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SCIENCE TEACHER EDUCATION

Strengthening the vision: Examining the understanding of a framework for teacher leadership development by experienced science teachers

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Abstract

The program team operating an NSF Noyce Master Teacher program has been building a conceptual framework for developing teacher leaders. The program has focused its efforts on a group of 16 chemistry and physics teachers in Southeast high-needs schools. The conceptual framework is based on the view that teacher leaders are those individuals who retain a classroom presence, while simultaneously innovating practice and empowering others. A core principle of the framework is that embodying these attributes requires an ability to see oneself and the teaching practice in a way that goes beyond the expertise associated with content and pedagogical knowledge. Evidence drawn from years three and four of the NSF Noyce Master Teacher program are presented to demonstrate the participating teachers' understanding of the framework's components. These data also indicate the potential of the teachers to use the framework's principles to engage in leadership activity. Characterizing such understanding and the changes in it are foundational to determining the way such a framework influences teachers' approaches to leadership. This paper has implications for the growing number of teacher leader initiatives across the United States, and for the question of whether science, technology, engineering, and mathematics (*STEM*) teacher leadership should be considered separately from a *general notion* of teacher leadership.

KEYWORDS

professional identity, professional vision, science teacher leadership, science teacher professional development

1 | INTRODUCTION

The greatest leaders mobilize others by coalescing people around a shared vision.

—Ken Blanchard[1]

In April 2016, the U.S. Department of Education released a STEM Dear Colleague letter[2] that identified strategic focus areas for future efforts in science, technology, engineering, and mathematics (STEM) education. Included in that list was an invitation to various agencies and institutions to support "leadership pathways for STEM educators" (p. 5). A national collaboration incentivized by the content of this letter created the "Building STEM Teacher Leadership" web site, hosted by the U.S. Department of Education.[3] This directive and effort related to STEM teacher leadership is aligned with a broader focus in the United States on teacher leadership, as represented nationally by the Teach to Lead program (https://teachtolead.org). Given the extent of the work in this area, it is critical that a strong research base related to approaches for developing and supporting teacher leaders be produced. However, reviews by York-Barr and Duke (2004) and Wenner and Campbell (2017) indicate that a lack of knowledge exists in relation to our comprehension of teacher leadership. Further, there has been limited exploration of whether teacher leadership in STEM contexts or involving STEM educators should be considered as having unique characteristics that would warrant a specific focus on STEM teacher leadership (Teacher Advisory Council & National Research Council, 2014). This paper seeks to contribute to the knowledge base regarding the general notion of teacher leadership by examining the ways participants in a Noyce Master Teacher program understood components of a conceptual framework designed to support their leadership development. This will provide insights into how one might formulate the process of promoting teacher leaders. Additionally, because the program focused on chemistry and physics teachers, some proposals will be made concerning STEM-specific aspects of and approaches to teacher leadership.

Since 2010 the authors of this paper have been part of the **I**nitiative to **I**ncrease and **M**entor **P**hysics and **C**hemistry **T**eachers (I-IMPACT) program, an effort funded by the National Science Foundation (NSF) to produce a cadre of 16 master teaching fellows (MTFs, experienced teachers) who will function as teacher leaders. A previous paper (Criswell, Rushton, McDonald, & Gul, 2017) described a conceptual framework that was in place at the beginning of that program, as well as the evolution of that framework through the first 2 years of the program's operation. This paper builds off of that one by looking at data from the first 4 years of the program to determine how the MTFs thought about key constituents of the I-IMPACT conceptual framework for teacher leadership: (1) professional vision (Goodwin, 1994), (2) professional identity (Gee, 2000–2001; Sfard & Prusak, 2005), and (3) the four metaphors of teacher leadership (Dempsey, 1992). Unpacking the relationship between our conceptual framework, the professional learning built from it, and the materialization of our MTFs' perspectives on teacher leadership has helped the I-IMPACT team strengthen our vision of teacher leadership. Readers should benefit from the unpacking that we do in this article by exploring more deeply their own conceptualizations of teacher leadership and the way that this is realized in efforts intended to support the development of teacher leaders.

Various researchers have shown evidence for the value of having both domain *general* and domain-*specific* knowledge (e.g., Costa, Nicholson, Donlan, & Van Herwegen, 2018; Michael & D'Ausilio, 2015). In a parallel fashion, we argue that there is value in looking at teacher leadership through a general educational lens (domain general) and through a STEM-specific lens (domain specific). Thus, this paper does present some ideas about how STEM teacher leadership may be distinguished from teacher leadership in non-STEM contexts or involving teachers with different disciplinary backgrounds. To support that stance, we believe it is important to identify issues specific to STEM teaching that might place different demands on STEM teacher leaders; there are four we will highlight here: One is that the implementation of the new national standards in math (Common Core Math Standards) and science (Next Generation Science Standards) "require[s] extensive involvement by teachers," as noted by Dr. Bruce Alberts in the STEM teacher leadership report prepared by Olson and Labov (2014, p. 13). A second issue is that "Professional development in STEM fields can be different than professional development in other fields because of the constantly changing base of knowledge in STEM areas," a point made by Mike Town, a high school STEM teacher, in the same report (p. 10). A third is that the emphasis of STEM in schools in ways that sometimes feels exclusionary to individuals representing other content

areas requires STEM teacher leaders who can guide truly integrative STEM approaches (Bequette & Bequette, 2012; Johnson, 2012). The fourth issue is that there are proportionally fewer school leaders (principals, superintendents) with STEM backgrounds than with other content backgrounds, increasing the importance of STEM teacher leaders (Glass, Björk, & Brunner, 2000). Thus, the discussion that follows will have an explicit and specific concern for *STEM teacher leadership*.

2 | OVERVIEW OF THE I-IMPACT CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

2.1 | Core components and relevant literature

Prior to beginning the professional learning work with the first cohort of I-IMPACT MTFs in March 2012, the program team had constructed a conceptual framework to guide that work. The evolution of the framework has been described in a previous paper (Criswell et al., 2017). For the purposes of this paper, we will overview the core components of that framework that were the focus of the current study. These are the components around which the professional learning was designed and therefore are the components for which we expected to see the MTFs' understanding made visible in our data.

In constructing our conceptual framework, we drew on Dempsey's (1992) *four metaphors for teacher leadership*: teacher leader as (1) fully functioning person, (2) reflective practitioner, (3) scholar, and (4) learning partner. We conceive of these four metaphors as different manifestations of leadership that teachers can exhibit as they engage in a range of leadership activities (Townsend, 2010). The four metaphors describe a teacher leader's trajectory through an ever-expanding sphere of influence, starting inside the classroom (fully functioning person and reflective practitioner) and moving outside the classroom (scholar and learning partner). This aligns our framework with other descriptions of teacher leadership, such as the Kentucky Teacher Leadership Framework.[4] We have refined the meanings for the metaphors as a result of insights gained through the I-IMPACT program. Specifically, whereas Dempsey focused teacher leader as scholar on learning from others, we have focused our work on this metaphor around having our MTFs communicate their expertise and leadership efforts to broader communities (e.g., dissemination of knowledge).

A second component of the I-IMPACT conceptual framework is Goodwin's (1994) notion of *professional vision*, which he defines as "the competent deployment of a complex of situated practices in a relevant setting" (p. 626). Goodwin suggested that this capacity was composed of three processes: (1) highlighting, (2) coding, and (3) producing material representations (p. 606). For teacher leaders, developing their professional vision allows them to support others in seeing their practice in ways compatible with visions for change. Olson and Labov (2014) illustrate the importance of this for STEM education reform efforts when they describe the case of a science teacher leader (Toby Horn) who was able to help a principal better understand the nature of STEM teaching and therefore contribute to the implementation of a sustainable change in his school (p. 6).

Jacobs, Lamb, and Philip (2010) provide empirical support for the link between professional vision and leadership. They found that a critical component of professional noticing—an adaptation of the construct of professional vision to make it more specific to teaching (Levin & Richards, 2011)—was significantly influenced by participation in leadership activities. Their findings indicate that teacher leadership activities strengthen professional noticing/vision; we assert that developing professional noticing/vision will also strengthen teacher leadership.

