QuarkNet

Evaluation of the QuarkNet Program: Evaluation Report 2018-2019

Prepared by:

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

Prepared for:

National Science Foundation
and
The QuarkNet Collaboration

July 2019

Race & Associates, Ltd.
Supporting Data-driven Decisions™

Evaluation of the QuarkNet Program: Evaluation Report 2018-2019 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).

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 in final form as an interim report). 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; and, 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.

Going forward a distinct difference between this and future evaluation reports will be the inclusion of actual evaluation results drawn from the Program Theory Model and based on the evaluation plan relative to teachers, centers and sustainability. Nevertheless, portions of this report may be presented again as a consistent reminder of the basis in which evaluation decisions and interpretations stem.

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. In this report, we have briefly highlighted the planned method to assess program outcomes through these measures directed toward teachers, centers, and the sustainability of the program and to link this information to program-operations data. We plan on analyzing results from teacher-level responses nested by centers (when feasible); and on linking program participation-level data to program outcomes and other data sources such as implementation plans and teacher interviews, when feasible. We also propose drawing on data from past evaluation efforts when relevant.

Program Recommendations

The following program recommendations are proffered:

1. The program has had a long standing practice of holding regularly-scheduled staff meetings. These tend to be topic/task specific meetings involving those most involved with that aspect of the program and tend to be held weekly. Continue to use this meeting structure to the extent that it is helpful. Include the evaluator in these discussions when meaningful and reasonable. Consider less frequent but periodic program-wide meetings to inform stakeholders across tasks and responsibilities to communicate across the program.
2. Continue to improve program documentation efforts and use it to inform other program staff and stakeholders as well as those external to the program.

3. 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.
4. Support efforts to gather program information contained in the program-operation databases including inputs from teachers, mentors, and program staff.
5. Continue to be mindful that QuarkNet is "first and foremost, a teacher professional development program."
6. Continue to maximize the use of Data Portfolio Activities[a] by teachers at center-led and QuarkNet-led workshops and meetings.
7. Continue to engage in reflective thinking on ways to help teachers integrate their QuarkNet experiences and instructional practices into their classrooms.
8. Support the development by teachers of implementation plans and the subsequent use of these plans in the classroom when feasible.
9. Continue to support the evaluation and its efforts as reasonable. Work with the evaluator, as planned, to help embed evaluation efforts and requirements within the structure and delivery of the program.

Evaluation Recommendations

The following evaluation recommendations are proffered:

1. Review and reflect on feedback from QuarkNet program staff on how the Program Theory Model (PTM) can be improved or changed to help improve its representativeness (as an "approximate fit") of the program and its Theory of Change.
2. Work with program staff to help articulate ways in which the PTM can be used and how to facilitate this use.
3. Help articulate the difference between program theory and program implementation and why this is important.
4. Implement the new, proposed evaluation plan to coincide with the 2019-2020 QuarkNet program year.
5. Review the PTM and evaluation measures to assure that implemented evaluation measures align with the PTM as planned.
6. Help program staff transition from past evaluation efforts that combined formative and summative efforts to an outcomes-based evaluation.
7. 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.
8. Work with program staff to help ensure that program-operations data are collected in a timely manner and with high compliance.
9. Work with QuarkNet program staff to distribute the Teacher Survey and implement the Center Feedback template.
10. Work to ensure that evaluation efforts and results are of value (or of potential value) to all those involved in the process.

[a]The Data Activities Portfolio is a vibrant, on-line compendium of classroom lessons that can be adapted at four distinct levels of student skill-sets; lessons that align with current scientific thinking; and instructional practices aligned with NGSS standards; and, modified based on teacher feedback.

Evaluation of the QuarkNet Program: Evaluation Report 2018-2019

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).

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).

The QuarkNet program is not static but has reflected 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 its 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 catchment area. In addition to these centers, there is the Virtual Center, which provides a home for teachers who no longer 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). (See Appendix A for a list of 2018-2019 centers.)

During this award period, a center is considered "active" if it provides at least one day of teacher development and "semi-active" if the center and its teachers participate in only International Materclasses, 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).

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

[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.

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

The QuarkNet program is not new but the external evaluator is. Accordingly we have proposed a new direction with this evaluation focused on the following: (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 sustain-ability of program centers, based on center-level and sustainability outcomes. Existing and new evaluation measures, based on the PTM, have been modified and/or created; and, will be used to assess program outcomes and program-center sustainability; supported by program-operations data obtained from teacher- and center-level databases. We will also draw on data from past evaluation efforts when relevant.

Why Develop a Program Theory Model?

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 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 may help to underscore the sustainability of participating centers.

We see the following benefits and uses derived by creating a program theory model:

- The program is articulated in a representative way reflecting its integrated components.
- Program strategies and measurable program outcomes logically link together.
- Going forward, 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). Such models facilitate the achievement of a common understanding of the program by stakeholders and the evaluator (Donaldson, 2007), as already stated, 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).

Through development of a program theory model that is specific to QuarkNet, we seek to:

1. Depict the *current* program as *designed*.
2. Succinctly describe the program structure and articulate core program strategies.
3. Identify program outcomes including sustainability.
4. Focus on logically linking strategies to outcomes.

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 (to be 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).

Development of the QuarkNet Program Theory Model

In sync with the start of the current award period, this phase of 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 we will discuss shortly, we have included a framework that adds program sustainability strategies and outcomes into the mix.

Program Anchors: Drawing from the Literature and Science Standards

The QuarkNet Program Theory Model has been anchored by drawing from effective professional development practices suggested by the literature; aligned program strategies with the Next Generation Science Standards science practices; and defined how the term "guided inquiry" is used.

<u>Effective Professional Development</u>

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.

