity – procedure. Think of this section as annotated student notes.

ASSESSMENT

Formative assessment includes discussion questions to ask students to increase conceptual understanding. Summative assessment includes tests, quizzes, oral and/or written report including the activity report that focuses on claims, evidence and reasoning. **Note:** Any assessment must address the learning objectives which means assessing what you want them to know and be able to do. Just indicating that students will write a report is insufficient. If a report is the best option, include some idea of what the report would be about. For example, an assessment about cosmic rays which follows from the questions raised in the sample description might be: What would you tell people who believe that cosmic rays originate from our sun? What evidence and reasoning would you provide to support your claim?

NOTE: WE PROVIDE TWO TEMPLATES FOR STUDENT PAGES.

GUIDELINES FOR WHICH TEMPLATE TO USE:

- For a level two or three activity, use a student report sheet and template two.
- For complex activities that require students to make a claim and provide evidence and reasoning, use a student report sheet and template two.
- An activity that addresses a claim based on observed data, such as *Mapping the Poles*, does not need a student report sheet because it is not complex. Contrast this with *Calculate the Z Mass* which requires analysis that is more complex.

- For an activity that focuses on learning a skill and/or exploring a model, a report sheet may be the only thing necessary, e.g., *Quark Workbench 2D/3D*; students make “rules” and have to back them up with reasoning, but not in the context of a scientific investigation. The activity *Dice, Histograms and Probability* explores histograms, so does not need a student report sheet: template one.

Clearly these guidelines are not hard and fast rules. Authors will have to decide for themselves which template to use. Luckily, there are several people in the review process who can act as consultants. NOTE: Some activities do not even need a student report sheet; e.g., *Dice, Histograms & Probability*. Those activities are explorations of a topic with the teacher acting as facilitator.

TITLE (TEMPLATE FOR STUDENT PAGES)
STUDENT PAGE

Template One:

Question(s), problem to solve; overall purpose of doing the activity - INTRODUCTION
Steps/guidelines; supporting content, materials, resources (including websites)

Claims, Evidence, Conclusions

For example, when the students have finished the activity, project on the screen the Elementary Particles chart again. Discuss the fact that they have investigated a small part of the Standard Model—one that describes formation of baryons and mesons. There is more to learn about the Standard Model—both for the students and for physicists.

- What rules did you discover that determine the composition of baryons? Mesons? What is the evidence for the rules? (Hint: Describe quark properties.)
- What role did quarks play in forming the mesons and baryons?
- In addition to quarks, what other particles are "fundamental"?
- What do physicists call the current theoretical framework for our understanding of matter?

The learning objectives were:

As a result of this activity, students will know and be able to:

- Identify the fundamental particles in the Standard Model chart.
- Describe properties of quarks, including color, spin, and charge.
- Describe the role of quarks in forming particles that are part of the Standard Model.
- State the rules for combining quarks to make mesons and baryons.

Template Two:

Question(s), problem to solve; overall purpose of doing the activity – INTRODUCTION
Objectives: Could be as simple as what is their task; does not have to be the learning objectives, but could be.
Student pages currently include (after a brief overview of the activity):

- What do we know?
- What tools do we need for our analysis?
- What do we do?
- What are our claims? What is our evidence?

Assessment is a student report.

Note: Edit the gray boxes to specifically address the questions in your activity. See *Calculate the Z Mass* for an example of a good report.

TITLE (TEMPLATE FOR STUDENT REPORT SHEET)

STUDENT REPORT

Research question:

Reason:

Physics principles:

Hypothesis and reasoning:

Claim:

Evaluate the accuracy of your hypothesis as an answer to the research question.

Evidence:

2–3 pieces of evidence (data, observations, calculations) that support the claim

Questions to consider: How did we test the hypothesis? What data supports the claim?

Reasoning:

Justify how and why the evidence backs up the claim. Use scientific principles to explain ***why*** you got this data. Use and explain relevant scientific terms.

Questions to consider: Why does the data compel this claim? Is anything left out?

Sources of Uncertainty in Measurement:

Question to consider: Why and to what extent can we trust your results?

How much do results vary in calculation of the Z mass? Why? Are their outliers? Why?

Practical Applications:

Questions to consider: How might this information be useful to the ATLAS and/or CMS collaborations? To the future runs of the LHC?

What is the value of what you learned?

Now, write your formal scientific conclusion statement. Combine your ideas from the previous pages into two or three well-constructed paragraphs that include the research question, your hypothesis, your evaluation of the hypothesis providing claim, evidence and reasoning, possible sources of uncertainty specific to your data and practical applications for your discovery.

ARCS Action, Relevance, Confidence, Satisfaction

Review Protocol – Revised 5/15/17

Name of Activity ____

Teacher pages ____ Student Pages ____

Date of Review ________________________________

Review Status (e.g., 2nd review) ____

General Note: Including their own wording in the review helps make the point.

Is in line with the NGSS Framework

1 – Includes a question to address and/or problem to solve; could be developing a model to explain a phenomenon or test a model

Notes: Should be engaging/attention-getting (A in ARCS model). Sets the stage for what students will be doing. Should be on Teacher Pages somehow but crucial that it is at the start of the Student Pages.

2 – Students gather data and/or test solutions; provide claims, evidence and reasoning.

Notes: Students are asking a question, solving a problem or creating a model. For asking a question or solving a problem, CER is obvious. For creating a model they should be describing why/how it is a model and its' limitation.

3 – Students use Science and Engineering Practices (Framework p. 3)

Notes: These may agree or somewhat disagree with what the author says they are. I find authors over-sell what they address.

4 – Address Cross Cutting Concept(s) and Core Idea (Framework p. 3)

Notes: See above

Macro Design

1 – A 'big idea' (core idea) is addressed; sub-ideas support the big idea (can be concepts and/or principles)

Notes: A 'concept' is a human-made idea, usually a definition. A 'principle' is a law such as F=MA, or rule such ' I before e except after c.' QN authors most often miss this most important part of the designing an activity. This is related to but not always exactly the same as the Enduring Understanding. In science, this is most often a principle. Instructional design suggests a principle be taught using cause-effect or effect-cause analyses; concepts using examples and non-examples.