Goodwin explained professional vision as entailing ways of seeing "answerable to the distinctive interests of a particular social group" (p. 606). We assert that the professional vision of those in STEM fields—or STEM teacher leadership work—would develop in those individuals unique ways of seeing events in the world. This statement from a recent Carnegie Report (Bybee & Chopyak, 2017) supports that assertion and connects it to STEM education: "Education leaders are looking for materials that support students in seeing the world in a way that more accurately reflects how scientists see the world …" (p. 3). In the I-IMPACT professional learning experiences, the program team tried to assist the MTFs in recognizing this unique way of seeing. For instance, we showed a TED Talk by Sarak Parcak that demonstrated

how she used her ability to recognize patterns to conduct archeology from space and to empower young Egyptians to use satellite technology to make their own archeological discoveries.[5]

Through their work to develop science teacher leaders, Sinha and Hanuscin (2017) have come to recognize "two different, but complementary, ways of conceptualizing teacher leadership … that of leadership as *practice* and leadership as *identity*" (p. 357, italics in original). As discussed above, professional vision is the component of the I-IMPACT framework that represents leadership as practice; in a similar vein, we have included *professional identity* (Beijaard, Meijer, & Verloop, 2013; Hsieh, 2015) within our framework as the component embodying leadership as identity. Our conceptualization of this component has been informed by the work of Sfard and Prusak (2005), who assert that identity is best understood as a narrative that is presented and represented (represented) within the discourse of those negotiating and formulating such identities (Gee, 2000–2001). We also have drawn on Luehmann's (2007) work, which describes how STEM teachers can move along a trajectory that will engender a professional identity amenable to leadership. Several of Luehmann's specific suggestions align with Dempsey's metaphors; for instance, "Position themselves within a larger political and cultural community of practice" (p. 823) undergirds teacher leaders as scholars.

Various researchers have linked teacher leadership and professional identity (e.g., Collay, 2006; Margolin, 2007; Marlow, 2009). However, Sinha and Hanuscin (2017) posit as the main finding of their work that [science] teacher leadership development can be "characterized as a synergistic interplay of an individual's views of leadership, engagement in leadership practices and identity development" (p. 368). Through our utilization of the I-IMPACT framework, we have recognized the need to explore concrete manifestations of the interaction between views of leadership/leadership practice and professional identity. For instance, a key challenge of forming a teacher leader identity relates to the ever-expanding sphere of influence associated with movement through each of the four metaphors. Specifically, with regard to STEM teacher leadership, the impact on one's professional identity seems particularly profound when extending one's sphere of influence includes disseminating knowledge or engaging in policy work (Luft, Whitworth, Dubois, Kind, & Berry, 2016)—i.e. serving as a teacher leader as scholar.

As noted above, Dempsey's four metaphors represent descriptions of how teacher leadership can be manifested. Professional vision and professional identity represent two components of our conceptual framework that describe mechanisms for how to develop teacher leaders. These components guided the design of the professional learning experiences provided for MTFs. For instance, one workshop session involved a discussion around a Veritasium video about how trees transport water to heights greater than 10 meters.[6] A critical point made through that discussion was that scientists may develop expertise—and eventually become leaders within their field—by taking risks, in the same way that science teacher leaders may have to accept risk taking as part of their professional identity (Reio, 2005). While there are two additional components (adaptive expertise and system sensitivity) that are part of our conceptual framework currently, they will not be discussed here because they were developed later in the program and were not used as significantly in the professional learning design during the program's first 3 years. The full conceptual framework is presented as Figure 1 at the end of the paper so that the reader may have a visual of its components and how they are related.

2.2 | A definition of teacher leadership

In their recent review on teacher leadership, Wenner and Campbell (2016) note that "conceptualizations of what exactly is meant by the term *teacher leader* are widely varied" (p. 135, italics in original). We thus found it critical to construct a clear definition of teacher leadership to use within the I-IMPACT program. This definition was created by distilling critical ideas from the I-IMPACT conceptual framework and synthesizing them with other significant ideas from the research literature. For instance, our definition was informed by Katzenmeyer and Moller (2009), who state, "… we advocate that teachers developing as leaders collaborate with their peers to understand first themselves, then their colleagues, and finally their schools" (pp. 58–59). Additionally, we drew from the work of Loucks-Horsley, Stiles, Mundry, Love, and Hewson (2010) discussion of the importance of *situational awareness* for effective school leadership. Finally, we appropriated Donaldson's (2007) notion that, instead of conceiving of school leadership hierarchically, it should be viewed relationally—with the relationships being used to mobilize people to improve practice (p. 27).

Synthesizing those various ideas resulted in the following definition of teacher leader:

- An individual gains a deep understanding of educational practice, and of her/himself in relation to that practice and to the system (both locally and more broadly) within which s/he operates.
- Through those understandings, the individual is able to work with others to develop a vision for producing innovation in the system, which, within school systems, means improving the practice of teaching and learning.
- As part of realizing of that vision, the individual is able to empower others to promote change and is able to modify and marshal available resources in a manner that ensures that this change is both productive and sustainable.

The first bullet point implies our integration of professional vision ("understanding of educational practice") and professional identity ("understanding of her/himself"). The second relates these two components to the development of a vision for leadership that can promote change within the system. The final bullet point emphasizes our view that teacher leadership should result in empowerment of others and in change that has a long-term impact.

While the program team continues to refine the conceptual framework, the core components and definition described above have guided our design of the I-IMPACT professional learning experiences throughout the program. Having collected significant data around the MTFs' participation in and views of those professional learning experiences, it became important to know to what extent these ideas made sense and were useful to them. Our argument is that we cannot determine how a teacher leadership development program impacts the work of its participants without first being able to describe how they think about the ideas that inform that program's design. Thus, the specific research question for this study is "What does the data from the I-IMPACT program indicate about the MTFs' understanding of key principles of the conceptual framework and about the potential utility of those principles in guiding their leadership activities?"

3 | CONTEXT AND METHODS

3.1 | Participants

There are a total of 32 fellows in the I-IMPACT program, split evenly between chemistry and physics, and between MTFs and teaching fellows (TFs). These fellows were accepted into the program over the course of two years; hence, there were two cohorts. This study focuses specifically on the MTFs because the explicit goal for their participation in the program was to have them develop into teacher leaders; the TFs were completing a teacher preparation program and then their initial years in the classroom during their time in I-IMPACT. The MTFs were drawn from schools geographically connected with the university through which the program is run, all of which would be considered urban or suburban contexts. The fact that the 16 MTFs work in 15 different schools and represent five different counties/school districts has allowed a wide variety of leadership activities and challenges to be addressed throughout the I-IMPACT program.

The MTFs comprise a limited demographic in that there are 15 White individuals and one African American. They nonetheless represent schools with diverse student populations, and that has allowed the MTFs to explore critical issues of equity in STEM (Basham, Israel, & Maynard, 2010) as part of their leadership discussions and activities. The gender breakdown is seven males and nine females. At the time of their acceptances into the program, the MTFs had a range of 5–17 years of teaching experience. Table 1 contains information about the MTFs who are discussed in the paper (using pseudonyms); a complete table appears as Appendix A.

In recruiting participants for I-IMPACT, the program team made clear to the administrators of those schools with whom we had partnered that we were seeking individuals who had the *potential* to be teacher leaders, but were not necessarily *already functioning* in leadership capacities. The goal of the program was to *develop* teacher leaders, not to *simply support* individuals for whom leadership activity had become the norm.

TABLE 1 Selected information about referenced MTFs

Pseudonym	Main subject	Years experience	Degrees/certifications
Cohort 1			
John	Physics	10	B.S. in science education, T-5 masters leadership, T-6 Ed.S. leadership, gifted certified, AP physics certified
Natalie	Chemistry	6	B.S. biochemistry, MAT chemistry education, chemistry and physics certified, gifted certified
Cohort 2			
Aimee	Chemistry	5	B.S. chemical engineering, Ph.D. chemical engineering, chemistry certified
Dennis	Physics	8	B.S. secondary science education, M.S. secondary science education
Lee	Physics	8	B.S. chemistry, M.Ed. science education, AP physics and chemistry certified, gifted certified
Mark	Physics	8	B.S., Ph.D. chemistry, AP physics and earth/space science certified, AP gifted training

3.2 | Professional learning structure

The MTFs in I-IMPACT were engaged in ~12 full days (~84 hours) of professional learning (PL) per year. The PL days were split between six and seven monthly Saturday meetings during the academic year and a weeklong retreat held in the summer. Each PL day was usually broken into three to five chunks lasting 1 to 2 hours. The exceptions were full-day sessions of intense professional development—as, for instance, sessions that were part of the coursework for the teacher leader endorsement (TLE) that the MTFs were obtaining.[7] The foci of the PL ranged across a number of areas, but can be summarized in the following categories: (1) content and pedagogical content knowledge enhancement, (2) teacher leadership skills and disposition development, (3) mentoring and professional learning community activities, and (4) panel discussions and dissemination activities.[8] In line with our attempts to support the MTFs in seeing themselves as leaders, the program team involved the MTFs in decisions about the nature and the structure of the PL starting in year 3. Additionally, more time was given to the MTFs to work on implementing their own individual and group leadership activities as we moved into year 4.