Table 1
Brief Description of Characteristics of Effective Professional Development
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, 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).

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

1. Is **content focused**.
2. Incorporates **active learning** utilizing adult learning theory.
3. Supports **collaboration**, typically in a **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 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:

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 injury (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, the teacher may likely be a mentor or lead/associate/staff teacher; and, the students may be participating teachers engaged in active learning as students or actual students engaged in activities from the Data Activity Portfolio.

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; and, reviewed and revised based on suggestions from the Principal Investigators (PIs). (A copy of the protocol and the list of stakeholders and evaluators who participated in this interview process are shown in Appendix B.) Each interview was conducted over the phone and most lasted between 1 to 1 ½ hours. When 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 were 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 Program Theory Model

In its fully articulated form, the PTM describes the QuarkNet program *as designed*. 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 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; the full model shown in Appendix C. The 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).

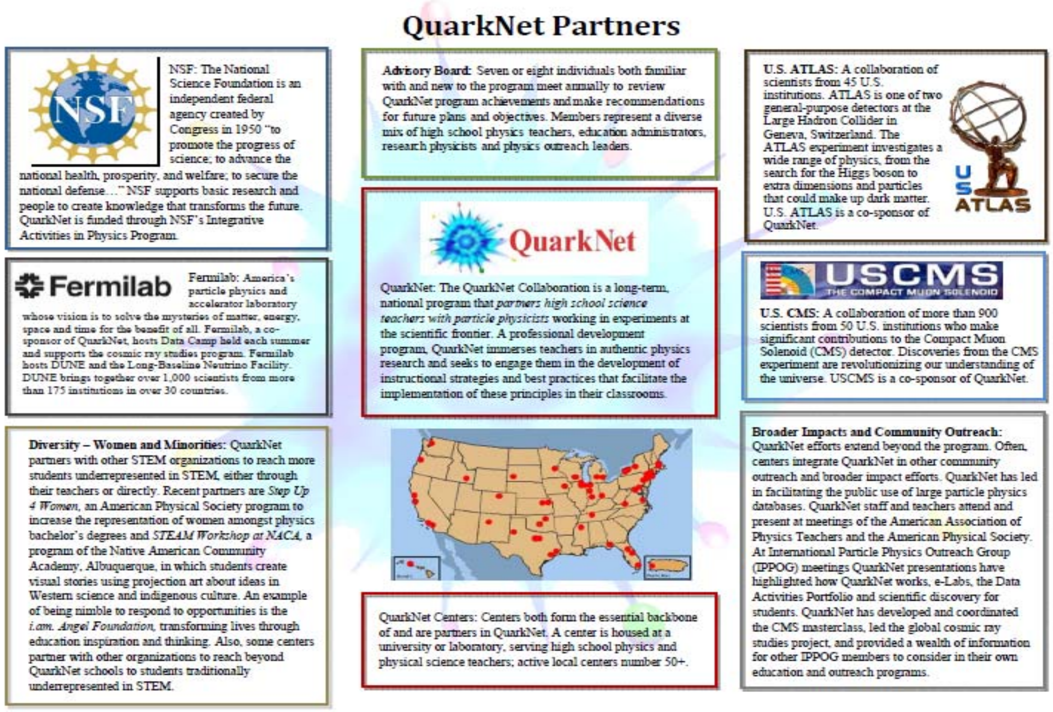

Exhibit A. The first page of the PTM highlighting key partners and outreach efforts.

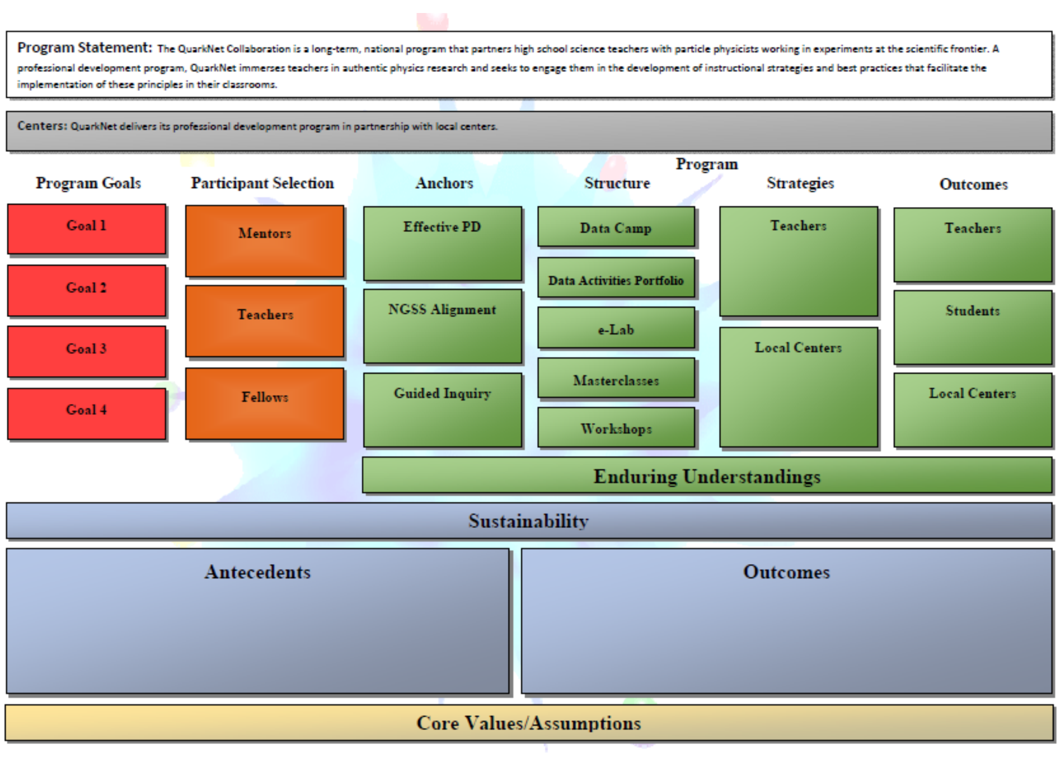

Exhibit B. The second page of the PTM which over views its component parts.