ARCS Action, Relevance, Confidence, Satisfaction

2 – Students apply science process skills and/or design technology
Notes: process skills are -–observe, contrast, evaluate, etc. Design technology is engineering so its: design, test, re-design, re-test…. These are usually addressed very well by QN authors but it's important to check. Also, an easy "very good" which is especially important if they don't do well in other categories.

3 – Format is guided inquiry
Notes: Awhile ago, most QN folks agreed that the accepted level for activities is 'guided inquiry; because the content is so advanced/complex. Now that there are '0' level activities, that might not be as important for those particular activities but should continue to be a guideline for other levels. Guided inquiry includes a lot of questions to guide understanding.

Micro Design
1 - There are behavioral objectives
Notes: Always a challenge. See below for what MJY sent to QN regarding developing objectives (easy five steps). Sometimes the biggest challenge is have authors address the objectives in their assessments,

If there is an objective, it should show up in the assessment.

2 – There are connections to the 'real-world' such as actual scientific exploration (modern physics) and/or skill that scientists use and/or promoting scientific literacy
Notes: Usually fairly well done. Is part of the 'R' in the ARCS model (relevance). When authors 'get into the weed' they frequently forget that not all students may think this is the greatest thing since sliced bread. Authors need to hang their enthusiasm on something real-world, which they know, but the students are unlikely to.

4 – Evaluation/assessment is based on whether or not the objectives are achieved; questions asked directly refer to the objectives (there are no distractions such as extraneous ideas)
Notes: "Write a report,' unless it is one of those developed for the activity that includes CER, will not suffice. Authors cannot be lazy about addressing the objectives. Also it is probably important to have something that addresses the EU as well. Especially for longer activities, look for formative evaluation that may include a discussion, completing a part of the report sheet for that activity, and/or reporting out.

OVERALL:
Notes: Consider which aspects of the activity are likely to lead to confidence and satisfaction ("C" and "S" of the ARCS model), Point out what was good, bad, ugly, beautiful… Let author know if you want to see it again.

ARCS Action, Relevance, Confidence, Satisfaction

Easy Five-Step Tutorial for Developing and Using Objectives:

1. What do you want teachers/students/participants to know and be able to do? (This step will be revisited as the assessment is developed, i.e., the assessment will determine the extent to which the participants have achieved the objectives.) Decide among objectives for content, skills, pedagogy (for teachers).
2. Determine which active/behavioral verb is best for assessing each behavior, which might include: explain, list, describe, interpret, compare, contrast, evaluate, predict, analyze, decide (NEVER 'understand'). Each objective must be measurable – in the assessment. If you have to ask yourself "how can I measure this?" you are on the wrong track. It should be obvious.
3. Look at your objectives to see if it isn't just a list of what you will do during the workshop. Example: look at the list of objectives for cosmic ray from Emanuel. If they are, think again—what do you actually want them to know and be able to do when they are finished with the workshop.
4. Pare objectives down to the essential four to six. You might have to think about the larger idea for some of them. Are they going to "develop a histogram" or "organize data"? But remember, again, these are what you will assess.
5. Figure out within the workshop and/or at the end how you will assess the extent to which the objectives have been achieved. It doesn't require a test but you might just have participants post how they have organized data, reported out their claims and provided evidence, listed crucial rules/principles, provided ideas for implementing in the classroom.

SHARE THE OBJECTIVES WITH PARTICIPANTS

As you continue to develop workshops and write activities, please remember to "start with the end in mind." Development comes ***after*** Step 1 (above).

QuarkNet Activity Review Narrative

March 8, 2019

Background

Jean Young, Instructional Designer, and Tom Jordan, Staff Coordinator, developed the activity templates. Jean oversaw activity review until Spring 2017 when the responsibility passed to Deborah Roudebush, Education Specialist. Jean trained Deborah in 2016. Included in the review and approval process were editors Marge Bardeen, PI, and LaMargo Gill. Jean, Marge, Deborah and Jeremy Smith, Education Specialist, developed a standard list of enduring understandings. Table 1 shows the status of the Data Activities Portfolio during 2016.

Table 1
Activity Review Status 2016

Activity	Review	#2 Review	Done	Posted
Calculate the Z Mass (T, S, R)	7/22/14	3/20/26		✓
Plotting LHC Discovery (T and S pages)	3/29/14	2/25/16	✓ 4/16	✓
Calculate the Top Quark Mass (T and S)	3/21/14	3/20/16		✓
Quark Workbench	3/20/14	3/15/16	✓	✓
Mass of U.S. Pennies (T notes, S handout)	3/10/14	2/25/16	✓	✓
Making it ‘Round the Bend (3 activities)	7/25/14	3/18/16		✓
Rolling with Rutherford (T notes)	3/10/14	2/25/16	✓ 4/16	✓
Dice, Histograms & Probability	3/19/15	4/27/16	✓	✓
Seismology				
Cosmic Muon Lifetime	8/2/16	10/11/16		
ATLAS Masterclass				
ALICE Masterclass				
CMS Masterclass				
LHCb Masterclass				
CMS Data Express *(Shift Report 8/2/16)*	7/21/14	3/15/16	✓ 4/16	✓
Cosmic Rays and the Sun (T notes)	3/17/15	2/25/16	✓	✓
TOTEM Data Express (T, S pages; report)	5/12/15	2/25/16	✓	✓
ATLAS Data Express	3/23/15	10/11/16	✓	✓
Cosmic Ray e-Lab				
LIGO e-Lab				
CMS e-Lab				

Activity Review 2017

In Spring 2017, Jean passed the review responsibilities to Deborah. Deborah focused the reviews and activity development on matching content to the template, uniformity of layout, language level for teachers with less content training, behavioral objectives and assessments directly tied to objectives. Deborah, Ken Cecire, Staff Teacher, and Shane Wood, Staff Teacher, agreed that the masterclass activities should be split since centers choose to study ATLAS Z-path, ATLAS W-path, CMS WZH-path or CMS J/Ψ-path. The team reviewed several activities again to better align them with the new guidelines.