All of the PL activities were designed with the conceptual framework in mind. Even aspects of the TLE endorsement were informed by conversations between the lead instructor of the endorsement courses and the project team. That instructor often explicitly referenced ideas from the framework, and we believe that the use of a common conceptual framework and shared language supported attainment of program goals related to leadership development.

Included in the design of certain PL sessions (less than one third of them) were features that explicitly focused on specific components of the conceptual framework. For instance, there were mentoring sessions framed around supporting the MTFs in serving as learning partners to the TFs, and there were sessions in which the program team and MTFs engaged in analysis of science teaching videos designed to develop professional vision. Starting in year 3, the program team formally introduced what were labeled as "professional vision" sessions into the daily calendar, usually as the opening activity of the day. These sessions involved the sharing of a video that the presenter felt captured some key idea of the work associated with teacher leadership, then the provision of a prompt(s) to generate discussion around the video. Those sessions were initially led by the program team members who conducted this research study (Gary and Brad), but, by the summer of year 3, they were being led by MTFs and even TFs.

3.3 | Data sources

The program team has collected a substantial amount of information about the MTFs' experiences from a number of sources. To provide a focused analysis for the purposes of this paper, we will limit our data discussion to three sources: the "professional vision" PL sessions described above, the focus group discussions, and the individual interviews.

Our choice to focus on the "professional vision" PL sessions, which made up less than 20% of the overall set of professional development sessions during years 3 and 4, is based on the fact that the program team had designed these sessions with the express purpose of conducting a formative assessment of the MTFs' understanding of key principles of the conceptual framework. The videos and prompts chosen (presented in Appendix B) were designed to elicit MTFs' ideas associated with the core components of the framework. The focus groups and individual interviews were conducted and transcribed by members of the program evaluation team; they therefore provide an effective means for triangulating the findings gleaned from the analysis of the professional vision sessions (Merriam, 2009). The focus group discussions and individual interviews were completed twice per year, once during the Spring Semester and once during summer. These were conducted at the site of the PL work. The program and evaluation teams collaborated on designing all protocols to ensure that key program goals were being examined. All of the MTFs participated in the focus group discussions and the individual interviews if they were present on the day the evaluation team conducted these. It is important to note that the identities of the MTFs in focus group discussions and individual interviews were not provided to the project team by the evaluation team as part of their commitment to MTFs to keep that data anonymous. As such, data associated with those sources will generically identify MTFs according to cohorts.

3.4 | Analysis approach

Our data set included transcripts of all 10 professional vision sessions occurring in years 3 and 1 of the I-IMPACT program, and 14 transcripts from focus group discussions and individual interviews conducted in years 1–4. An a priori set of codes (Saldaña, 2015) was developed by integrating our conceptualizations of the four metaphors with our conceptualizations of professional vision and professional identity: Each of the four metaphors was defined/described in terms of what one's professional identity and professional vision would "look like" in relation to that metaphor of teacher leadership activity. Those definitions are presented in Table 2.

TABLE 2 Definitions of the four metaphors in terms of professional identity and professional vision

Metaphor	Professional identity code / Professional vision code	Definition/description
Fully functioning person	Showing a sense of her-/ himself related to the profession	While the person recognizes there may be room for improvement, s/he feels and expresses confidence in her/his capacity within the classroom
	Seeing the *nature* and *context* of her/his classroom practice	There is a developing ability to recognize key events in the classroom that are significant (highlighting), even if the *why* and *how* are not clear or cannot be labeled (coding)
Reflective practitioner	Showing a sense of how her/his relation to profession might change	These are expressions of a sense of the need to change along with a certain comfort level related to making changes. Also, they are statements of professional growth.
	Seeing the *meaning* of practice and how to *reconstruct* it in context	There is more of an ability to identify the why and how of significant events (coding), which allows for a better formulation of means to improve – both practice and relationships.
Learning partner	Showing a sense of the way to maximize others' potential practice	Here there would be expressions of being confident enough to move individuals/groups to a higher level in the profession; also, how one does this without alienating collaborators.
	Seeing the means and measure of realizing innovation in practice	This requires systems thinking/adaptive expertise to see what innovation would require, but also, what is different in others' contexts—i.e. highlighting new things or re-coding existing things.
Scholar	Showing a sense of how to contribute to community knowledge base	Now the individual sees her/his worth within the profession to a high enough degree that s/he is willing to share her ideas productively within the community.
	Seeing the potential for innovation in context and within community	The ability to highlight and code has developed to a level where the individual can start producing artifacts suggesting meaningful change within the profession.

Coding was conducted by one graduate and one undergraduate student working under the supervision of the lead authors. Training sessions were held biweekly over a period of 3 months (six sessions). In between sessions, the two students coded segments from one of the data sources, then determined the level of matching of their codes. In the sessions, the students and the lead researchers worked through the nonmatching cases to refine definitions and achieve common understanding about the coding process (Holton, 2007). All transcripts from the three data sources were coded based on the scheme in Table 2. The undergraduate and graduate student achieved an interrater reliability of 89%, as determined by calculating the percentage of matching codes out of the total coded turns within the complete data set. Matching codes were defined as instances where the codes were the same and at least 50% of the coded text for the coders matched (Lampert & Ervin-Tripp, 1993).

To challenge any conclusions, we might draw about the way in which the MTFs understood and might potentially utilize key ideas from the conceptual framework, we explicitly engaged in a search for negative cases (Larsson, 2009; Mahoney & Goertz, 2004). Specifically, we looked for discursive events in which one individual surfaced an issue, described a challenge, or presented an opportunity related to teacher leadership and the other individuals involved in the conversation either offered no discernible response to it or responded with a pessimistic view of likely outcomes from these situations. We labeled these events as *missed opportunities*, and we will include insights gained from such events in the next section.

4 | PRESENTATION OF DATA

4.1 | Structure of the data presentation

Our research question for this study is "What does the data from the I-IMPACT program indicate about the MTFs' understanding of key principles of the conceptual framework and about the potential utility of those principles in guiding their leadership activities?" Given this, the presentation of data will be aligned with the conceptual components found in Table 2 (codes for data analysis). We will first examine the MTFs' understanding and potential use of professional vision, followed by a section on their understanding and potential use of professional identity. Within each of those sections, there will be subsections linking professional vision/identity to the four metaphors and the way they seem to be conceived by the MTFs. Finally, there will be a section that addresses a significant missed opportunity that speaks explicitly to the way the MTFs seem to understand one of the four metaphors. The first two sections will provide additional insights about the MTFs' sense of the four metaphors in relation to professional vision and professional identity. Within each section, we will provide data across our three sources (transcripts of the professional vision sessions, focus group discussions, and individual interviews) to offer evidence for our claims related to the research question.

