

Program attributes for developing and supporting STEM teacher leaders

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ABSTRACT

This study shares findings from a review of eight science, technology, engineering, and mathematics (STEM) teacher leader programs across the United States. With limited empirical research in STEM teacher leadership, the goal of the study is to build the research knowledge about STEM teacher leader conceptualization and structure. Results from this descriptive case study showed that the programs either focused on *developing* teacher leaders or *supporting* teacher leaders. Programs focused on *developing* teacher leaders typically were programs working with teachers new to the idea of teacher leadership whereas programs focused on *supporting* teacher leaders tended to work with teachers who had some prior experience with teacher leadership. Using a constant comparative analysis, additional results revealed all programs included emphasis on professional development, graduate coursework, networking, mentoring, and sharing knowledge with differing degrees of prominence depending on if the program's focus was on developing or supporting teacher leaders. Implications include specific program curricula that may be implemented in STEM teacher leader programs.

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Introduction

Attention to teacher leadership efforts has grown internationally through comprehensive reviews (Frost, 2011; Nguyen et al., 2019; Pineda-Báez et al., 2020; Wenner & Campbell, 2017; York-Barr & Duke, 2004). More specifically, science, technology, engineering, and mathematics (STEM) teacher leaders are becoming increasingly important (National Research Council, 2014; Yow et al., 2021). Hence, finding ways to develop STEM teacher leaders needs investigation (Sinha & Hanuscin, 2017; Smith et al., 2017).

In 2018, a multi-institution research study supported by the National Science Foundation (NSF) Robert Noyce Teacher Scholarship Grants (also known as Noyce grants) began studying the structures of eight STEM teacher leader programs (also referred to as projects). Those projects were at different points of implementation: five had concluded at least one year before data collection started, while three were still in progress. Additionally, these projects were geographically distributed across the United States. The descriptive case study (Yin, 2017) explored in this study focused on the research question *How do STEM teacher leader programs differ in conceptualization and structure?* The study uses aspects of the Smylie and Eckert (2018) 'conceptual-theoretical model' (p. 556) to present program conceptualizations and structures. The concepts of communities of practice (Wenger, 2010) and professional identity (Caza & Creary, 2016; Day, 2018) are also employed to look across all eight programs. It is important to note that given the current dearth of research on STEM teacher leader program attributes (Mohan et al., 2017; National Research Council, 2014), this study solely focused on program attributes and not on the impact of those program

attributes on program completers. Since program completer impact was beyond the scope of this study, subsequent studies are in progress to analyze program impact on program completers.

Conceptual framework

Smylie and Eckert (2018) highlighted a need to distinguish between the development of the leader (an individual) and the development of leadership (the process of developing leadership in an individual). We conceptualize this distinction as being between *developing* teacher leaders and *supporting* teacher leadership. To help further explain this distinction, one may think of developing teacher leaders as working with novice teacher leaders and supporting teacher leadership as working with more experienced teacher leaders. The first group (novice teacher leaders) are teachers being introduced to teacher leadership and program design must be based on their initial learning about becoming a teacher leader. The second group (more experienced teacher leaders) are teachers being supported in their teacher leadership, in some cases already having completed an initial teacher leader development program. The eight Noyce projects showed variation in which of those two goals (developing or supporting) was emphasized and in how the achievement of the goal was envisioned.

Smylie and Eckert (2018) laid out a framework that represented ‘a conceptual–theoretical model to guide the practice of teacher leadership development’ (p. 556). Their model has eight core components. Given the projects in this study were predominantly university-based as opposed to school-based, this paper addresses the four framework components not focused on the school systems themselves. The focus of this paper will be on components that can be related to the structure and implementation of each of the Noyce projects, as presented in Table 1.

Table 1. Components of Smylie and Eckert (2018) teacher leader framework and key question to be addressed (Table view)

Component of Smylie & Eckert Framework	Key Question to Be Addressed in Project Analysis
Teacher Leadership Outcomes	What were the teacher leader identities conceptualized by the projects through their goals and outcomes?
Teacher Leader Capacity	What were the selection criteria for individuals in each of the projects and what was their experiential background as teachers/teacher leaders?
Developmental Activities and Experiences	What was the nature of the professional learning experiences and other activities conducted by each project, including opportunities for content learning and networking?
Teacher Leader Practice	What were the teacher leader activities that directly engaged the fellows, with a specific concern for opportunities for mentoring and professional presentations?