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.

Who is the Audience*?* The audience for the PTM is someone who is or not familiar with QuarkNet and who has an interest in or a stake in the program. 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 articulates key program outcomes that need to measure (and why).

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 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 (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 Compact Muon Solenoid (CMS) experiment at CERN2'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 [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. Master-classes 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).

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.

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. Activities increase in complexity, sophistication and expected student engagement from Levels 0 to 4 (level 4 activities are in the works). Pathways provide guidance for teachers to develop a sequence of lessons or activities appropriate for their students and to help build student skills-sets. 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 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. Figure 1 shows an example of a suggested pathway extracted from the Data Activities Portfolio. (There are pathways for each data strand, LHC: Understanding Colliders; LHC ATLAS: ATLAS Masterclass Preparation; LHC CMS: Focus on Special Relativity; LHC TOTEM: Interference Patterns; and, Cosmic

Data Activities Portfolio Sample Pathways for Each Data Strand

LHC: Understanding Colliders

Level 0	Level 1	Level 2	Level 3	Level 4
Dice, Histograms and Probability	Rolling with Rutherford	4 Masterclasses	**CMS e-Lab**	
Making it 'Round the Bend	**Calculate the Top Quark Mass**	**CMS Data Express**	Cosmic Ray e- Lab	
Mass of U.S. Pennies	**LHC Discovery**	**ATLAS Data Express**	LIGO e-Lab	
Quark Workbench	Calculate the Z Mass			
	Seismology			

In *Making it 'Round the Bend*, students learn that magnets can bend a beam of charged particles in a circular path. The *Top Quark* activity allows students to discover how conservation of energy and conservation of momentum work in relativistic systems focusing on a single event. In the *LHC Discovery* activity, students gather data using both CMS event data and ATLAS event data. Then, choose between the *CMS Data Express* or *ATLAS Data Express* so students analyze a larger dataset. The *CMS e-Lab* is the culminating activity.

Figure 1. Sample pathway of Data Activities Portfolio extracted from QuarkNet website https://quarknet.org/sites/default/files/sample_pathways_01dec17.pdf

Ray Studies.) 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. The alignment of program anchors, i.e., effective professional development, NGSS standards and guided inquiry, with core strategies is shown in Table 3. The program anchors have already been described. Core strategies are articulated relative to the overall program, participating teachers and local centers. This table (and this section of the PTM) presents the grounding of these program strategies in 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, guided-inquiry learning; and, big ideas in science and enduring understandings. Strategies directed toward teachers include: *Engage as active learners, as students;* and, *Discuss the concept of uncertainty in particle physics*. There are two strategies 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 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

Table 3. QuarkNet: Aligning Core Strategies with Program Anchors

<table>
<tr><th>Program Anchors: Effective Professional Development and Best Practices</th><th>Core Strategies: What Happens in QuarkNet?</th></tr>
<tr><td>
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.
</td>
<td rowspan="2">
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.

</td></tr>
<tr><td>
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, theses practices are intended to better specify what is meant by inquiry in science.
https://www.nextgenscience.org

Asking questions (for science) and defining problems (for engineering).
Developing and using models.
Planning and carrying out investigations.
Analyzing and interpreting data.
Using mathematics and computational thinking.
Constructing explanations (for science) and designing solutions (for engineering).
Engaging in argument from evidence.
Obtaining, evaluating, and communicating information.

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

Patterns
Cause and Effect
Scale, Proportion and Quantity
Systems and System Models
Energy and Matter in Systems
Structure and Function
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)]
</td></tr>
</table>

Table 4. QuarkNet: 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. *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.

inquiry and NGSS science and engineering practice and other science standards as applicable (as well as other standards such as AP and others); 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;* 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 have been incorporated into a Teacher Survey that will be distributed on an annual basis. And program outcomes related to mentors and interactions between mentors and teachers will be captured in a template directed to obtain feedback from participating centers (as well as sustainability outcomes). These principal evaluation measures will be supported by linking this information to operations data obtained from a program-wide database; and if feasible, available implementation plans developed by participating teachers, and select interviews with participating teachers.

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?

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)

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 to 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 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).

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 and how factors related to this activity may help in the longevity of the center's broader impacts.

Before embarking on a description of how teacher-level and center-level outcomes will be measured during this evaluation, it is important to briefly describe a picture of how the program is implemented.

Implementation of QuarkNet Program

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

As part of the implementation of the QuarkNet program, staff members hold weekly meetings to focused on program-wide issues and discussions; IT needs and updates; and activities development for the Data Activities Portfolio (personal communication, email M. Bardeen, April 17, 2019).

Table 6
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.