4.2 | MTFs' understanding of professional vision and its relation to leadership activities

4.2.1 | Professional vision and the sense of fully functioning teacher leader

Professional vision had been an explicit focus of the I-IMPACT professional learning experience from the beginning when Brad (program team) ran a session to explain this construct and its relevance to teacher leadership at the first professional learning day. Part of the integration of professional vision into the professional learning in I-IMPACT was to have regular analysis sessions using videos from such sources as TIMSS (https://www.timssvideo.com) and Tools for Ambitious Science Teaching (https://ambitiousscienceteaching.org/video-series/). Despite this emphasis, the MTFs had difficulty fully understanding the meaning of professional vision, in part because members of the program team who were less involved in the research effort occasionally treated it as synonymous with a *vision for leadership*. This confusion is apparent in data from the winter year 3 individual interviews. In a section specifically designed to elicit the MTFs' ideas about professional vision, one cohort 2 MTF stated,[9] "But I think what this program has added onto that vision would be the leadership portion—that I'm not just helping my students achieve, but that other teachers are teaching better because of me." While it is encouraging to read that this MTF recognized how the program had

supported her/him in functioning as a learning partner for other teachers, her/his use of "vision" suggests that professional vision had been confused with vision for leadership. This, along with similar pieces of data, indicated a potential barrier to the MTFs' development as fully functioning teacher leaders: It is critical for teacher leaders to understand how "seeing" their practice more thoughtfully (professional vision) can support them in "seeing" their leadership work more meaningfully (vision for leadership). Various measures were taken to make the distinction between professional vision and vision for leadership more clear to all I-IMPACT participants.

While the initial confusion around professional vision was a concern, there was evidence of intuitive understandings about this core framework component that suggested a foundation on which more precise understandings could be built. For instance, in the same individual interview set that was referenced above (winter year 3), and in the same section of the interview (related to professional vision), another cohort 2 MTF stated, "As far as the way I run my classroom, I'm focusing a lot more on some of the things I've learned in the program. Like this past summer, we talked a lot about focusing on big ideas, big picture ideas that connect across ideas. Been trying to pull more of that into my classroom." This individual clearly associated professional vision with classroom practice and, in particular, being able to identify ("see") the big ideas that could tie different concepts within the curriculum together. We believe such understanding supports the MTFs in their development as both fully functioning teachers and teacher leaders.

In a later portion of the winter year 3 individual interview focused on understanding the role of reflection in the MTFs' leadership development, another cohort 2 MTF suggested that

> I think I do reflect more on what is working and what's not working and what could be working better—not just being happy that something went okay, that my students did okay or my students even did well, but saying, "Okay, they did do well." Now, what was best about that? What can I pull from that to make it even better next time?

The program team emphasized that, to provide instructional leadership (Neumerski, 2013), one has to evolve one's professional vision to be able to identify the factors that make pedagogical practices effective or not (highlighting) and be able to articulate those factors to others (coding). This statement indicates that, despite the confusion that might have existed at this point in the program, the message of how professional vision can support one's work as a teacher leader as reflective practitioner had been understood by this MTF.

4.2.2 | Professional vision and teacher leader as learning partner: The influence of mentoring

The program team strongly believes that professional vision development is fundamental to science teacher leadership development. This perspective comes from our stance that science teachers can best empower others and facilitate change if they deeply understand and can communicate their practices, especially those consistent with recent reforms (e.g., in the Advanced Placement Program and NGSS). This capacity, then, can be transferred to leadership practice as teachers utilize their professional vision to better imagine and define their vision for leadership to broader educational communities. We saw mentoring of new science teachers as a means of both supporting the MTFs' professional vision development and enabling them to engage in a critical form of teacher leader as learning partner (Davis et al., 2015). As such, the MTFs in both cohorts were asked to function as mentors to I-IMPACT TFs within the MTFs' first 2 years of the program (during the TFs' student teaching experience).

Several statements made by MTFs in the focus group discussions and individual interviews indicated that they recognized the role that developing professional vision played in their mentoring work. For instance, one of the cohort 2 MTFs, in the winter year 3 individual interviews, noted that s/he wanted to understand what strategies the TFs had learned in their preparation program because, "maybe best practice to those teachers is not what I'm saying the best practice is. Are there certain things that they want us to look for?" This suggested the need to generate a shared understanding of best practice through conversations between teacher preparation faculty, MTFs, and TFs. Those conversations occurred in year 3 of the program, as we trained the MTFs on the use of the EQUIP observation rubric.[10] The program team had the MTFs use this to analyze videos of the TFs' classroom practice, something they did collaboratively with the TFs while they were student teaching. While we do not have data on the immediate impact of this training, we do have data to show that the MTFs understood the relationship between their professional vision development and their mentoring capacity. In the summer year 4 cohort 2 focus group discussion, one MTF noted how her/his comfort

and skill in acting as a mentor had improved prior to hosting a second mentee: "This time, I felt much more prepared to be helpful to a student teacher. I think that was, in part, because I had more experience, but in part because I had began thinking about more carefully why it is that I do what I do, the way that I do it. I had come to a place where I could articulate that to other people."

It is crucial, in acting as a teacher leader as learning partner, to recognize that professional vision is mutually constructed, so that mentors/experienced teachers should be evolving their professional vision based on insights gained from mentees/new teachers, not just the other way around. In the winter year 4 cohort 1 focus group discussion, one MTF indicated that s/he had recognized this bidirectional flow of professional vision development:

> It's given you a chance to have other opinions to validate, not only what you do in the classroom, but giving you other things to try and other perspectives to look at. It gives you a fresh set of eyes, because the TFs are just coming out. I don't see it the way they see it. I need another way to look at it.

4.2.3 | Broader understandings of the relationship between Professional vision and teacher leadership

The data presented to this point suggest that, to a certain extent, the MTFs had achieved an understanding of professional vision commensurate with the conceptualization the project team had tried to convey. What that data has not done is to clearly show that the MTFs themselves were able to connect professional vision with teacher leadership. That the MTFs were effectively making this connection by year 3 of the program is evident in the statement below made by cohort 2 MTF Dennis. The statement came during the initial professional vision session in the summer of year 3 as part of a discussion, led by Gary (program team), around a video from a NY Times piece in which Jerry Seinfeld explained how he wrote his Pop Tart comedy bit (a clip link is in Appendix B). This video was intended to get at the difference between expertise and leadership. Here is what Dennis said:

> I think what's really important from being a good teacher, to being a teacher leader, is understanding why you're a good teacher, and being able to explain that to other people, and that's—it's not an easy thing to do. I mean, sometimes, I feel like a lesson went really well, and, if I want to be able to try to communicate with somebody else exactly how I talked about it, sometimes I'll have a difficult time.

Dennis's words illustrate both the highlighting ("understanding why you're a good teacher") and coding ("being able to explain that to other people") processes of professional vision. More importantly, he explicitly articulates the link between this component of the conceptual framework and teacher leadership. Evidence that the ability to make this link was not isolated to a single MTF came from a separate professional vision session (also led by Gary and focused on a TED talk by Sarah Parcak; see Appendix B) that was held in the spring of year 4. During that session, Lee (cohort 2 MTF) said, "So I think that's [knowing what is important in what a student says] something hard to teach. But maybe that would be something, learning how to show someone why that's an important statement or something like that in our teaching. I think that would be a challenge for a teacher leader." A science teacher must be able to recognize key ideas in students' mental models to help them refine their thinking (Levin, Hammer, & Elby, 2012); a teacher leader as learning partner must be able to recognize key ideas in their collaborator's thinking to empower them to promote change (Banilower, Boyd, Pasley, & Weiss, 2006).

That the MTFs continued to deepen their understanding of professional vision and to more fully integrate it with their notion of teacher leadership is visible in this passage from one of the cohort 2 MTFs captured during the summer year 4 focus group discussion:

> We think of this as a leadership program. So, I think we focus on outside of our classroom so much. We forget maybe what's going on inside our classrooms and how we've changed and grown as teachers and how we see our students and we see those lines of questioning and we know how to guide the students more. Maybe, to us, it [professional vision] just seems like a small piece, because it's in our rooms. And that we are trying to talk more about leadership roles that we've taken on, or that we see ourselves taking on. Because we feel like that's what this program is about.

This passage identifies specific aspects of classroom professional vision that the MTF recognized: "we see those lines of questioning" and "we know how to guide our students more." The MTF's words also allude to an important tie between professional vision and professional identity: That the way the MTFs' professional vision has evolved impacts the teacher leadership opportunities that they are able to see themselves accepting. It is critical to the I-IMPACT program team that the MTFs translate the strengthening of their professional vision into a stronger professional identity as teacher leaders. It is also critical that they recognize the relationship between changes in their professional vision inside their classrooms and their leadership work related to producing changes outside their classroom, something to which this MTF refers.