To fully investigate structural similarities and differences between the Noyce projects (e.g., what components and delivery of each program were similar or different), two other concepts are needed: community of practice (Wenger, 2010) and professional identity (Caza & Creary, 2016; Day, 2018). Wenger (2010) speaks to the need for a community of practice to be more significant than simply a group or team, but rather for that community of practice to be mutually engaged around the group or team’s purpose. Using aspects of Wenger’s community of practice framework allows us to analyze the way that the structures and experiences within the Noyce programs enabled communities of practice to exist. We use this lens as a broader grain size of analysis than the components of the Smylie and Eckert (2018) framework, and thus make more holistic statements about the nature of the Noyce projects relative to this concept.

The other concept required is professional identity (Caza & Creary, 2016; Day, 2018). Several authors have indicated that the formation of an appropriate professional identity is critical to the development of

teacher leaders (e.g., Collay, 2006; Criswell et al., 2018a; Sinha & Hanuscin, 2017). In particular, creating a sense of belonging (such as to the Noyce program; Jones, 2010) – belonging to a group with a common goal to improve – may positively influence teachers' leadership identities as their identities are strengthened by belonging to a group with the common goal of improving STEM education. As with community of practice, professional identity is used at a broader grain size by examining how developmental experiences and teacher leader practices within the projects may have been associated with a sense of belonging and a sense of empowerment for the Noyce program completers (hereafter referred to as fellows). This sense of belonging and its connection to teacher leadership development is a key contribution of this study. Offering potential teacher leaders a strong community of practice to which they can belong (i.e., a Noyce community in this study) creates a space for their growth and development as teacher leaders (Struyve et al., 2014).

Literature review

Hunzicker (2017) described a conceptual model for a teacher's development from teacher to teacher leader as a slow and recursive process, impacted by teacher dispositions and beliefs, availability of leadership opportunities, professional development, and other contextual factors. This model suggests particular areas of foci to connect with Smylie and Eckert (2018) components focused on teacher leadership.

Teacher leadership

Teacher leadership has been in the literature for almost 50 years (Andrew, 1974). According to Wenner and Campbell (2017), teacher leaders are 'teachers who maintain K-12 classroom-based teaching responsibilities, while also taking on leadership responsibilities outside of the classroom' (p. 7). Those responsibilities can be both formal and informal, and teacher leaders often find conflict in their work and identities in how best to merge their role as both a teacher and a leader (Cooper, 2020). Teacher leader characteristics include a focus on student learning, strong knowledge of content, empowerment of self and others, building trusting relationships, and collaboration (Lumpkin et al., 2016; Yow, 2007).

STEM teacher leadership

Research has also emphasized the need for content-specific teacher leadership development (Berg et al., 2014; Wenner & Campbell, 2017; Yow et al., 2021). Therefore, the research on STEM teacher leadership is growing. For example, Gillespie (2015) speaks to the need to develop strong STEM teacher leaders to help develop and guide STEM teachers. Knapp (2017) offers an autoethnography of her journey as a reluctant mathematics teacher leader. Smith et al. (2017) report on the use of an analytical framework to support mathematics teacher leadership development. Another study describes a professional development program for high school chemistry and physics teachers and cite program aspects that either discouraged and encouraged teacher leadership growth (Criswell et al., 2018). These studies tend to review an individual or one program, rather than looking across STEM teacher leader programs to gain a broader view of STEM teacher leadership development.

The National Research Council (2014) compiled a significant synthesis of the literature on STEM teacher leadership. The report identified a specific challenge that needed to be met by STEM teacher leaders: helping to support the implementation of the Common Core Math Standards (National Governors Association Center for Best Practices, Council of Chief State School Officers, 2010) and Next Generation Science Standards (NGSS Lead States, 2013). The report also discussed a more general need to involve STEM teacher leaders in 'education policy and decision making' (p. 14). Subsequently, the report notes that the empowerment associated with inclusion in such policy and decision making could have a greater impact on STEM teacher retention than even pay raises. Little attention in this report was given to the specific structures of STEM

teacher leader projects that had the greatest efficacy in developing the teachers' leadership capacity. This is an area in need of more focused investigation.