Table 2
Activity Review Status 2017

Activity	Posted
CMS Data Express	8/17
Plotting LHC Discovery	8/17
Calculate the Top Quark Mass (T and S)	8/17
Quark Workbench	8/17
Calculate Z Mass	9/17
ATLAS Z-path Masterclass	11/17
Mass of U.S. Penny	11/17
CMS ZWH-path Masterclass	12/17

Ken, Shane and Deborah decided we could facilitate teacher usage by identifying pathways or a series of activities that follow a theme. While these pathways were a desirable goal, it became clear that there were many gaps in the skills students needed to use higher-level activities. This led to the development of new activities.

The team documented the meaning of activity levels, the list of enduring understandings, and the pathway guidance. They posted these documents in the Data Activities Portfolio in the introductory paragraphs of the webpage.

Activity Review 2018

The focus in 2018 for Deborah, Ken and Shane was on finishing the review of the previously posted activities and filling in the gaps for improved pathway guidance. The team brainstormed methods of making the pathways more accessible for teachers as well as easier to edit and maintain. Deborah worked with Joel Griffith, IT Staff, to design a modification to the Data Activities Portfolio pages to allow teachers to use a pull-down menu of topics to select a pathway. The target for completion of this feature is Summer 2019.

Table 3 lists the activities posted in 2018.

Table 3
Activity Review Status 2018

Activity	Posted
ATLAS W-path Masterclass	1/18
CMS J/Ψ	2/18
Shuffling the Particle Deck	2/18
Making It ‘Round the Bend: Qualitative*	4/18
Making It ‘Round the Bend: Quantitative*	5/18
Mapping the Poles	6/18
Signal and Noise: The Basics	6/18
Quark Workbench 2D/3D**	8/18
Signal and Noise: Cosmic Muons	9/18
Mean Lifetime Part 2: Cosmic Muons***	9/18

*Jeff Rodriguez, University of Cincinnati QuarkNet Center, developed the simulation that made these activities possible.

**Lachlan McGinness is an Australian physics teacher and visiting fellow at the Australian National University. He created the 3D puzzle activity while appointed as Teacher in Residence at CERN in 2018.

***Originally posted as Cosmic Mean Lifetime.

Activity Review 2019

The focus in 2019 for Deborah, Ken and Shane is on developing neutrino activities to support a neutrino strand and neutrino pathways. There are still five posted activities that have not undergone full review. Deborah continues to work with Joel to design a modification to the Data Activities Portfolio pages to allow teachers to use a pull-down menu of topics to select a pathway. The target for completion of this feature is Summer 2019.

Table 4 lists the activities under review in 2019.

Table 4
Activity Review Status 2019

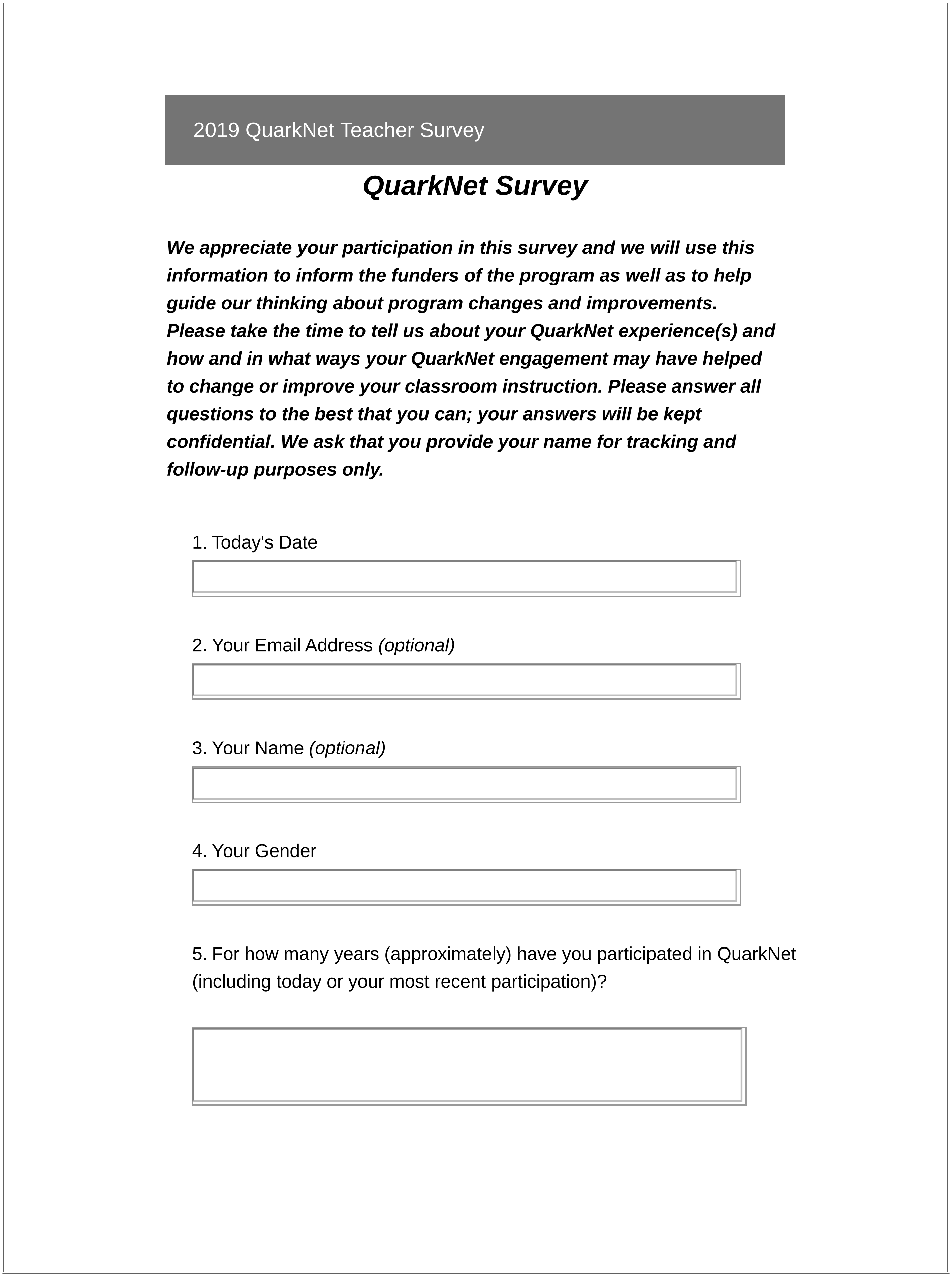
Activity	Posted
ALICE Masterclass	
LHCb Masterclass	
Cosmic Rays and the Sun	
Cosmic Ray e-Lab	
CMS e-Lab	

Table 5 contains a list of activities currently under development. These activities are primarily to support a neutrino strand as well as strands for special relativity and uncertainty. The staff is developing a draft Level 4 activity to test with teachers and students.