4.3 | MTFs' understanding of professional identity and its relation to leadership activities

4.3.1 | Professional identity and teacher leader as scholar: Finding louder voices

The program team's view of teacher leader as scholar has been that this manifestation of leadership involves sharing the stories of one's leadership activities and lending one's voice to policy discussions. In the early stages of I-IMPACT, it was not apparent to the program team that this understanding of teacher leader as scholar might create an uncomfortable space for some of the MTFs. Nor did the program team recognize that the MTFs might respond to and reformulate that understanding in ways that would keep them away from that uncomfortable space. A cohort 2 MTF narrated a view of her/his teacher leader identity in the summer 4 focus group discussion that brought this issue to light: "[You] can also lead by example. You may not be blogging about everything you do or tweeting about it—getting this following or anything, but the teachers that you work with, the teachers that get paired with you, learn from you and your quiet leadership alongside that person." While this was coded as "Professional Identity – Teacher Leader as Learning Partner," it seemed productive for the project team to consider a different manifestation of teacher leader as scholar as suggested by this MTFs' words. Our definition of teacher leader includes the idea that "the individual is able to empower others to promote change," so it seems valid to propose, in line with what the MTF is implying, that helping others to gain a voice by leading alongside them would be a form of teacher leader as scholar. In other words, our analysis of the data caused us to reformulate *our understanding* of this aspect of teacher leadership.

In the same segment of the summer 4 focus group discussion, another cohort 2 MTF further validated the teacher leader identity being described by the MTF quoted above and helped to augment the image of what it would look like: "I want to be able to pull them along. You might be the leader that's not in the front, you may be like the one who is in the middle going, 'We can do this.'" Cain (2012) makes a powerful argument for this kind of quiet leadership, or, leadership from the middle, and the program team continues to explore ways to promote that understanding of teacher leader as scholar.

While the data cited above offered examples of the MTFs narrating themselves as quiet leaders, other data suggested transformations in the way the MTFs saw themselves exhibiting leadership. Data from the same focus group discussion (cohort 2, summer 4) demonstrated that at least a couple of MTFs had become comfortable with identities as more vocal leaders and indicated what the I-IMPACT program had done to support this transformation. One MTF noted, "I think that that [the program] has given me more confidence in the sense that … that, when I go back to my school, sometimes my quiet opinions have become much louder opinions." The evaluation team's summary of another cohort 2 MTF's response provided further explained the identity change and the reasons for it: "Another MTF attributed her confidence to her recognition that her contribution was valuable, if not unique: 'I think it's given me more confidence that my opinion or my perspective of what teaching should be is not unique; it *is* … even more so than [I] thought to begin with.'" The program team has interpreted this in terms of the conceptual framework: As individuals recognize that others see the issues in education similar to the way they do, those individuals become more comfortable in moving from quiet leadership to vocal leadership. This transformation in leadership identity is supported by an evolving professional vision that allows a group of teacher leaders to better see and articulate educational issues, and achieve consensus viewpoints about them.

One aspect of leading alongside others is understanding how to build the best relationships to accomplish leadership goals. In the summer 4 cohort 2 focus group discussion, one MTF had conceptualized a change in her/his approach

to building such relationships as better recognizing how to maximize "informational transactions" (so labeled by the evaluation team). This is how the cohort 2 MTF described that change:

> I've begun to see the value of continuing relationships or building and maintaining relationships and continuing to feed off of each other in unexpected ways. I do things now that I wouldn't have done three years ago. I make it a point to introduce myself to people who may have come and talk to me about a certain topic. Whereas, before, I would have just taken in information and gone about my way.

It is not clear from the data what caused the MTF to understand the value of this aspect of being a teacher leader as scholar. However, the program team contends that bringing in nationally recognized science teacher leaders, such as Ramsey Musallam, whose TED Talk is well known to many science teachers,[11] and Larry Dukerich, who is one of the lead educators for the American Modeling Teachers Association, contributed to this. One important aspect of their interactions with the MTFs is that individuals such as Ramsey and Larry were asked to share the stories of their journeys into leadership. The program team believed that seeing that the stories of these individuals were not that different from their own stories would strengthen the MTFs' teacher leader identities (Janson, 2008) and make them more confident in pushing the boundaries of their comfort zones.

4.3.2 | Professional identity and becoming a fully functioning teacher [leader]: Your failures are your experience

There was an important discussion thread that linked the MTFs' understanding of leadership to their views of risk taking (Birkeland Nielsen, Eid, Mearns, & Larsson, 2013; Lumby & Foskett, 2011) and that occurred across three professional vision sessions in the summer of year 3. The first session was lead by John (cohort 1 MTF) and associated with a Veritasium video. The video focuses on explaining how trees transport water from their roots to their uppermost branches (see Appendix B). However, the video also devotes time to having scientists present hypotheses about this issue—hypotheses that are ultimately shown to be incorrect. Natalie (cohort 1 MTF) highlighted this feature:

> But, that's what I kind of took away from it, like all those experts, they took a risk to try to figure out how this new system works, to see the system differently than they had before. And I think that's, you know, essential to leadership, too. You have to take risks, you have to be okay with, with failures, and not always feeling like you have the answers.

In this statement, Natalie echoed a key idea that the program team had developed as one of the maxims of our conceptual framework: *To be able to see differently, you must be able to see as*—connecting professional vision (see as) to a vision for leadership (see differently). Natalie, though, took this further by building a bridge to professional identity: As a leader tries to promote change and innovation—seeing and doing things differently—they are going to inevitably be confronted with failures. And leaders must be comfortable with those failures and the sense of not having all of the answers that comes with such experiences; this is likely core to becoming a teacher leader as fully functioning person. Natalie also connected this to a systems perspective, and it is clear that becoming fully functioning as a teacher or teacher leader is contingent on understanding the system in which one operates. Tapping into their existing knowledge of systems thinking (Rosenkränzer, Kramer, Hörsch, Schuler, & Rieß, 2016) could be a powerful way for science teacher leaders to understand their work.

The relationship between risk taking and leadership would be taken up again in the next professional vision session. This session was lead by Natalie and focused on a TED talk by Uri Alon.[12] Alon's main idea in the talk was that, on the way along the supposedly linear path between a scientific research problem and its solution (point A ➔ point B), we often end up at a point C—which he metaphorically referred to as *the cloud*—where the way forward is not so clear. Of course, the sense of uncertainty we feel when we realize we are in the cloud produces a great deal of discomfort, and Mark (cohort 2 MTF) noted in the discussion following the video that this was part of the professional identity of becoming a fully functioning teacher leader:

And I tell my kids in my classroom [that they need to be okay with feeling uncomfortable]. And I would be a total hypocrite if I didn't do the same thing and feel like I wasn't stretching myself and being in an area of discomfort or trying to stretch. You know, stretching them as students and trying to teach them to think more strongly. And the same thing for me, professionally and personally, is, sometimes in order to improve or become greater, you have to be uncomfortable for a set amount of time. And if that discomfort never comes, then you're being very complacent and plateauing. So if you have to put yourself in situations, I think that's hopefully what most of us are trying to do—do things that are new and different in this program to make us uncomfortable, so that we learn from it and grow from it and hopefully become better professionals and teacher leaders.

A great deal of the ensuing conversation revolved around how the development of adaptive expertise allows you to be more fully functioning as a teacher and teacher leader through taking risks because "If you have this one plan, and you have no idea what you'll do if that fails, then you can't adapt. But if you've done something five different ways, then try something new," you can adapt if it doesn't work (Dennis, cohort 2 MTF). However, for Russell (cohort 1 TF), that suggestion carried with it a concern for him as a novice in the profession:

And so, and that's hard as a new teacher that yeah, in five years, or like you [Aimee, cohort 2 MTF] said, in eight years, I'll do great. Well, I can't have that conversation for seven more years, you know. And that's—that's stressful. And I mean, Ashley [cohort 1 MTF, who was Russell's mentor for student teaching] is always like, "It's no big deal." [Pause] It's a total *big deal to* me.

While there were a number of ways that the MTFs in that session could have responded to Russell's point, the response that was given by John (cohort 1 MTF) indicates where the MTFs were in relation to their understanding of risk and being a fully functioning teacher/teacher leader:

But I think that's what she's [Ashley's] saying to you, though. What she's saying is it's no big deal if you fail, because we all fail … So when you say, I can't buy that experience, what she's saying is, "This is your experience." Your failures are your experience, and that's what science is anyway, right?