Methods

This descriptive case study (Yin, 2017) investigated program attributes of eight STEM teacher leader projects across seven states. These cases were chosen because they are a part of a collaborative research grant studying STEM teacher leadership. These cases were funded twice by NSF – once to develop STEM teacher leaders and a second time to then study the impact of those STEM teacher leader programs – so they are seen as having merit for further investigation. The cases in this study are the eight programs and their implementation of the phenomenon of STEM teacher leader programs. The guiding research question was *How do STEM teacher leader programs differ in conceptualization and structure?* The following sections describe the context, data collection, and data analysis.

Context

Each program was a part of the same federally funded (NSF) Noyce grant program and had been awarded funding separately in earlier rounds of competitive funding cycles. The projects, focusing on some combination of mathematics, science, and STEM, with rural and urban teachers, had an average of 23 participants with a range from 16 to 33 in each program (see Table 2). These projects lasted 5–7 years, with some still in progress at the time of Blinded Program data collection.

Table 2. STEM teacher leader program details (Table view)

	Discipline	Grade Band	Setting	Participants
Project A	Mathematics	K-12	Urban & Suburban	33
Project B	Mathematics	6-12	Urban	20
Project C ¹	STEM	6-12	Urban	18
Project D	STEM	K-12	Urban	22
Project E	Chemistry & Physics	9-12	Urban & Suburban	16
Project F	Mathematics	K-12	Rural & Urban	30
Project G ¹	STEM	K-6	Rural	14
Project H ¹	Mathematics & Science	6-12	Rural	20
Total Participants				173

¹These projects are still in progress.

Data collection

The study involved four data sources from all of the projects: (1) grant proposal documents, (2) interviews with each project principal investigators, (3) external evaluation reports, and (4) project documentation, including annual and final funding agency reports, and other project-specific data. These four data sources were chosen because they would provide insight into the planning (conceptualization) and implementation (structure) of the programs. Institutional Review Boards approved the study at each institution and consent was obtained to review all documents and interview transcripts.

Grant proposals

Each site submitted a copy of its original project proposal documents. These grant proposals were each 15 pages long and prepared by the principal investigators. Each proposal included information about the project

conceptual frameworks, broader project goals and objectives, details about the project team members, and explanations of the external evaluation process (see National Science Foundation, 2009, 2012, 2015, for grant proposal criteria). The funder specified the required sections of the proposal, such as Project Scope, Leadership Program, and Recruitment and Selection. The funder also included some requirements such as program participants must hold a master's degree or show success on a standardized examination, but the predominant amount of content and program design was left open to be developed by the proposers.

Interviews

Each project principal investigator was engaged in a semi-structured interview that lasted 60–90 minutes. These interviewees were chosen because they were the leader of each project and hence, would be able to speak to the research question foci of conceptualization and structure of their respective program. The basis of these interviews was to gain deeper insight into the principal investigators program development by, for example, asking questions about the project proposals as well as asking questions about program design or conceptualization that may not be reflected in other project data. Of the nine interviewees (six females and three males), each was an American who holds a doctoral degree and works as a professor at major American universities. Each interview was either held in person or via a video call. All interviews were audio recorded and transcribed. Sample protocol questions include: *What are the features of the Noyce project? What experiences can a fellow expect when participating in the project? Who was involved in providing these experiences? Would you create different experiences looking back? How did you think about building networks to support the project? What were the desired outcomes? What was the vision for the project and how did it develop?*

External evaluation reports

Each site submitted an annual external evaluation report for its project. The completed projects also submitted their final reports. The evaluation reports were required by the funder and completed by independent agencies not associated with the projects to allow for objective feedback. Included in the annual, evaluation, and final reports were information such as program components, meeting agendas, focus group summaries from project participants, and outcomes such as how many participants completed certain coursework or degrees.