Table 5
Activities Under Development 2019

Activity	Posted
Mean Lifetime Part 3: MINERvA	
Feynman Diagrams	
To Catch a Speeding Muon	
Neutrino Hide & Seek (a reworked Calculate Top Quark Mass)	
Special Relativity Holds the Answers	

Appendix F



2019 QuarkNet Teacher Survey

QuarkNet Survey

We appreciate your participation in this survey and we will use this information to inform the funders of the program as well as to help guide our thinking about program changes and improvements. Please take the time to tell us about your QuarkNet experience(s) and how and in what ways your QuarkNet engagement may have helped to change or improve your classroom instruction. Please answer all questions to the best that you can; your answers will be kept confidential. We ask that you provide your name for tracking and follow-up purposes only.

1. Today's Date

2. Your Email Address *(optional)*

3. Your Name *(optional)*

4. Your Gender

5. For how many years (approximately) have you participated in QuarkNet (including today or your most recent participation)?

Only the title of the survey has changed from one program year to the next.

6. What is the name/brief description of the QuarkNet program/workshop that you participated in today (or most recently)?

7. What is the name of the QuarkNet center (university/institution) where you have participated?

8. What is the name of the school (or district) where you teach?

9. What best describes the location of your school?

○ Rural ○ Urban, central city ○ Urban ○ Suburban

10. For how many years have you been at this school?

11. How many years have you been teaching?

12. Do you teach physics?

○ Yes ○ No

13. *If yes, please specify year (e.g., 9th, 10th) and whether General or Conceptual, AP, Honors.*

14. Can we contact you for a follow-up interview to talk with you about your approach to teaching?

○ Yes ○ No

○ Other (please specify)

Your Participation in QuarkNet Workshops/Programs

15. Which QuarkNet Workshops or Programs have you participated in? *(Check all that apply. If not on the list, please provide a brief description.)*

☐ Data Camp

☐ ATLAS Data Workshop

☐ CMS Data Workshop

☐ CMS e-Lab Workshop

☐ Cosmic Ray e-Lab Intro Workshop

☐ Cosmic Ray e-Lab Advanced Topics Workshop

☐ Neutrino Data Workshop

☐ ATLAS Masterclass

☐ CMS Masterclass

☐ Neutrino Masterclass

☐ CERN Summer Program

☐ W2D2

☐ International Cosmic Day

☐ International Muon Week

☐ Other (please specify)

16. Of these, which do you think have been most helpful to you in your teaching? *Please briefly describe why.*

Your Use of the Data Activities Portfolio

The Data Activities Portfolio is QuarkNet's online compendium of instructional materials and suggested instructional pathways.

17. Have you used any of the activities in the Data Activities Portfolio in your classroom?

○ Yes ○ No

18. Please give us an example(s) of which of these activities in the Data Activities Portfolio you have used most often and/or that you think have been most helpful in teaching physics related to content and/or pedagogy.

19. Would you recommend (or have you recommended) the Data Activities Portfolio to other high school physics or physical science teachers?

○ Yes ○ No

20. Please tell us why you would or would not recommend instructional materials in the Data Activities Portfolio.

Your Assessment of QuarkNet

Please rate the following strategies based on your current QuarkNet program experience and, if applicable, on your previous involvement in QuarkNet programs to date. If you have participated in QuarkNet for many years, please respond based on what you think the cumulative effect of this participation has been over the past two years.

21. QuarkNet provides opportunities for me to:

	Poor	Fair	Average	Good	Excellent	N/A
a. Engage as an active learner, as a student.	○	○	○	○	○	○
b. Do science the way scientists do science.	○	○	○	○	○	○
c. Engage in authentic particle physics investigations (that may or may not involve phenomenon known by scientists).	○	○	○	○	○	○
d. Engage in authentic data analysis experiment(s) using large data sets.	○	○	○	○	○	○
e. Develop explanations of particle physics content.	○	○	○	○	○	○
f. Discuss the concept of uncertainty in particle physics.	○	○	○	○	○	○

22. QuarkNet provides opportunities for me to:

	Poor	Fair	Average	Good	Excellent	N/A
a. Engage in project-based learning that models guided-inquiry strategies.	○	○	○	○	○	○
b. Share ideas related to content and pedagogy.	○	○	○	○	○	○
c. Review and select particle physics examples from the Data Activities Portfolio instructional materials.	○	○	○	○	○	○
d. Use the pathways, suggested in the Data Activities Portfolio, to help design classroom instructional plan(s).	○	○	○	○	○	○
e. Construct classroom implementation plan(s), incorporating experience(s) and Data Activities Portfolio instructional materials.	○	○	○	○	○	○
f. Become aware of resources beyond my classroom.	○	○	○	○	○	○

23. Please use the space below to tell us anything you would like us to know regarding your ratings of the strategies mentioned above.

2019 QuarkNet Teacher Survey

Your Assessment of QuarkNet (con't.)

Please rate the following big-picture strategies based on your current QuarkNet experience and, if applicable, on your previous involvement in QuarkNet programs to date. If you have participated in QuarkNet for many years, please respond based on what you think the cumulative effect of this participation has been over the past two years.

24. QuarkNet provides opportunities for me to be exposed to:

	Poor	Fair	Average	Good	Excellent	N/A
a. Instructional strategies that model active, guided-inquiry learning (related to NGSS science and engineering practices).	○	○	○	○	○	○
b. Big Idea(s) in Science (cutting-edge research) and Enduring Understandings (in particle physics).	○	○	○	○	○	○

25. Provide opportunities for teachers and mentors to:

	Poor	Fair	Average	Good	Excellent	N/A
a. Interact with other scientists and collaborate with each other.	○	○	○	○	○	○
b. Build a local (or regional) learning community.	○	○	○	○	○	○

26. Please use the space below to tell us anything you would like us to know regarding your ratings of the big-picture strategies mentioned above.