In a culminating moment of this multiconversation thread, John made a statement—*your failures are your experience*—that transformed the relationship between risk and leadership. John's understanding of that relationship is that, instead of fearing the failure that inevitably accompanies becoming a teacher/taking on leadership, one needs to embrace such failure as *part of the pathway to becoming* a fully functioning teacher/teacher leader. Significantly, John's closing connection to science ("that's what science is anyway") demonstrated his ability to code this critical idea in a way that should have allowed it to resonate with Russell. It also illustrated how conversations around *STEM* teacher leadership may be different from *general* conversations about teacher leadership, as John was referencing an aspect of the nature of science (Allchin, Andersen, & Nielsen, 2014) in drawing this parallel.

4.4 | A missed opportunity: Teacher leaders as learning partners with administrators

The data presented above illustrate the varied ways in which the MTFs have taken up important principles related to the conceptual framework. Importantly, though, there were several occasions within the data set where such uptake of ideas could have occurred and did not. We have chosen one of these missed opportunities to discuss here. It was chosen because we were able to identify various related pieces of data throughout our corpus to allow us to perhaps understand why the lack of uptake occurred. That data also allowed us to determine how prevalent the issue that it represented was. It is critical to present an instance like this as both an example of a disconfirming case (Tsang, 2014) of the positive influence of the I-IMPACT program on the MTFs' understanding of leadership, as well as an illustration of the work that remains to be done in supporting the MTFs' development as teacher leaders.

The critical event took place during Gary's (program team) professional vision session focused on the Seinfeld video. It occurred when Courtney (cohort 1 Teaching Fellow) drew a parallel between something Seinfeld said and her own experiences interacting with administrators:

> *I thought it was funny that he [Seinfeld] said, "Explaining this whole thing to you is a waste of time," which is exactly the way I feel about producing lesson plans for my administrators. Why don't you just come and see what I'm doing? But like, me writing all this down in this format for you, is to show you that I'm doing what I'm supposed to be doing, and to me this is like, kind of comical.*

One would expect to find data illustrating the expression of concerns about the educational focus of administrators by this group of new and experienced teachers. However, one would also have anticipated that one of the MTFs would have recognized that it is the role and responsibility of teacher leaders to engage administrators in conversations about their foci so as to generate a common understanding of effective practice—including the production of artifacts to represent that practice. In the terminology of the I-IMPACT conceptual framework, there was an opportunity for the MTFs to describe how they could act as teacher leaders as learning partners with administrators by having conversations to promote a shared professional vision with them. No such recognition of this role and responsibility occurred in the discussion around Courtney's remark. A field note associated with the Seinfeld session marked this issue.

The identification of this issue caused the program team to conduct a broader review of the data related to it. That broader review indicated that there was, in fact, little evidence of the MTFs showing a comfort or a capacity for functioning as learning partners with administrators. The immediate response of the program team to this insight was to have a panel discussion involving several regional administrators during the year 4 summer retreat. We also dug deeper into the data to understand better the nature of this issue and its prevalence so as to better structure future experiences in I-IMPACT to more fully address it.

A couple pieces of data that provided further insights into this issue were found within the year 1 cohort 1 focus group summary. This data represented the cohort 1 MTFs' very early views of teacher leadership as they had only been in the program for a half a year by that point. When asked to describe a definition of teacher leadership in relation to leadership activities, one MTF said that s/he was concerned with trying "… to help provide a support network for teachers coming into our disciplines. I think … if you come into a chemistry or a physics position you can feel very alienated." Later in the same focus group, in response to a prompt about the experiences they had had with the program to that point, one MTF noted, "I feel like, just within this room, I have a support network. I feel like I feel comfortable enough emailing anybody in this room and asking a question … and I don't think I've ever really felt like that before, even though I've been teaching 5 years." If one's professional identity is tightly tied to the disciplinary community of which one is a part (e.g., chemistry and physics teachers in this case), and if there is a belief that members of that community experience isolation, then it would make sense that most activities of teacher leader as learning partner would focus on one's peers rather than on one's administrators.

Another insight into the source of this issue came from the winter year 3 cohort 2 individual interviews. Within a discussion of the current state of their teacher leadership efforts, one of the MTFs opined,

> *Our school I feel has a lack of leadership from the administrative level. We have a principal who is a really nice guy. He does good things, but I feel like if I were to be talking to him about possible things to do in the school, that he would … To me he's kind of a "yes man"—besides [saying] that's a great idea, there's really no follow up.*

It stands to reason that, as one's own understanding of leadership and the use of it to affect change increases, one would concomitantly become less tolerant of those in formal leadership positions who do not facilitate such efforts. This would likely manifest itself as the teacher leaders not working *with* those individuals—i.e. serving as learning partners, but instead trying to work *around* them to produce change (Hinnant-Crawford, 2016). That approach to leadership would appear as indispensable in situations where there is regular turnover in administrators in a school, something alluded to in this quote from the summer year 3 cohort 2 focus group discussion:

> *My understanding of what a teacher leader is, and working with other teachers in my school, is that maybe it doesn't matter to me much if the administration changes. I definitely feel like I have a clearer idea of it's about having relationships with other teachers in the building, and those relationships exist regardless of changes in administration I guess is what I mean.*

There were examples from the data where MTFs suggested that, in fact, they had come to understand how and in what ways they could serve as teacher leaders as learning partners with administrators. For instance, in the summer year 4 cohort 2 focus group, one MTF said, "I kind of feel like there are some issues I feel more responsible to start trying to help fix and maybe work with my administrators to try to help." In the winter year 3 cohort 2 individual interviews, an MTF was more specific about the ways in which the I-IMPACT program had supported her/him in envisioning this kind of teacher leadership: "I feel that I am empowered to discuss things with the administration, maybe share some articles, personal research proving things to back up ideas I might have. Just to form that team between the teachers and the administration, try to build the school culture."

While there was data showing ways in which the I-IMPACT program had supported the MTFs in understanding how to be teacher leaders as learning partners with administrators, there was also data that showed where the program could have facilitated that understanding more. For example, the program team missed an opportunity to use the TLE in which the MTFs were engaged early in the program to build understanding of this form of leadership. In the summer year 2 cohort 2 focus group discussion, one MTF complained that

> I felt that with the TLE course that it was geared more towards administrators, or from an administrator's perspective, and I felt like that aspect of it was not beneficial to us. A lot of it was geared towards teachers, but I felt like the administrative parts of it could've been avoided to give more time to some of the things we felt were more important.

There was an opportunity to tie the structure of the TLE course to professional vision and the way it can support one in being a learning partner. One cannot serve as a learning partner without working to attain a communal professional vision with one's collaborators. In that sense, focusing the TLE course on "an administrator's perspective" would allow MTFs to highlight and code aspects of their practice in ways that would make sense from an administrator's point of view. This can allow consensus to be reached as to how to achieve desired changes in schools. Had the TLE course been framed this way, the MTFs might have understood what it means to be a learning partner to an administrator—and there might have been a productive reply to Courtney's remark.

5 | DISCUSSION AND IMPLICATIONS

The significant increase in emphasis placed on teacher leadership in the past decade requires a deeper understanding of the conditions needed to support the development of teacher leaders. The I-IMPACT conceptual framework has provided guidance for us to structure the conditions for the training of 16 science teacher leaders—the MTFs. The focus of this paper was on analyzing the MTFs' understanding of the components of that framework. Our argument is that this understanding will determine the extent to which the framework can serve as a support mechanism for the MTFs' development as teacher leaders.

The data analysis focused on the four metaphors of teacher leadership and on the components of professional vision and professional identity. The significance of professional vision to our framework was captured in the first of our bullet points defining teacher leadership (see the Literature Review) when we stated, "An individual gains a deep understanding of educational practice …." The second bullet point suggests that "through those understandings [of professional vision] the individual is able to work with others to develop a vision for producing innovation in the system." Through these statements, we are asserting that, to become a fully functioning science teacher leader, one must have an evolved professional vision that allows one to work with others to develop a vision for leadership. One of the findings from the data analysis was that, in the early stages of the I-IMPACT program, the MTFs did not fully understand this relationship, and so confused professional vision with vision for leadership. It is clear from this that successful application of the framework requires those using it to fully distinguish between the two concepts. More recently, we have tried to help the MTFs understand how their ability to identify and articulate key aspects of NGSS-like practices, such as the use of phenomenon (Bobrowsky, Korhonen, & Kohtamäki, 2014) and storylines (Roth, 2014) in their teaching—i.e. their

professional vision can enhance their ability to work with students, parents, and administrators to bring about reform in science teaching—i.e. their vision for leadership.