Project documentation

The funder also required annual and final reports from each project. The three ongoing projects have not ended so do not yet have final reports. These reports were completed by the principal investigator and offer insight into how the proposals were operationalized. Reports may also include meeting agendas and outcomes such as presentations or published papers based on the project. Some projects also shared documentation including written reflections by participants, or transcripts of selection interviews of participants. Project documents such as these, as well as external evaluation reports, for example, are important for this study as they provide recorded information about each project that is able to be reviewed and analyzed to address the research question.

Data analysis

Data analysis occurred in three phases. Before data analysis begun, strategies to minimize researcher bias were carefully considered (Galdas, 2017). Having at least two research members from the team independently review the same data source as well as member checking detailed later were used to reduce researcher bias (Morse et al., 2002).

Phase 1 included an initial review of the grant proposals and principal investigator interview transcripts. The research team conducted a preliminary review of those two data sources to gain an initial perspective of

similarities across and differences among the projects. The research team met multiple times to discuss preliminary codes that were emerging across those two data sources. Phase 2 included an expansion of the data sources to include External Evaluation, Annual, and Final Reports. The research team then used the constant comparative method (Glaser, 1965; Kolb, 2012) across these four data sources to determine common sub-codes that aligned to the four key areas of exploration: the main-codes of Teacher Leadership Outcomes, Teacher Leader Capacity, Developmental Activities and Experiences, and Teacher Leader Practice (Smylie & Eckert, 2018). The constant comparative method was chosen to allow the research team to review data across sources, compare data across sources to reveal trends in the data, and then finalize trends from the data based on multiple iterations in the data. The unit of analysis was at the phrase or sentence level. Excel was used to record and organize codes. Each researcher independently reviewed the same data sources across one project, then reconvened to discuss initial codes found during that first analysis to determine common and axial codes. Phase 3 began with the research team discussing final codes to use across all five data sources. For example, all project data included references to graduate degrees or coursework so this data was coded using the sub-code ‘graduate coursework.’ This sub-code fell under the main-code from Smylie and Eckert (2018) Developmental Activities and Experiences as it was intended to further develop fellow content and pedagogical content knowledge to allow them to grow as teacher leaders positioned to help other teachers improve their practice. Any uncertainties or discrepancies were discussed among the research team until consensus was met. Then, the research team conducted a final analysis across all four data sources to finalize codes and themes. Data were coded by at least two members of the research team. The coded data were then organized into the four categories (Table 1) to allow patterns across the Noyce projects being studied to be determined, specifically similarities and differences in terms of features of the programs’ structures that related to leadership development and support. A total of 2,579 pages were reviewed for the analysis. Table 3 includes a breakdown of total pages reviewed per project.

Table 3. Total pages reviewed per project (Table view)

	Pages Reviewed
Project A	179
Project B	374
Project C	99
Project D	357
Project E	432
Project F	809
Project G ¹	19
Project H	360
Total Pages Reviewed	2,579

¹Project recently begun.

A draft version of the manuscript was shared with all principal investigators to allow for member checking. All principal investigators supported the manuscript with one principal investigator noting an error in their project description, which was corrected.

Results

The results section is organized around Smylie and Eckert’s (2018) last four components: Developmental Activities and Experiences; Teacher Leader Capacity; Teacher Leader Practice; and Teacher Leadership Outcomes (see Table 1). The Teacher Leadership Outcomes are presented first, representing the goals and objectives of each program. Teacher Leader Capacities are discussed next, captured in the selection criteria

used by each project. Developmental Activities and Experiences are described third, illustrating the professional learning experiences provided by each project to facilitate the fellows' development into teacher leaders. Finally, Teacher Leader Practices are addressed, demonstrating how the projects supported fellows in functioning as teacher leaders. For Developmental Activities and Experiences, we focus on Professional Development, Graduate Coursework and Networking as these areas emerged from the data. For Teacher Leader Practices, we emphasize Mentoring and Sharing Knowledge as these areas also emerged from the data. All five of these dimensions were prominent in all projects.