Your Assessment of QuarkNet (con't.)

The next set of questions will ask about classroom instruction and QuarkNet's influence.

27. In thinking about your approach to teaching, please rate the frequency in which you engage in each of the following in your classroom.

	Almost Always	Very Often	Sometimes	Not Very Often	Rarely	N/A
a. Discuss and explain concepts in particle physics.	○	○	○	○	○	○
b. Engage in scientific practices and discourse.	○	○	○	○	○	○
c. Use particle physics examples, including authentic data, when teaching subjects such as momentum and energy.	○	○	○	○	○	○
d. Review and use instructional materials from the Data Activities Portfolio.	○	○	○	○	○	○
e. Selecting these lessons guided by the suggested pathways.	○	○	○	○	○	○
f. Facilitate student investigations that incorporate scientific practices.	○	○	○	○	○	○

28. Now, indicate the degree to which you think QuarkNet has contributed to your implementation of these instructional strategies in your classroom.

	Very High	High	Moderate	Low	Very Low	N/A
a. Discuss and explain concepts in particle physics.	○	○	○	○	○	○
b. Engage in scientific practices and discourse.	○	○	○	○	○	○
c. Use particle physics examples, including authentic data, when teaching subjects such as momentum and energy.	○	○	○	○	○	○
d. Review and use instructional materials from the Data Activities Portfolio.	○	○	○	○	○	○
e. Selecting these lessons guided by the suggested pathways.	○	○	○	○	○	○
f. Facilitate student investigations that incorporate scientific practices.	○	○	○	○	○	○

29. In thinking about your approach to teaching, please rate the frequency in which you engage in each of the following in your classroom.

	Almost Always	Very Often	Sometimes	Not Very Often	Rarely	N/A
a. Use active, guided-inquiry instructional practices that align with science practice standards (NGSS and other standards).	○	○	○	○	○	○
b. Use instructional practices that model scientific research.	○	○	○	○	○	○
c. Ilustrate how scientists make discoveries.	○	○	○	○	○	○
d. Demonstrate how to use, analyze and intepret authentic data.	○	○	○	○	○	○
e. Demonstrate how to draw conclusions based on these data.	○	○	○	○	○	○
f. Become more comfortable teaching inquiry-based science.	○	○	○	○	○	○

30. Now, indicate the degree to which you think QuarkNet has contributed to your implementation of these instructional strategies in your classroom.

	Very High	High	Moderate	Low	Very Low	N/A
a. Use active, guided-inquiry instructional practices that align with science practice standards (NGSS and other standards).	○	○	○	○	○	○
b. Use instructional practices that model scientific research.	○	○	○	○	○	○
c. Illustrate how scientists make discoveries.	○	○	○	○	○	○
d. Demonstrate how to use, analyze and interpret authentic data.	○	○	○	○	○	○
e. Demonstrate how to draw conclusions based on these data.	○	○	○	○	○	○
f. Become more comfortable teaching inquiry-based science.	○	○	○	○	○	○

Your Assessment of QuarkNet (con't.)

31. Please respond to the following statements.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
a. I use resources (including QuarkNet resources) to supplement my knowledge and instructional materials and practices.	○	○	○	○	○
b. I have increased my science proficiency.	○	○	○	○	○
c. I have developed collegial relationships with scientists and other teachers.	○	○	○	○	○
d. I think my students have become more comfortable with inquiry-based science.	○	○	○	○	○

Your Assessment of QuarkNet (con’t.)

This last set of questions asks about your students' classroom engagement and how QuarkNet may have influenced (through your participation and/or your students) this engagement. In your judgment, please indicate ...

32. My students are able to:

	Almost Always	Very Often	Sometimes	Not Very Often	Rarely	N/A
a. Discuss and explain concepts in particle physics.	○	○	○	○	○	○
b. Discuss and explain how scientists develop knowledge.	○	○	○	○	○	○
c. Engage in scientific practices and discourse.	○	○	○	○	○	○
d. Use, analyze and interpret authentic data.	○	○	○	○	○	○
e. Draw conclusions based on these data.	○	○	○	○	○	○

33. Now, indicate the degree to which QuarkNet (either because of your participation and/or theirs) has contributed to your students' engagement. QuarkNet has helped my students to:

	Very High	High	Moderate	Low	Very Low	N/A
a. Discuss and explain concepts in particle physics.	○	○	○	○	○	○
b. Discuss and explain how scientists develop knowledge.	○	○	○	○	○	○
c. Engage in scientific practices and discourse.	○	○	○	○	○	○
d. Use, analyze and interpret authentic data.	○	○	○	○	○	○
e. Draw conclusions based on these data.	○	○	○	○	○	○

34. Please use the space below for anything else you would like us to know about your QuarkNet experience or your approach to teaching science in your classroom. *Thank you for your participation. We appreciate it!*

UPDATE: QuarkNet Teacher Survey

IMPORTANT. ***Please complete this UPDATE only if you have completed the 2019 QuarkNet Teacher Survey, which you should complete only once. Please answer all questions (a total of 10) to the best that you can; your answers will be kept confidential. We ask that you provide your name for tracking and follow-up purposes only. Thank you for your participation, we appreciate it!***

1. Today's Date

2. Your E-mail Address (Optional)

3. Your Name (Optional but very helpful to know)

4. What is the name of the QuarkNet Center where you have participated today (or most recently)?

UPDATE: QuarkNet Teacher Survey

The next set of questions asks about how you intend to use (or have used) QuarkNet content and materials as a teacher in your classroom.

5. 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.

6. Using QuarkNet content and materials in my classroom, when teaching physics (or related science) I am able to: (*Check all that applies*.)