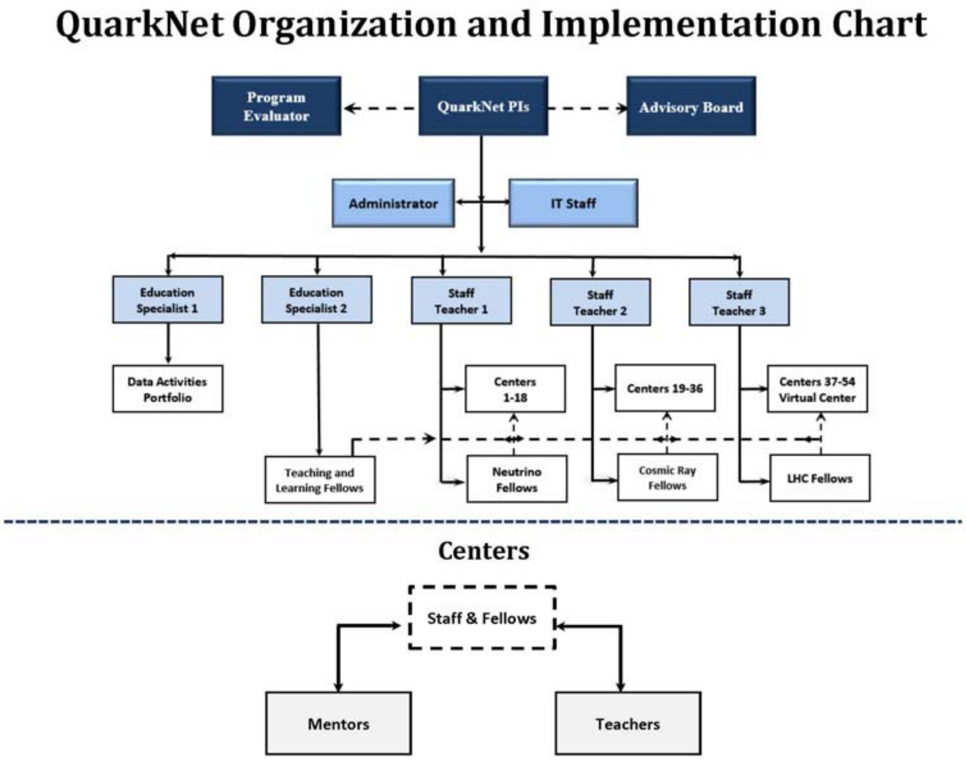

Figure 2. An overview of the Organization and Implementation Chart of the QuarkNet Program.

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 are workshops conducted through the national program or that are center-run.

Starting with the 2019-2020 program year and during this current award period, each center has been budgeted for 30 teacher-days. As noted in an email blast, 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 January 18, 2019). To help centers plan for the 2019-2020 program year (a program year typically starts 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).

Data Activities Portfolio: Instructional Design and Review of Activities

Figure 3 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 Mc Tighe (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.

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 pathway examples 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 pathway guidance; developing neutrino materials; and creating activities at level 4. A brief history of the development and review of activities in the Data Activities Portfolio is shown in Appendix E.

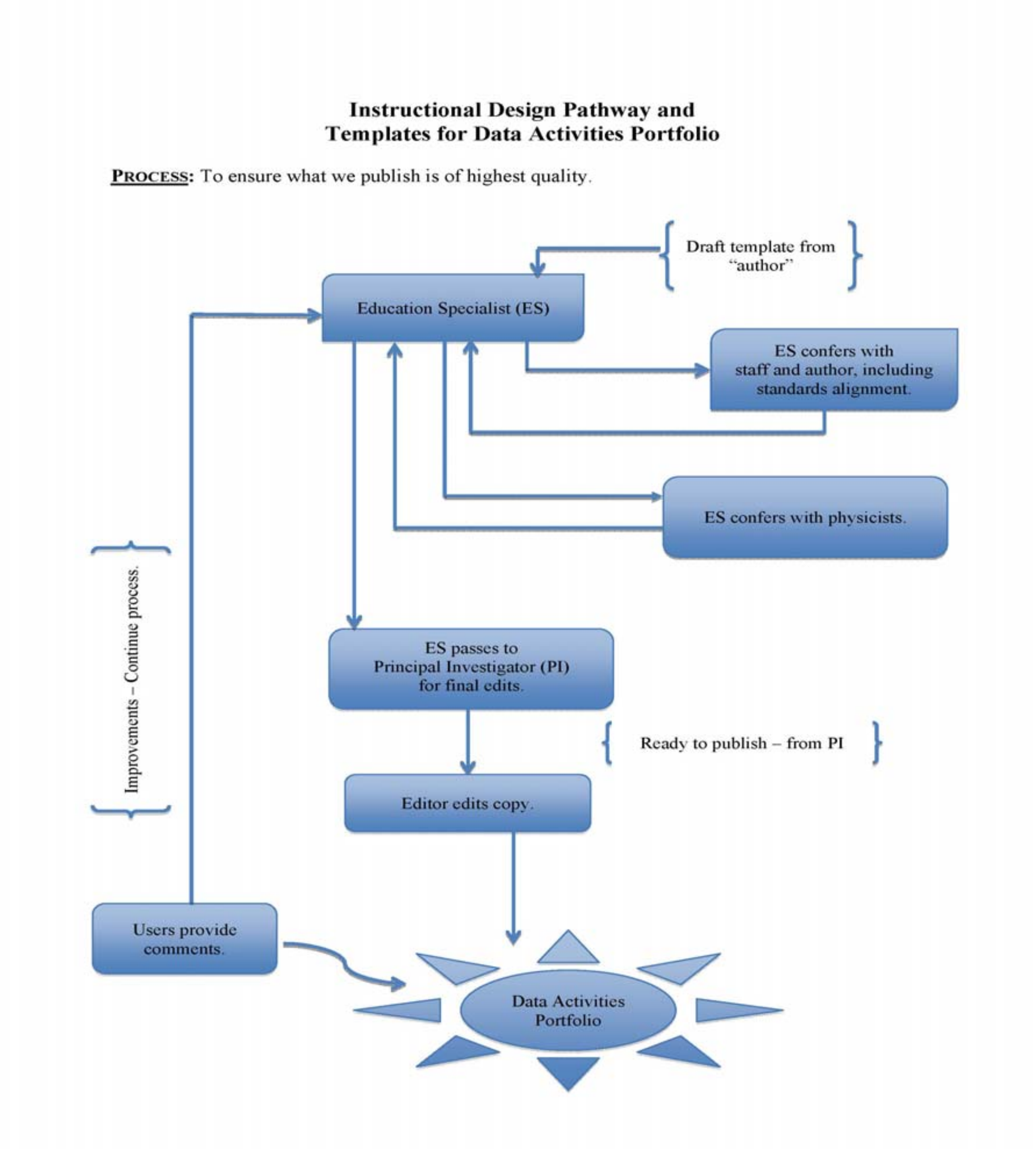

Figure 3. Instructional Design Pathway for Data Activities Portfolio (created by Young, Roudebush & Bardeen)