Teacher leadership outcomes

This section describes the goals and desired outcomes of the projects, highlighting similarities and differences across the projects relative to these elements. Data were mainly drawn from the grant proposals, with other data sources serving to triangulate findings and extend our understanding. Grant proposals served as the main data source here because they offered insight into the goals and outcomes planned by each program that contributed to teacher leaders identity outcomes. This section addresses the first query of the research question (i.e., how do STEM teacher leader programs *conceptualize* teacher leader programs) by sharing results from how principal investigators designed each program.

All projects included goals related to improving fellows' content, pedagogy, and teacher leadership skills. For example, one of project A's goals was to 'improve the fellows' mathematical content knowledge and pedagogical content knowledge' (evaluation report). All projects also included a pedagogical goal that spoke to the need to improve STEM learning for all students by cultivating 'high quality STEM instruction for all students' (project C, annual report). In addition, all programs included some attention to the development of leadership skills in participants. Whereas some projects spoke more broadly about teacher leadership development, other projects included more specific language in their goals. For example, one of project G's goals is to 'develop and implement STEM initiatives in the rural schools in which fellows teach, and disseminate the models and results of these initiatives as part of fellows' ongoing commitment to rural teacher leadership in STEM' (proposal).

The Teacher Leader Competencies (Teacher Leadership Institute, 2018) delineate three different categories of teacher leadership: instructional, association, and policy. Instructional Leadership Competency means teachers sharing their teaching expertise with others. Association Leadership Competency means learning how to facilitate and guide productive groups toward collective action. Policy Leadership Competency means teachers serving in local and national leadership capacities to help shape policy. Our analysis of the proposals revealed few specific references to either association or policy leadership goals in any of the projects. Project H mentioned a desired outcome of having their fellows become active in state and national STEM teachers' associations through membership and presentations (interview). Also, project C provided an *education policy* pathway as one of the professional learning tracks from which its fellows could choose (proposal). Otherwise, there was little overt attention to these two categories of teacher leadership.

Project goals seemed to diverge a bit based on whether the project was *developing* teacher leaders and/or *supporting* teacher leaders. For example, projects A, C, D, and F were all continuations of previous teacher leader programs. For example, project A had recently concluded another nationally-funded grant program which included a component focusing on developing teacher leaders so this teacher leader project included many of the same participants (interview). Therefore, since those participants had already completed a teacher leader *development* program, project A was more focused on *supporting* teacher leaders. Projects B, E, G, and H were starting initial teacher leadership programs and, as such, their initial experiences focused on *developing* teacher leaders, whereas the middle and latter parts of their programs focused on *supporting* teacher leaders. By *supporting*, it is important to note that teacher leadership in these programs continued to

include practice-based learning, building leadership as practice (Grootenboer, 2018; Raelin, 2016). Hereafter, developing teacher leader programs (i.e., Projects B, E, G, H) will be designated ‘DTLP’ and supporting teacher leader programs (i.e., Projects A, C, D, F) will be designated as ‘STLP’.

Teacher leader capacity

Teacher leader capacity focuses on an individual’s potential and receptivity to serve as a teacher leader. This section addresses the research question by offering insight into how program developers conceptualized their teacher leader programs based on the criteria they set forth in selecting participants. For example, some projects required established leadership positions before accepting participants into the program, which indicated their concept of an appropriate participant in their teacher leader program included someone with previous leadership experience. They conceptualized their program to serve this type of participant.

To determine teacher leader capacity, we reviewed the criteria used by each program in selecting their fellows. Much of the selection criteria was required by the funder. For example, strong impact on student achievement was required, which often included submissions of videotaped lessons or student work samples as evidence. Each project also had a requirement of a minimum three years of teaching experience, while most projects added additional years as a preference. As a comparison, project C (STLP) preferred a minimum of eight years of experience (proposal), while project H (DTLP) preferred a minimum of five years or more of experience (proposal). This section addresses the first query of the research question (i.e., how do STEM teacher leader programs *conceptualize* teacher leader programs) by sharing results from how principal investigators designed program admission requirements based on their conceptualization of the program.