	Almost Always	Very Often	Sometimes	Not Very Often	Rarely	N/A
a. Discuss and explain concepts in particle physics.	○	○	○	○	○	○
b. Engage in scientific practices and discourse.	○	○	○	○	○	○
c. Use particle physics examples, including authentic data, when teaching subjects such as momentum and energy.	○	○	○	○	○	○
d. Review and use instructional materials from the Data Activities Portfolio (DAP).	○	○	○	○	○	○
e. Select (DAP) lessons guided by suggested sequencing.	○	○	○	○	○	○
f. Faciliate student investigations that incorporate scientific practices.	○	○	○	○	○	○

7. *To Continue*: Using QuarkNet content and materials in my classroom, when teaching physics (or related science) **I** am able to: (*Check all that applies.)*

	Almost Always	Very Often	Sometimes	Not Very Often	Rarely	N/A
g. Use active, guided-inquiry instructional practices that align with science practice standards (NGSS and other standards).	○	○	○	○	○	○
h. Use instructional practices that model scientific research.	○	○	○	○	○	○
i. Illustrate how scientists make discoveries.	○	○	○	○	○	○
j. Demonstrate how to use, analyze and interpret authentic data.	○	○	○	○	○	○
k. Demonstrate how to draw conclusions based on these data.	○	○	○	○	○	○
l. Become more comfortable teaching inquiry-based science.	○	○	○	○	○	○

Other (please specify)

The last set of questions asks about the use of activities from the Data Activities Portfolio, your perceptions about student engagement, and final thoughts.

8. 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.)*

9. Using QuarkNet content and/or materials, which of these behaviors do you think your **students** will be able to do (or are able to do) in your classroom? *(Check all that applies.)*

	Almost Always	Very Often	Sometimes	Not Very Often	Rarely	N/A
a. Discuss and explain concepts in particle physics.	○	○	○	○	○	○
b. Discuss and explain how scientists develop knowledge.	○	○	○	○	○	○
c. Engage in scientific practices and discourse.	○	○	○	○	○	○
d. Use, analyze and interpret authentic data.	○	○	○	○	○	○
e. Draw conclusions based on these data.	○	○	○	○	○	○

Other (please specify)

10. What else would you like to tell us about your QuarkNet experience as you reflect on applications in your classroom?

QuarkNet Center Feedback

Your help is important. Please respond to this information request based on your current QuarkNet program experience and, if applicable, on your previous involvement in QuarkNet programs at your Center. If your Center has participated in QuarkNet for many years, please respond based on what you think the cumulative effect of this participation has been over the ***past two years****. We will ask you to complete this form only once. We can help clarify something if needed and we can aid in helping you complete this form if necessary.*

We are asking that this form be completed only once. With help from QuarkNet staff and the evaluator, we are asking for a conference call with person(s) at your center most familiar with these program efforts, such as the mentor(s), fellows and/or lead teachers in order to complete the requested information. Section I asks for information about you, your Center and who is completing this form and for what time period. Section II asks to specify what QuarkNet events your Center has participated in; we have started this process by including engagement information based on agendas from previous workshops and past annual reports that your Center has posted on the QuarkNet website. Section III asks for a reflection on outcomes; and Section IV asks about effective practices that align with the sustainability of the program. (Use an additional page for any comments you may have.) If you have any questions, please email Kathryn Race at race_associates@msn.com.

I. **Center Information**: *Please provide information about the Center and who is completing this form.*

Date:

Which Center? (*please specify name and location of center*):

Who completed this form? (*Please indicate all individuals who helped to complete this form):*

What time period is covered by these observations? (*e.g., 2017-2018; 2018-2019*):

How many years (approximately) has your Center participated in QuarkNet?

II. **QuarkNet Program Activities**: *Please indicate which of the following QuarkNet programs have been implemented at your Center in the past two years, based on your Center's typical engagement in this program. (Check all that apply).*

Check, if yes ✔	*QuarkNet Program Component*	*Held during the summer (✔ or indicate dates)*	*Held during the calendar year (✔ or indicate program year)*	*Other (please specify)*
	National Workshop (facilitated by national program staff or fellows) Workshop list at https://quarknet.org/page/summer-workshop-opportunities-quarknet-centers			
	Center-run Workshop (facilitated by center with center-focused topics/interests)			
	Data Camp:			
	1. Center-level teacher(s) participates at Fermilab			
	2. Teacher(s) introduces activity/methods at Center (based on Data Camp experience)			
	Data Activities Portfolio: Activities at https://quarknet.org/data-portfolio			
	1. Work through and reflect on activity/ities (in the portfolio) at the center.			
	2. Present/discuss examples of classroom implementations based on these activities			
	Masterclass(es): Held one or more at center			
	Cosmic Ray Detector *(e.g., assemble, calibrate)*			
	Other *(please specify any other center-led or center-wide event)*			

QuarkNet Websites: https://quarknet.org/; https://quarknet.org/page/summer-workshop-opportunities-quarknet-centers;
https://quarknet.org/data-portfolio

III. **Center-level Outcomes**: *Please indicate which of the following QuarkNet program outcomes have been evident, by whom and the degree of QuarkNet's influence at your Center in the past two years. (Check all that apply.)*

Center-level Outcomes	Who?						QuarkNet's Influence?					
	Almost All	Most	Some	A Few	Rarely	Don't Know	Very High	High	Moderate	Low	Very Low	Does Not Apply
Engage Teachers as Active Learners, as Students (across workshops/events)												
During National/Center-run Workshops or Programs, Teachers Experience Active, Guided-inquiry Instruction through:												
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. Construct explanations and designing solutions.												
7. Engaging in argument from evidence.												
8. Obtaining, evaluating, and communicating information.												
Networking/Community Building:												
1. Teachers engage/interact with mentors and other scientists.												
2. Teachers engage/interact with other teachers.												
Teachers as Leaders:												
1. Provide leadership at local centers.												
2. Attend and/or participate in regional and national professional conferences sharing their ideas and experiences.												
Teachers and Mentors: Form lasting collegial relationships through interactions and collaborations at the local level and through engagement with the national program.												
Mentors: Become the nexus of a community that can improve their teaching, enrich their research and provide broader impacts for their university.												

Figure 5. Section III of the Center Feedback Template.