Our data analysis showed that, with a concerted effort on emphasizing the distinction, the MTFs did gain clarity on the meaning of professional vision. More importantly, the MTFs started to understand the connection between their evolving professional vision and their development as science teacher leaders. Specifically, the data suggested that the MTFs began recognizing the way in which their growth into fully functioning science teacher leaders, as supported by an evolving professional vision, could enhance their work as teacher leaders as learning partners and scholars. Moreover, the MTFs—as well as the program team—came to realize that an evolving professional vision can strengthen one's professional identity as a science teacher leader in two significant ways. First, it can help one recognize what it is in one's practice that is valuable and why, so that one can gain the self-efficacy to share those aspects of one's practice with others (Angelle & Teague, 2014). This supports one's work as a teacher leader as scholar. Second, it enables one to better see how the strengths and weaknesses in one's own practice align with the core issues of a change effort, such as the implementation of NGSS, to allow better decisions to be made about how and when to engage in leadership activities (Westaby, Probst, & Lee, 2010). Identifying the core issues of a change effort and recognizing those efforts for which they are best positioned to have an impact will allow teacher leaders to function more efficiently and support them in maintaining a better work-life balance in the face of additional time commitments demanded by their leadership activities (Hansuvadha, & Slater, 2012).

From the bullet points representing our definition of teacher leadership, the "deep understanding … of her/himself in relation to that practice and to the system within which s/he operates" represents professional identity. Our data indicate that the MTFs recognize that they must be willing to embrace risk as not only a *necessary component of* teacher leadership, but perhaps even as *part of the pathway to* teacher leadership. In other words, a fully functioning teacher leader might only become so after s/he has learned how to respond to risk productively. We found limited data specifically addressing teacher leader as reflective practitioner – other than in sections of focus group discussions specifically examining the role of reflection in the MTFs' leadership development. This has caused us to consider a revision to our conceptual framework, as will be discussed below.

In attempting to present a trustworthy (Anney, 2014) analysis of the MTFs' understanding of the principles within the I-IMPACT conceptual framework, we highlighted a missed opportunity related to teacher leader as learning partner. We identified the MTFs' strong proclivity to function as learning partner to *colleagues* – both inside and outside their schools. A couple of the MTFs clearly connected this to concerns about the sense of isolation and lack of peer networks associated with their disciplines (chemistry and physics). We identified that same concern as one of several possible explanations for why there was a missed opportunity related to the MTFs acting as learning partners to *administrators*. It is important for the science education community to recognize that the commitment to their disciplinary communities, heightened by limits in the number of colleagues with whom they interact, may cause chemistry and physics teachers to overly focus on being a learning partner to colleagues—at the expense of being a learning partner to administrators. This may especially be true in rural areas (Goodpaster, Adedokun, & Weaver, 2012). This issue is likely to be exacerbated in the case where science teachers feel a tension with administrators because the administrators do not have science backgrounds and cannot offer the kind of support science teachers seek (Bruce-Davis et al., 2014). There is research to suggest how productive relationships with administrators might be engendered (Hess, 2015; Mills, Huerta, Watt, & Martinez, 2014), and the science education community should give attention to this aspect of science teacher leadership.

With regard to teacher leader as scholar, the data suggested that some MTFs initially had understandings of this metaphor more aligned with the limited description of it offered by Dempsey (1992) than the more expansive view of it held by the I-IMPACT program team. Dempsey's description focused on teacher leaders as *consumers* of scholarship, whereas we have focused on teacher leaders as *producers* of scholarship. If one could show that science teacher leaders were generally less inclined to engage in communicating the outcomes of their leadership activity or to publicly voice views on policy matters than teacher leaders from other disciplinary backgrounds (e.g., social studies), hen this would have important implications for professional learning designed for science teacher leaders. We do not have literature or data to verify that this difference exists, but have anecdotal evidence from our work

with broader groups of teacher leaders. Recognizing the value of having science teacher leaders participate in conversations related to such important issues as the debates around politically-charged aspects of the new science standards (Mervis, 2013; Rothman, 2011), this becomes an aspect of science teacher leadership needing further study.

The project team recognizes that we ourselves have additional work that needs to be done. First and foremost, we need to determine whether the understandings our MTFs exhibited in the data are being translated into commensurate science teacher leadership activities. A significant limitation of this particular study is that we have focused on what the MTFs *say* as our main form of evidence of their understanding of the principles we have emphasized. The literature indicates that there are often significant differences between one's espoused beliefs and one's enacted beliefs (Chen & Leung, 2015; Skott, 2014). Thus, to truly demonstrate that the I-IMPACT conceptual framework and the professional learning designed around it have influenced the MTFs in their process of becoming and being teacher leaders, we will need to, in the future, show the ways that they have acted in accord with that framework.

While the focus of this paper was on exploring the MTFs' understanding of the principles of the I-IMPACT conceptual framework, the program team continues to employ our research to refine that framework. For instance, within the first couple years of the project, we had paired the original two components of the framework – professional vision and professional identity – with two additional components: *adaptive expertise* (Crawford, Schlager, Toyama, Riel, & Vahey, 2005) and *systems thinking* (Senge, 2006). We see both of these as ways for the MTFs to enhance the insights gained from developing their understandings of themselves (professional identity) and of their practice (professional vision) and apply them to their leadership activities. We highlighted that Natalie invoked a systems perspective in the discussion around the Veritasium video, and we have other pieces of data that show that MTFs have taken up a systems approach. This is significant because researchers (e.g., Hoban, 2002; Kensler, Reames, Murray, & Patrick, 2012) have shown how systems thinking can improve one's leadership capacity. There is an important converse to this effect that has implications for science teacher leadership: Developing a deeper understanding of systems thinking from engaging in leadership activities can support a science teacher's classroom activity as she can better facilitate her students' use of the crosscutting concept of *systems and system models* in exploring scientific phenomena (Gunckel, Covitt, Salinas, & Anderson, 2012).

Further, we have revised our set of metaphors for describing manifestations of teacher leadership. Recognizing that the distinction between teacher leader as fully functioning person and teacher leader as reflective practitioner had little analytical utility—and likely little practical utility—we collapsed these into the new metaphor *teacher leader as effective practitioner*. We maintained the metaphor *teacher leader as learning partner* as is. Finally, in line with the descriptions of the different spheres of influence of a teacher leader (Dozier, 2007), we have replaced a removed metaphor (fully functioning person) with *teacher leader as policy voice* (see Figure 1 below for the current conceptual framework). From a survey response given by one MTF following a recent I-IMPACT meeting, it is evident s/he is ready to move into this sphere:

> I'd like the group to start taking on bigger issues in our profession. I think we've dealt intrinsically enough over the past few years. Time to think broader. Ex.: College Board monopoly and its impacts on the education system. Socioeconomic segregation. What should new teachers be teaching? What is education really, and how have the government and corporations Americanized, capitalized, and characterized it?