Project selection criteria differed in a few areas. Depending on when the project was proposed to the funder (i.e. pre-/post-2015 call), some programs had to require a master’s degree for project admission, whereas other projects were required to provide fellows with an advanced degree (for example, a master’s or doctoral degree). For instance, projects C, D, E, F and H (STLP, STLP, DTLP, STLP, and DTLP, respectively) required participants to already hold a master’s degree. Conversely, projects A and G (STLP and DTLP, respectively) had to provide fellows with an advanced degree. Project A, for example, offered secondary participants a master’s, educational specialist, or Ph.D. in mathematics education, which included required courses in mathematics and mathematics education totaling at least 24 credit hours (evaluation report). Principal investigator interview data, along with data from proposals and evaluation data supported this result. The need for content-expertise as part of teacher leadership development has been cited in the literature (Berg et al., 2014; Wenner & Campbell, 2017). Thus, these programs either requiring or providing advanced study in participant content areas is seen as part of participant potential to serve as a STEM teacher leader.

Some projects included additional selection criteria beyond what was required by the funder, such as principal recommendations, as seen in interviews, proposals, external evaluation, and project documentation data. All four STLPs included such additional criteria. For example, projects A and F (both STLPs) cited past participation in a teacher leader program as favorable in the selection process. Application materials for these projects often included a request for evidence of leadership activities already completed or in progress. In contrast, DTLPs often included components, such as an essay, where applicants described their potential to serve in leadership roles. Project E (DTLP), for example, asked about any formal teacher leadership roles and activities during the selection interviews, and actually demonstrated a preference for candidates who showed leadership potential but who had not formally been in leadership roles or engaged in leadership activities (proposal).

Developmental activities and experiences

This component focuses on events and happenings within each program intended to help fellows grow as teacher leaders. The findings related to this component will be presented with regards to three key

dimensions: Professional Development, Graduate Coursework, and Networking. This section addresses the second query of the research question (i.e., how do STEM teacher leader programs *structure* teacher leader programs) by sharing results from what components – what structures – programs included in each program.

Professional development

DTLPs tended to initially devote more professional development to strengthening teachers' instructional practices than on other aspects of their professional growth. In the initial years of project H (DTLP), a STEM nonprofit completed a week-long professional development immersing the mathematics and science teachers in STEM topics – specifically technology and engineering, given that these areas were less familiar to the teachers (annual report). Supported by interview data, in later years, once fellows felt more confident in their content, project H shifted professional development to focus more on association and policy leadership (Teacher Leadership Institute, 2018).

STLPs tended to include more of a broader-educational-community focus in professional development. For example, project A (STLP) fellows attended half-day workshops each quarter and completed a mathematics curriculum guide for K-12 teachers in their partner schools. Not only was this curriculum guide development a form of professional development, but this document also was used to guide the content focus in subsequent professional development meetings in this project and in the schools (interview). Several of the projects used their professional development time to educate school administrators on STEM content. This had the potential to create better alignment between the fellows' Noyce and school communities of practice (Oppi et al., 2020; Qanay et al., 2021). STLPs seemed to incorporate this aspect of administrator involvement throughout their projects, whereas DTLPs tended to include this component later in the project, often after realizing it was a necessary element not included in the original project planning.

Graduate coursework

All data sources indicated that all programs showed a preponderance of graduate coursework focused on STEM content, with less of it related to education or leadership. The difference, however, across the DTLPs and STLPs came in the form of the placement of coursework in the project timeline and the depth of content. For example, project H (DTLP) fellows completed three graduate content courses during the first two years of the program. The mathematics fellows completed Algebra, Geometry, and Data Analysis & Probability; the science fellows completed Biology, Chemistry, and Physics (proposal). Project G's 15-month master's degree program (DTLP) included four content courses across the STEM fields during the first two years of the project: science, technology, engineering, and mathematics (evaluation report). The intent of including these courses early in the project was to help fellows develop expertise and confidence in these areas, something that would likely have enhanced their teacher leader identity (Mangin & Stoelinga, 2009).

For STLPs, content courses were more explicitly identified and at a more advanced level than DTLPs. For example, in project A (STLP) fellows earned either Master's, Educational Specialist, or Ph.D. degrees with courses focused on Mathematical Knowledge for Teaching (Hill et al., 2005, 2004). Interview data, external evaluation data, and proposal data showed this coursework lasted throughout the project and as would be expected for a terminal advanced degree, covered topics in more complexity than DTLPs.