IV. **Center-level Success Factors:** *Please view the center's QuarkNet engagement through the lens of the Success Factors related to effective practices as described below.*

Effective Practices/Success Factors[a]	Meets Criteria?				Comments: Please use this space (and additional space if needed) to explain your ratings or to indicate action that may need to occur.
	Yes	Yes, but[1]	No	Unsure	
1. *Program provides opportunities for a* ***strong teacher leader****.* (Teacher provides leadership in areas of content and/or is a technical expert; models exemplary pedagogical skills; able to provide organizational skills. These characteristics may be present in one or a team of teacher leaders.)					
2. *Program provides opportunities for a* ***strong mentor****.* (Mentor provides leadership skills mainly of content and/or technical expertise; understands education and professional development -- working with teacher leaders as needed; models research.)					
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.)					
4. *Meaningful activities* (The standard for meaningful activities is focusing topics in modern physics, discussing how to implement this content in classrooms, conducting research and discussing scientific inquiry methods; using Data Activities Portfolio instructional materials.)					
5. *Directly addresses classroom implementation of instructional materials for all teachers.* (Time for teachers to discuss Data Activities Portfolio instructional materials and pathways; to consider NGSS, AP, IB or other science standards; presentation(s) from veteran teachers on classroom implementation experiences or similar engagement.)					
6. Program is able to provide regular contact and support with teachers. (Specific support and or follow up from staff; staff teachers are available and/or volunteers who support teachers, especially related to classroom implementation.)					
7. Money for additional activities or additional grants. (Seeking additional funding to fulfill the mission/objectives of the center; providing supplemental or complementary support for QuarkNet e.g., providing transportation, lodging, buying equipment; providing food.)					
8. Stable participant base.(A stable participant base can provide an expert group that can help other teachers, support outreach, and provide organizational leadership.)					
9. Addresses teacher professionalism. (The standard is to provide opportunities for at least a few teachers to attend professional meetings; support teachers taking leadership roles in their school, school districts, outreach, and highlight PD opportunities for continuing development.)					
10. Establish a learning community. (The standard is forming a cohesive group where teachers learn from one another; engage with mentors and other scientists; provide outreach to other teachers.)					

[a] This section of the protocol has been adapted from M.J. Young & Associates (2017, September). *QuarkNet: Matrix of Effective Practices.*

[1] Needs work or fine tuning; or, there are notable caveats.

Please use an additional page for any comments you may have. Thank you for your participation.

QuarkNet and COVID-19
May 1, 2020

Introduction: The COVID-19 crisis has profoundly affected QuarkNet and our teachers. Summer workshops at centers and other opportunities have been cast in doubt, re-imagined, or postponed. Almost all of our teachers have had to cope with a shift to online remote teaching. Quickly, staff realized that it would be important to maintain contact and support our teachers. Working from home, as the teachers and their students are, staff adjusted and created offerings to help teachers engage students with meaningful learning in physics. This report shows what we have done and how.

Before addressing the issues and initiatives related to the crisis, we note that the staff has maintained contact with one another and continued routine aspects of QuarkNet. Tuesday staff conferences and Wednesday technical conferences which are conducted remotely continue unabated. The weekly newsletter, the *Friday Flyer*, continues and has, if anything, taken on a stronger role to connect QuarkNet members. Staff continue to field questions from and check in with mentors and teachers. Next week, staff will contact all mentors to get updates on summer plans in light of the crisis and offer support. Staff still meet remotely with fellows—perhaps more than ever. For example, the monthly LHC and Neutrino Fellows monthly videoconference has become weekly so that Ken Cecire and Shane Wood can consult with them on the initiatives below. With the whole group mostly limited to home, it has become their virtual “night out.”

Support for Teachers: As schools moved to remote online learning in March, staff realized that teachers were entering a new world and needed support. Staff built and continue to support online resources to assist teachers in remote teaching and maintaining their access to QuarkNet content and practices:

- Resources for Physics Teaching Online. This page has resources on remote online learning, physics simulations and online lessons, and more. We have propagated it outside QuarkNet; as of May 1, teachers have accessed it over 900 times.
- QuarkNet Zoom Channels for Videoconferencing. We opened six Zoom channels on the Notre Dame Zoom account for QuarkNet teachers who might not otherwise have a robust way to communicate with students or colleagues.
- Resources for Cosmic Ray Analyses Online. Using the Cosmic Ray e-Lab, teachers can engage students remotely in physics research projects with data from QuarkNet cosmic ray detectors. This “how to” guide includes instructions and pre-selected useful data files.
- Using the CMS e-Lab. Using the CMS e-Lab, teachers can engage students remotely in physics research projects with data from CERN’s Large Hadron Collider. This “how to” guide includes instructions and suggestions for meaningful studies.
- Comments on Adapting Data Activities to Teaching Online. Staff and LHC fellow Jeremy Wegner added comments to the Data Activities Portfolio to explain how students can engage in 16 different data activities at home in collaboration with teachers and often peers. To see such comments, one must log into the QuarkNet website. This page was added to make these comments available to all teachers, logged in or not. Mr. Wegner also contributed a Visual Python simulation online so the popular Rolling with Rutherford activity could be included.

Staff adapted the weekly QuarkNet newsletter, the *Friday Flyer (FF)*, for the current crisis. While the sections are familiar, much of the content shifted to making teachers aware of the support and new activities that have become available. *FF* has kept up with particle physics news, opportunities for teachers, and even a little humor throughout the crisis while being a conveyor of information QuarkNet teachers need. (Read the May 1 issue.)

Staff announced another project for teachers and students on May 1: the QuarkNet Wednesday Webinars (QW2). Experts will give webinars on particle physics-related topics between May 6 and June 10. Teachers and students will connect from home to learn new things about particle and contemporary physics. Like all of the Zoom webinars mentioned above, these will be recorded to widen their usefulness.

Cosmic Ray Studies: With many cosmic ray detectors inaccessible while teachers and students work from home, the total number of cosmic ray data file uploads is down. The number of cosmic ray analyses on the e-Lab, however, has increased as several teachers have challenged their students to perform measurements with existing data. Staff created a page containing resources for cosmic ray analyses online (see section above) to support teachers and students during this time of distance learning. Additionally, a few detectors continue to upload data. A staff member moved one of the detectors at Fermilab to his home in order to provide an updated standard data set for the e-Lab.

Masterclasses: International Masterclasses (IMC) run each year in and around March; they were just starting as the COVID-19 crisis set in. Masterclasses began to shut down and by March 18, further IMC videoconferences were canceled, effectively ending IMC 2020. One of the last masterclasses in the U.S. was done remotely by LHC fellow Jeremy Wegner and his students in rural Indiana. A few other groups also attempted remote masterclasses with varying success.