Table 7
Instructional Materials in the Data Activities Portfolio

Level	Activity	Data Strand	NGSS Practices
0	Making it 'Round the Bend – Qualitative	LHC	4,5,7
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	What Heisenberg Knew	Neutrino	2,4,5,6,7,8
1	The Case of the Hidden Neutrino	LHC, Neutrino	4,5,6,7
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	Making it 'Round the Bend – Quantitative	LHC	4,5,6,7
1	Signal and Noise: Cosmic Muons	Cosmic Ray	4,5,6,7,8
1	Mean Lifetime Part 1: Dice	Cosmic Ray, LHC	4,5
2	ALICE Masterclass	LHC	1,3,4,5,6,7,8
2	LHCb Masterclass	LHC	1,3,4,5,6,7,8
2	Plotting LHC Discovery	LHC	4,6,7
2	Cosmic Rays and the Sun	LHC	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	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
2	Mean Lifetime Part 3: MINERva	Cosmic Ray, Neutrino	2,3,4,5,7
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 (6/13/2019)
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. Construct explanation and designing solutions. 7. Engaging in argument from evident.
8. Obtaining, evaluating, and communicating information.

Data Activities Portfolio: Activities, Masterclasses and e-Labs

Table 7 provides a list of the current activities in the Data Activities Portfolio; there are a total of 30 activities (and two more in the pipeline as of June 2019). Each of these instructional materials is available through the QuarkNet website, https://quarknet.org/

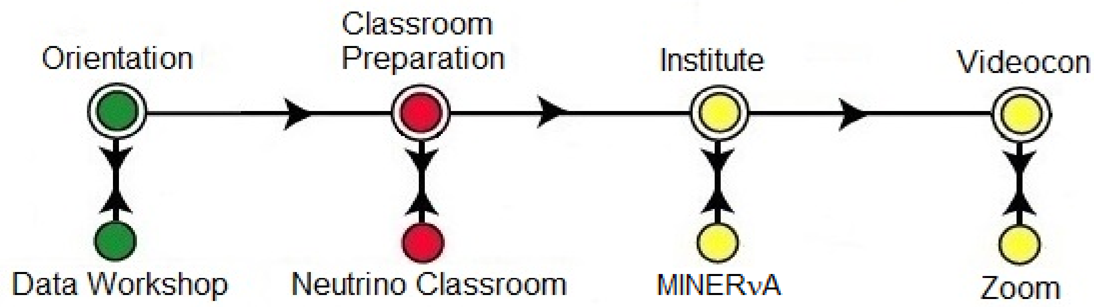

Figure 4. Neutrino Masterclass Project Map 2019 (developed by Cecire, Bilow and Wood).

data-portfolio. The data strand and level are indicated on this website along with the alignment of NGSS science practices and topic/content title. Topics include: Data Analysis, Measurement, Particle Composition, Electric Potential, Lorentz Force, Motion of Charged Particles, Momentum Conservation, and Student Data. Teacher Notes, Student Guide files (and at times other support materials) information on technology requirements; and estimated class time to implement are also provided.

Level 3 instructional materials, which are contained in the Data Activities Portfolio, are supported with masterclasses and e-Labs (and soon to be level 4). 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 4. 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." http://tiny.cc/numc19.

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 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).

The Program's Website

With or without a user account (a guest user account is available) a visitor to the QuarkNet website (https://quarknet.org/) can assess 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 recent 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.

As we will describe shortly, teacher and center-level database information obtained from the website will be integrated into the evaluation plan to help describe the type and level of engagement in the program by teachers and centers over the course of this award period.

Development of Evaluation Measures

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

To full 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 have been designed. These are intended to roll out to coincide with the 2019-2020 program year, which began in summer 2019. In support of this evaluation effort, program operations data from two newly created databases (teacher-level activity and center-level databases) will be linked to these 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).

Assessment of Program Outcomes at the National and Center Levels

A Teacher Survey has been developed to assess program outcomes at the national and center levels as perceived by participating teachers. The Teacher Survey asks teachers 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. (The full survey is shown in Appendix F.)

A more detailed description of strategies and program outcomes covered in this survey is shown in Table 8. 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, these teachers are asked to reflect on student-level outcomes they have perceived in their classrooms and the degree to which QuarkNet has influences these behaviors as well (e.g., *Discuss and explain concepts in particle physics*).

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

We recognize that most teachers experience QuarkNet through their engagement of the program at a given center. As such, the center provides the context in which the teachers experience QuarkNet and at the same time, centers are a source of outcomes in their own

Table 8
Teacher Survey: Teacher Perceptions of Exposure to Program Core Strategies and Assessment of Program Outcomes

<table>
<tr><th>Core Strategies</th><th>Outcomes</th><th>Evaluation Measure</th></tr>
<tr>
<td>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).</td>
<td rowspan="3">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.</td>
<td rowspan="3">The Teacher Survey is intended to assess the perceptions of teachers 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 the SurveyMonkey platform. The intent is for teachers to complete the survey during their on-site program engagement.