Hopefully, we can continue to support all of the MTFs into expanding their spheres of influence and in their becoming and being teacher leaders. And, ideally the I-IMPACT framework will serve as a model to assist others in their work around STEM teacher leadership.
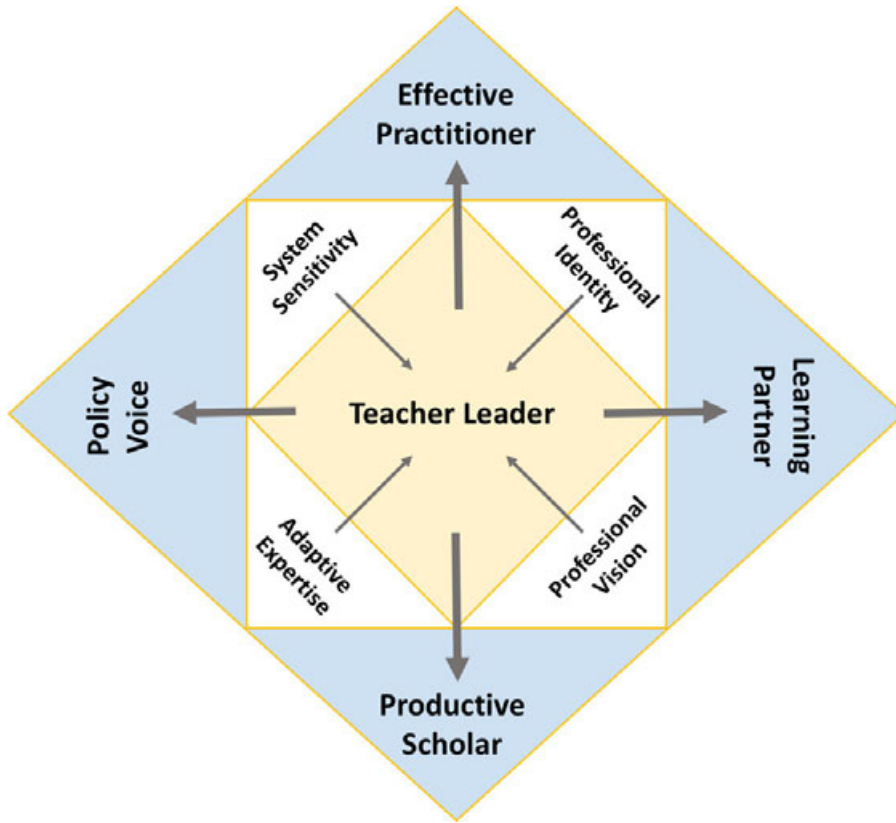
FIGURE 1   The updated I-IMPACT teacher leader conceptual framework [Color figure can be viewed at wileyonlinelibrary.com]

ENDNOTES

[1] This quote was found on AZ Quotes, which is retrieved from http://www.azquotes.com/quote/520723.

[2] That STEM Dear Colleague letter can be accessed at https://www2.ed.gov/programs/promiseneighborhoods/stemdearcolle agueltr.pdf.

[3] The Building STEM Teacher Leadership web site was originally hosted at http://stemteacherleadership.org, but has since been moved to https://innovation.ed.gov/what-we-do/stem/building-stem-teacher-leadership/.

[4] The Kentucky Teacher Leadership Framework can be accessed at https://education.ky.gov/teachers/Documents/Kentucky %20Teacher%20Leadership%20Framework.pdf.

[5] Sarah Parcak's TED Talk can be accessed at https://www.ted.com/talks/sarah_parcak_archeology_from_space. Information about its use in the I-IMPACT professional learning experiences can be found in Appendix B.

[6] The Veritasium video "The Most Amazing Things about Trees" can be accessed at https://www.youtube.com/watch?v = BickMFHAZR0. Information about its use in the I-IMPACT professional learning experiences can be found in Appendix B.

[7] The I-IMPACT team contracted with a local service agency to provide the MTFs the coursework needed to complete the TLE. The training associated with the endorsement was provided by George (pseudonym) who has maintained involvement in the program even after his training work was completed. The TLE coursework was completed the first 2 years of the program by each cohort.

[8] An example of dissemination activities was the yearly retreat we held in October starting in 2014 where MTFs and TFs ran sessions where they shared best practices with each other and with other regional Noyce fellows and secondary teachers.

[9] As noted in the Methods section, the identities of the MTFs in the focus groups and individual interviews were not shared with the research team by the evaluation team as a means of maintaining a commitment to anonymity made to the MTFs by the evaluation team during the informed consent process.

[10] The EQUIP (Electronic Quality of Inquiry Protocol) is an observation protocol by Marshall, Horton, Smart, and Llewellyn (2009). This should not be confused with the EQuIP rubric for analyzing curricular materials for their alignment to the 3D learning emphasized in NGSS.

[11] The talk is titled "3 Rule to Spark Learning" and can be accessed at https://www.ted.com/talks/ramsey_musallam_3_rules _to_spark_learning.

[12] Natalie had sent an email out to the entire I-IMPACT community a month before the summer year 3 retreat discussing the Alon video and its impact on her thinking about teacher leadership. The content of that email can be found at the end of our previous paper (Criswell, Rushton, McDonald, & Gul, 2017).

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APPENDIX A: SELECTED INFORMATION ABOUT THE I-IMPACT MASTER TEACHING FELLOWS

Pseudonym	Main subject	Years experience	Degrees/certifications
Cohort 1			
Ashley	Chemistry	10	B.S. in life science education, T-6 broad-field science, gifted certification, working on Ph.D. in science education
Henry	Physics	17	B.S. in aerospace engineering, M.S. in aerospace engineering, T-5 certification in physics and mathematics, gifted in-field
John	Physics	10	B.S. science education, T-5 masters leadership, T-6 EdS leadership, gifted certified, AP physics certified
Natalie	Chemistry	6	B.S. in biochemistry, MAT chemistry education, chemistry and physics certified, gifted endorsement
Patty	Chemistry	8	B.A. chemistry and biology, M.Ed. science education, broad-field science, gifted in-field
Tess	Chemistry	5	B.S. chemistry, M.S. forensic science, chemistry certified, gifted in-field
Cohort 2			
Aimee	Chemistry	5	B.S. chemical engineering, Ph.D. chemical engineering, chemistry certified, teacher leader endorsement
Barrett	Physics	8	B.S. microbiology, masters science education, physics certified
Cassandra	Chemistry	6	B.S. chemistry, M.Ed. educational administration and policy, physics and chemistry certified, gifted endorsement
Dennis	Physics	8	B.S. secondary science education, M.S. secondary science education, broad-field certified
Elaine	Physics	11	B.S. physics, masters of education, broad-field certified
Lee	Physics	8	B.S. chemistry, M.Ed. science education, AP physics and AP in chemistry certification, broad-field certified, gifted certified
Mark	Physics	8	B.S., Ph.D. chemistry, AP physics and earth/space science certified, AP gifted training
Marty	Physics	5	B.S. chemistry, M.Ed. educational administration and policy, physics and chemistry certified, talented and gifted endorsement
Melanie	Chemistry	7	B.S. chemistry education, M.S. math education, provisional gifted certified
Wendy	Chemistry	5	B.S. chemistry, MAT chemistry, physics and chemistry certified, gifted in-field

APPENDIX B: A LIST OF THE PROFESSIONAL VISION SESSIONS

Presenter	Date	Topic and links
Gary	Jul 16, 2014	Jerry Seinfeld ➔ How to Write a Joke (https://www.nytimes.com/video/magazine/100000001965963/jerry-seinfeld-how-to-write-a-joke-.html)
Brad	Jul 17, 2014	Beau Lotto TED Talk ➔ Science Is a Tool for Everyone (https://www.ted.com/talks/beau_lotto_amy_o_toole_science_is_for_everyone_kids_included)
Mandy[a]	Jul 18, 2014	Gummy Bear and Kiwi Wontons (https://www.foodnetwork.com/videos/chopped-gummy-bear-wontons-0131770.html)
John	Jul 21, 2014	Veritasium, The Most Amazing Thing about Trees (https://www.youtube.com/watch?v = BickMFHAZR0)
Natalie	Jul 22, 2014	Uri Alon ➔ Innovation and the 'Cloud' (https://www.ted.com/talks/uri_alon_why_truly_innovative_science_demands_a_leap_into_the_unknown)
Tess	Dec 6, 2014	Panel Discussion involving Neil DeGrasse Tyson (https://www.youtube.com/watch?v = KEeBPSvcNZQ)
Aimee	Jan 31, 2015	The 2009 Ig Nobel Prize for Public Health (https://www.youtube.com/watch?v = Kxf3HK21BWI)
Marianne[a]	Mar 7, 2015	Mr. Rogers defending PBS to Senate (https://www.youtube.com/watch?v = yXEuEUQIP3Q)
Gary	Apr 18, 2015	Sarah Parcak TED Talk (https://www.ted.com/talks/sarah_parcak_archeology_from_space)
Brad and Jasper	Aug 29, 2015	Veritasium Video on Learned Helplessness (https://www.youtube.com/watch?v = YMPzDiraNnA)

[a]Denotes a TF presenter.