QuarkNet took the next step modifying the current CMS masterclass for remote learning. The simplified measurement focuses on muon tracks, and new online support enabled students to learn what to do via four screencasts and to complete the measurement with some coaching from their teachers. The result was a new remote learning masterclass, the Big Analysis of Muons in CMS (BAMC). Staff built a support infrastructure with student and teacher pages on the QuarkNet website, Zoom Q&A sessions for teachers, an April 15 webinar talk on the Standard Model and CMS by a Kansas State University particle physicist, ample tables for recording results online in the CMS Instrument for Masterclass Analysis (CIMA), and an April 17 webinar to discuss the data with three particle physicists. About 180 teachers and students attended each of the webinars and an estimated 240 students analyzed over 11,000 CMS events, one-by-one in the iSpy event display. BAMC provided a robust stress test for CIMA (which it passed), an opportunity for teachers to do a meaningful remote project with their students, and the chance for hundreds of students to be “particle physicists for a day” at home. Along the way, Staff developed capacities with webinars and designing remote learning experiences. And it all worked very well, with ample compliments from teachers and students.

With the success of BAMC in April, staff has started another session for May, opening this session up to more international participation. There are still details to sort, but the masterclass talk will take place on May 19 with the videoconference to follow later that same week.

Fellows Workshop: Meetings of QuarkNet fellows are vital to their development and foster communication among the groups. These meetings have maintained the coherence of their work. Staff had planned an in-person workshop for fellows who present our national workshops for May 15-17 at Fermilab. Now, staff is planning a virtual workshop. The primary goal is to enable select fellows to create remote online workshops that will be offered to teachers through our centers in Summer 2020. The fellows virtual meeting will also provide the opportunity to share ideas among groups of fellows and continue the focus on research-based best practices in offering professional development.

Data Camp: Each year, Data Camp brings 24 teachers from around the country to Fermilab for a week-long, multi-faceted workshop that includes tours, talks, particle physics data analyses, and the exploration of data activities to bring back to the classroom. This “classic” Data Camp will not be offered in 2020; instead, the Teaching and Learning Fellows will conduct a virtual/remote workshop that emphasizes the use of coding skills as they pertain to physics in general and particle physics in particular. Another goal of this virtual workshop, still under development, is to give teachers some comfort and confidence that, if remote learning is continued in the fall, they will have the skills and resources to implement something interesting, challenging, and useful with their students.

Summer 2020 Workshops at Centers: Summer workshops at many centers are among the QuarkNet highlights for teachers, mentors and staff. These meetings are the primary pathway to offer teachers at QuarkNet centers opportunities to develop professionally, build community, learn new physics, and improve their teaching. At this point, there is much uncertainty regarding these workshops. Staff, mentors, and lead teachers are discussing possibilities, which so far include:

- Rescheduling the workshop for late summer and/or fall in hopes that face-to-face meetings will be possible then.
- Offering a virtual workshop, in which centers would meet for at least a portion of their workshop time remotely.
- Cancelling the 2020 workshop, with a plan to meet again in 2021.
- Other creative solutions.

Staff is working with fellows to re-tool some of our national workshops in order to offer them remotely. Virtual summer meetings could also allow teachers to share successful strategies and tools with each other for teaching in a virtual setting, as the possibility of teaching this way may extend into the next academic year for at least some teachers.

STEP UP: In 2019, QuarkNet began a partnership with STEP UP, a program that supports teachers to encourage more women and minorities to pursue physics as a career. As part of this partnership, nine QuarkNet leaders, including staff, educational specialists, fellows and teachers, attended the 2019 STEP UP Summer Institute to become ambassadors for the program. Deborah Roudebush, QuarkNet Educational Specialist and STEP UP ambassador, has taken the lead in coordinating work that is beneficial to both organizations. As part of this work, several STEP UP classroom activities have been edited to fit our format. Soon, we will post these activities in the Data Activities Portfolio. The 2020 STEP UP Summer Institute will be virtual, and Deborah is helping STEP UP leaders plan for this event. Several QuarkNet STEP UP ambassadors from 2019 plan to attend the 2020 institute as well. In addition, Deborah and the staff are coordinating QuarkNet STEP UP ambassador efforts to arrange virtual STEP UP workshops open to all QuarkNet teachers.

IT Infrastructure: Support for remote teaching and learning and carrying out new initiatives online only work if the IT infrastructure is strong. Fortunately, QuarkNet has been in a very good position in this regard. The QuarkNet servers at Notre Dame were not significantly affected by the COVID-19 crisis. IT staff was already working remotely, and Notre Dame has provided ongoing support. ND Studios assisted the staff in setting up webinars and exploring the capabilities of Zoom. The IT staff continues to work on development and maintenance of QuarkNet resources such as e-Labs and masterclass tools. One area of concern in International Masterclasses was the response of the CMS Instrument for Masterclass Analysis (CIMA) to large numbers of students; this eased when IMC 2020 was canceled and gave IT staff time to fix problems. The first BAMC masterclass in April served as a stress test for CIMA: it passed and the few non-critical issues that remained were identified. The current situation did delay the installation of new QuarkNet servers to improve capacity and performance. As the old servers are still working well, this has not been a problem.

Evaluation: Given that many centers do not have plans for the summer yet, we were able to reach out to more than the planned centers to obtain information about center-level outcomes and sustainability factors. We contacted a total of ten centers, with all but two either completing or in the process of completing this. The unexpected effect of these conversations, especially for the six centers we have recently contacted, have been reflections on how each center might incorporate virtual workshops or other outreach to their teachers as necessary now and in the future

Going forward, evaluation plans will include possibly “observing” virtual workshops, attending some in person events if this becomes possible; and urging workshop participants to complete the new abbreviated (short ten questions) Teacher Survey. The external evaluator also plans on incorporating implementation plans as part of the evaluation effort as well as the new information we glean from the short Teacher Survey. If we are forced to engage in virtual workshops as the usual means of implementing workshops, then she would like to work with staff to glean how and what formative evaluation efforts would be helpful for them.