This is an annual event. These data will be linked to operations data (level of participation) and information obtained from participating centers where possible.</td>
</tr>
<tr>
<td>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.</td>
</tr>
<tr>
<td>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.</td>
</tr>
</table>

Table 9
Linking Core Strategies and Outcomes to the Center Feedback Template

<table>
<tr><th>Core Strategies</th><th>Outcomes</th><th>Evaluation Measure</th></tr>
<tr><td>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.</td><td rowspan="3">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.</td><td rowspan="3">The Center Feedback template is intended to serve as a guide or protocol in capturing center-level information related to implemented program strategies and well as key center-level outcomes. (See Appendix G 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 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 10.</td></tr>
<tr><td>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.)</td></tr>
<tr><td>Local Centers: In addition, through sustained engagement provide opportunities for teachers and mentors to:
• Interact with other scientists and collaborate with each other.</td></tr>
</table>

right. To this end, the Center Feedback template was designed to assess this program context; assess center-level outcomes (see Table 9); and, gather information on success factors as a means to assess sustainability outcomes (see Table 10). It is a 4-page form that is divided into four sections: these are: Section I which requests information about the Center (who is participating in the evaluation and who is completing the form); Section II asks about program events over the past two years; Section III gathers information about center-level outcomes (described in Table 9); and Section IV is focused on the Success Factors listed in Table 10). The full template is shown in Appendix G; Figure 5 provides an image of Section III of the template.

Table 10
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. 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. 6. Program diffusion, replication (in other sites) and/or classroom adaptation occur.	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.

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.

Implementation of QuarkNet 2018-2019 Program Year

A list of QuarkNet Workshops held during the 2018-2019 program year by QuarkNet staff is shown in Table 11. Data Camp was implemented at Fermilab from July 16-20, 2018.

Table 12 lists a summary of meetings and workshops held at QuarkNet Centers and led by the individual centers. Together, 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 Appendix A for a list of these centers.

A breakdown of participants for the 2018-2019 program year is provided in the annual report to NSF.

Table 11
2018 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 and Iowa State Univ.	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
Oklahoma State University	Cosmic	Week of July 23	
Hampton, George Mason and W&M Univ.	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

Table 12
2018 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 - Santa Cruz	
Boston area/Brown University	August 14-15	University of Cincinnati	
Brookhaven National Laboratory	June 25-29	University of Florida	August 25-26
Catholic University of America	August 13-17, plus 3 days in fall	University of Hawaii	June 2-3, September 29
Colorado State University	August 8-10	University of Houston	
Fermilab/University Chicago	July 18-20	U of Illinois Chicago/Chicago State University	June 25-29
Florida Institute of Technology	None	University of Iowa/Iowa State	July 9-13
Florida Int'l University	None	University of Kansas	June 11-13
Florida State University	July 23-27	University of Minnesota	June 12-14
Idaho State University		University of Mississippi	June 25-26
Johns Hopkins University (MD)	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 Lab	June 18-22	University of Oklahoma	
Northern Illinois University	June 25-29	University of Oregon	June 18-22
Oklahoma State	~July 23-27	University of Pennsylvania	
Purdue University		University of Puerto Rico-Mayaguez	Sept 2018, Feb-Mar 2019
Purdue University Northwest	June 18-22	University of Rochester	
Queensborough Community College		University of Tennessee	July?
Rice University/University of Houston	June 25-29	University of Washington	August 17-19
Rutgers University	July 9-13	University of Wisconsin-Madison	
Southern Methodist University	Aug 6-10	Vanderbilt University	June 25-29
Syracuse University	Aug 8-10	Hampton, George Mason and William and Mary University	Aug 6-8
Texas Tech University	June 13-15	Virginia Tech University	July 23-26
University at Buffalo	Aug 23-24	Virtual Center	July 11-14
University of California - Riverside	June	Wayne State University	

Implementing the Evaluation: Highlighting the Proposed Plan

The new evaluation efforts began in September 2018 to coincide with the roll-out of the 2019-2020 program year. That is, the lion share of QuarkNet programs, at participating centers, occur over the summer; thus, the implementation of the proposed evaluation plan has been rolled out to coincide with summer 2019 activities for the Teacher Survey and in September 2019 for the Center Feedback template.

In the planning of the 2019-2020 program (as usual), in January 2019, 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).

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 planned summer (2019) engagement. 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 this survey in the agenda of the event as well. Teachers were encouraged to self-identify on the survey to facilitate the linking of this survey information to program participation levels. In this way, we plan on embedding evaluation requests and requirements along with other program announcements and actions.

We anticipate that this survey will be an annual event; however, if a teacher self-identifies an individual teacher will be asked to complete this survey only once. That said, we anticipate that teachers will continue to update their information in the teacher database on an annual basis; ultimately balancing the information demands required from the teachers and the need/desire for up-to-date program participation information.

As implied, the unit of measure for this survey is the individual teacher. The PDF version of the survey is shown in Appendix F (as already noted), although teachers will participate in this survey electronically through the SurveyMonkey platform. Teachers will be asked to complete this survey, while they are at their at-site QuarkNet event. It is estimated that the survey will take about 15-20 minutes to complete, and teachers are given the option of stopping and starting the survey in order to change or revise their responses at a later data. Teachers are expected to complete this survey using their own electronic devices, although using his or her phone to complete the survey is not recommended.

Table 13
Participation in QuarkNet (Prior to Current Workshop):
Responses to 2015, 2016, and 2017 Surveys

Number of Years	2015	2016	2017
New	50	54	46
1-2 years	50	61	41
3-4 years	38	26	26
5-10 years	50	46	44
Over 10 years	20	28	27
Total	208	215	184

Note. Raw SPSS data from Beal & Young, 2017

To help increase the response rate, email reminders will be sent to teachers who did not respond during their at-site program participation; these reminder emails will be sent out based on a roster of participating teachers, created by the Program Administrator.

Depending on the success of the survey, we may follow-up with teachers via an interview, if teachers agree to this in future program years. As relevant and feasible, we will also use teacher survey data collected from the past evaluation (2012 to 2017) in an attempt to depict a more complete picture of teacher engagement, school and classroom information, and perception of program outcomes. For example, Table 13 shows a breakdown of teachers (who participated in surveys from 2015, 2016 and 2017) showing the number of years teachers have participated in QuarkNet (based on data collected from Beal & Young, 2017). This breakdown is based on 607 responses (not a unique count of teachers); approximately 500 teachers participated annually during this time period (QuarkNet proposal, 2018).

Of importance, our plans are to link teacher responses from the survey to program participation data captured in the teacher-level database (and as described in the next section, center-level program engagement). We will use the information obtained from the database to be able to better describe the level of program engagement by teachers, in terms of annual numbers; demographics (who); and the level of program engagement (number of years and type of engagement) – thus describing program outcomes embedded in the context of program engagement.

Finally, we plan on triangulating this information with implementation plans developed by participating teachers (when these are collected) as well as to link teacher program engagement to information obtained from the centers. This evaluation effort is describe next.

<u>Implementing the Center Feedback Template</u>

Using the Center Feedback template, we have proposed a plan to collect center-level information based on a procedure that will involve mentors and teachers at the center; the staff teacher who supports the center; and the external evaluator. Because this template is a bit more complicated than a survey per se, we have proposed a pilot test of 3-6 centers with a proposed start of September 2019 (that is, two to three centers for each staff teacher). To begin, we will start with mature centers that are active and have been active in QuarkNet perhaps for many years. We will rely on the help of QuarkNet staff teachers for the selection of these centers with approval from PIs as needed.

We will announce this effort via email (over PI's signatures and support). For the first few centers, we will test whether or not it is necessary to involve staff teachers in this early contact with mentors/teachers or if the evaluator could serve in this capacity alone. To this end, we will schedule and conduct a conference call with the center (to include those most engaged in the program, i.e., the mentor and teacher); the staff teacher who works with the center; and, the evaluator. We anticipate the mentors and teachers at a center will clearly know what they have done via QuarkNet engagement, how frequently this engagement has been and what's been typical. They may be less clear, however, as to how to reflect this on the Center Feedback template, especially sections on outcomes and success factors. The external evaluator and staff teacher will work with the mentor(s) and teachers at a given center to help them do this. After this center-based discussion, a post-interview call (or email) with the evaluator and QuarkNet staff teacher(s) will occur to agree on a final representation of these responses – i.e., a consensus of the reported ratings and/or responses; add or support the information that has been gathered; and, resolve any discrepancies as needed.

We will use this early experience to determine whether or not this first step can be conducted by the external evaluator without the initial help from a staff teacher. If viable, going forward the external evaluator will work directly with the individual center to initially gather this information. After this center-based assessment, the evaluator will meet with the QuarkNet staff teacher(s) to review the ratings. Again, the intent is to reach a consensus on these rating; if a consensus is not reach, differences in perspectives will be noted.

If the pilot test is successful, we will continue to roll out this contact with other centers with the ultimate intent of obtaining information from all active centers as well as other semi-active centers. Thus, this effort would continue over the remaining period of this award. It is likely that we will use a rolling strategy so there are a fixed number of centers in this outreach queue; adding new centers to the queue as other centers complete their Center Feedback form. If feasible, we will reach out to centers no longer engaged in QuarkNet.

Of importance, information gleaned from this process will be linked to data obtained from the center-level database as needed.

We see the information gleaned from this process as serving multiple purposes. We hope that this information will help QuarkNet staff teacher(s) identify areas of need that the individual center might have. Also, the completed Center Feedback template may help a center document and support its engagement and success in broader impact engagement.

For the external evaluation, the ultimate purpose of this information is to provide a context in which the teachers engaged in QuarkNet; and perhaps to better explain how this information relates to or explains/supports individual teacher outcomes. It will also provide evidence of achievement (or not) of center-level outcomes and sustainability outcomes as articulated in the PTM.

Finally and as already stated, we will link this information to data obtained taken from the center-level database.

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 in final form as an interim report). 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; and, 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.

Going forward a distinct difference between this and future evaluation reports will be the inclusion of actual evaluation results drawn from the Program Theory Model and based on the evaluation plan relative to teachers, centers and sustainability. Nevertheless, portions of this report may be presented again as a consistent reminder of the basis in which evaluation decisions and interpretations stem.

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 (201). 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. In this report, we have briefly highlighted the planned method to assess program outcomes through these measures directed toward teachers, centers, and the sustainability of the program and to link this information to program-operations data. We plan on analyzing results from teacher-level responses nested by centers (when feasible); and on linking program participation-level data to program outcomes and other data sources such as implementation plans and teacher interviews, when feasible. We also propose drawing on data from past evaluation efforts when relevant.

Program Recommendations

The following program recommendations are proffered:

1. The program has had a long-standing practice of holding regularly-scheduled staff meetings. These tend to be topic/task specific meetings involving those most involved with that aspect of the program and tend to be held weekly. Continue to use this meeting structure to the extent that it is helpful. Include the evaluator in these discussions when meaningful and reasonable. Consider less frequent but periodic

program-wide meetings to inform stakeholders across tasks and responsibilities to communicate across the program.
2. Continue to improve program documentation efforts and use it to inform other program staff and stakeholders as well as those external to the program.
3. 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.
4. Support efforts to gather program information contained in the program-operation databases including inputs from teachers, mentors, and program staff.
5. Continue to be mindful that QuarkNet is "first and foremost, a teacher professional development program."
6. Continue to maximize the use of Data Portfolio Activities by teachers at center-led and QuarkNet-led workshops and meetings.
7. Continue to engage in reflective thinking on ways to help teachers integrate their QuarkNet experiences and instructional practices into their classrooms.
8. Support the development by teachers of implementation plans and the subsequent use of these plans in the classroom when feasible.
9. Continue to support the evaluation and its efforts as reasonable. Work with the evaluator, as planned, to help embed evaluation efforts and requirements within the structure and delivery of the program.

Evaluation Recommendations

The following evaluation recommendations are proffered:

1. Review and reflect on feedback from QuarkNet program staff on how the Program Theory Model (PTM) can be improved or changed to help improve its representativeness (as an "approximate fit") of the program and its Theory of Change.
2. Work with program staff to help articulate ways in which the PTM can be used and how to facilitate this use.
3. Help articulate the difference between program theory and program implementation and why this is important.
4. Implement the new, proposed evaluation plan to coincide with the 2019-2020 QuarkNet program year.
5. Review the PTM and evaluation measures to assure that implemented evaluation measures align with the PTM as planned.
6. Help program staff transition from past evaluation efforts that combined formative and summative efforts to an outcomes-based evaluation.
7. 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.
8. Work with program staff to help ensure that program-operations data are collected in a timely manner and with high compliance.
9. Work with QuarkNet program staff to distribute the Teacher Survey and implement the Center Feedback template.

10. Work to ensure that evaluation efforts and results are of value (or of potential value) to all those involved in the process.

References

Beal, G., & Young, M. J. (2017, December). *QuarkNet 2012-2017 Summative Evaluation Report* (and raw data).

Brett, B., & Race, K.E.H. (2004, November). *Aligning logic models with organizational mission: Part I Development of a student learning outcomes model for a network of private schools.* Presented at the Annual Meeting of the American Evaluation Association, Atlanta, GA.

Donaldson, S. I. (2007). *Program theory-driven evaluation science: Strategies and applications*. New York: Lawrence Erlbaum.

Desimone, L. (2009). Improving impact studies of teachers' professional development toward better conceptualizations and measures. *Educational Researcher, 38(3),* 181-199.

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

DuBow, W. M., & Litzler, E. (2019). The development and use of a theory of change to align programs and evaluation in a complex, national initiative. *American Journal of Evaluation*, 40(2), 231-248.

Dusenbery, P., & W. Lee, S. (1998). *The MarsQuest Education Project* (Vol. 30).

Herron, M.D. (1971). The nature of scientific enquiry. *School Review, 79*(2), 171- 212.

Institute of Education Sciences and National Science Foundation. (2013, August). *Common guidelines for education research and department*. Washington, DC: U.S. Department of Education and National Science Foundation.

Kellow, J. M. (2007). Modified Herron's model. Creative Commons.

McNeill, K.L., and J. Krajcik. 2008b. Inquiry and scientific explanations: Helping students use evidence and reasoning. In, *Science as Inquiry in the Secondary Setting*. J. Luft, R. Bell, and J. Gess-Newsome (Eds.) , 121–134. Arlington, VA: NSTA Press.

National Academies Press. (2013). N*ext Generation Science Standards*. For States by States Volume 1 and 2. Washington, DC: Author.

QuarkNet Proposal to NSF. (2018).

QuarkNet Program Theory Model. (2019).

Race, K., & Brett, B. (2004, July). *Evaluation of the Cristo Rey network schools.* Chicago: Race & Associates, Ltd.

Rallis, S. F. (2013) Remembering Carol Weiss: My advisor; My teacher. *American Journal of Evaluation*, 34(3), 448-450.

Renger, R. (2006). Consequences to federal programs when the logic-modeling process is not followed with fidelity. *American Journal of Evaluation, 27,* 452- 463.

Rogers, P. J., Petrosino, A., Huebner, T.A., & Hasci, T. A. (2000). Program theory: Practice, Promise and problems. In, P.J. Rogers, T.A. Hasci, A. Petrosino. *Program Theory in Evaluation: Challenges and Opportunities. New Directions for Evaluation, 87,* 5-13.

Rossi, P H., Lispey, M. W., & Freeman, H. E. (2004). *Evaluation: A systematic approach.* (7th ed.). Thousand Oaks, CA: Sage.

Sample, M. (2011, April 23). Teaching for undercoverage rather that coverage. *The Chronicle of Higher Education.*

Scheirer, M. A. & Dearing, J.W. (2011). An agenda for research on the sustainability of public Health programs. *American Journal of Public Health*, 101(11) 2059-2067.

Scheirer, M. A., Santos, S. L. Z., Tagai, E. K., Bowie, J., Slade, J., Carter, R., & Holt, C. L. (2017). Dimensions of sustainability for a health communication intervention in African American churches: A Multi-methods study. *Implementation Science, 12*, 43-56.

Weiss, C. H. (1995). Nothing as practical as good theory: Exploring theory-based evaluation for comprehensive community initiatives for children and families. *New approaches to evaluating community initiatives: Concepts, methods, and contexts*, 65-92.

Wiggins, G. J. & McTighe, J. (2005). *Understanding by Design Expanded 2nd Edition* Alexandria VA: Association for Supervision and Curriculum.

Young, M. J. (2017, October). *QuarkNet: Matrix of Effective Practices.* Tucson: M. J. Young & Associates.

Young, M. J., Roudebush, D., & Bardeen, M. (2019). *Instructional Design Pathway and Templates for Data Activities Portfolio.*

Young, M. J., Bardeen, M., Roudebush, D., Smith, J. & Wayne, M. (2019, January). *Enduring Understandings.*