Networking

The networking undertaken in each project will be delineated into two areas: vertical and horizontal. Vertical networking occurs between professionals who are perceived to have different professional status, whereas horizontal networking occurs between professionals who are perceived to have the same professional status (Hwang et al., 2004). These networking opportunities aided in the development of teacher leadership identity (Evans & Stone-Johnson, 2010) by allowing participants to connect with professionals they saw as in a more advance position than themselves who they viewed as leaders (vertical networking) as well as

colleagues who they viewed as leaders (horizontal networking). Once they were able to connect and interact with these leaders, they began to realize they had similar traits or were viewed as peers by these individuals, which helped develop their teacher leader identities.

Vertical networking Vertical networking occurred in two areas across programs: project team networking and external networking. Project team networking happened when fellows would network with members of the program teams. External networking happened when fellows networked with professionals they met at conferences, for example, or who were invited as guest presenters to project meetings.

Program team networking Formal opportunities for fellows to network with program management team members were included in all projects. Data from DTLPs suggested more emphasis on program team networking than STLPs. This result may be explained because STLPs had often followed programs where the fellows and project team members had already worked together. Hence, these programs would have already established networks amongst the project team. For example, project G (DTLP) included opportunities for fellows to serve on summer graduate course instructional teams alongside project staff and graduate students (annual). Project B (DTLP) data included comments describing how the fellows would contact the project staff ‘in all kinds of areas of life and work. So, there, we had a pretty nice personal relationship’ (interview). It seemed that fellows having close relationships with university faculty served as a form of validation for fellows’ teacher leader identities. As fellows and project team members worked more closely, some of these networks became more horizontal in nature, such as when fellows began team-teaching university courses with project faculty.

External networking Projects also included aspects such as conference attendance and guest contributors that encouraged networking with groups and individuals external to the project. For example, all projects provided opportunities for fellows to travel to professional conferences where they were able to network with additional STEM teachers and teacher leaders. Another type of networking, as seen in all projects, were the invitation of nationally recognized STEM teacher leaders to interact with fellows. As part of these experiences, the individuals were asked to share stories of their journeys into teacher leadership, which served to provide models of the fellows’ possible selves as teacher leaders. With project D’s (STLP) focus on teacher research, they provided opportunities for fellows to connect with STEM education researchers nationally (proposal). Interestingly, data from the program evaluations suggested that the fellows viewed these researchers as if they were peers rather than as if they had a higher professional status, suggesting that the fellows had been positioned to view these as horizontal rather than vertical networks.

Horizontal networking Projects embedded virtual and face-to-face horizontal networking opportunities, such as professional development and graduate coursework, for fellows to interact with one other. Fellow networking existed across all DTLPs and STLPs. Project F (STLP), for example, established a listserv but the program staff were intentional about giving the fellows time to respond to one other’s questions and comments before responding, in order to allow fellows to network among themselves and develop confidence in their own expertise. Project staff would only ‘jump in if I felt like I had something unique to add, that nobody had said after a day or two’ (interview). Project D (STLP) spoke to their program structure of mostly setting up teams of teacher leaders, which encouraged networking and team learning (Bouwman et al., 2017). As teacher research was a key aspect of their project, the evolution of those teams continued with only teachers serving on those teams as they had developed the research and networking skills needed to sustain the team work (interview). Across all projects as seen in interview, external evaluation and project documentation data, fellows created additional opportunities to network. Project A (STLP), for example,

noted that ‘one of the fellows started a twitter chat that would be weekly, and so people would get online and tweet’ (interview). Many projects spoke to group or individual texts as an important way for fellows to connect, especially in time sensitive ways. For example, since project H (DTLP) worked with rural teachers, two physics teachers who were the only physics teachers in their district would routinely text each other to gain answers to student questions or to find resources for upcoming lessons (interview). Networking in project E (DTLP) was influenced by the creation of smaller professional learning communities (PLCs) within the larger fellows’ cohort community. These project PLCs identified educational concerns to address, such as the number of out-of-field physics teachers in the state, and worked to design and implement solutions to those concerns (evaluation report). In 7 of the 8 projects, PI interviews and evaluation reports spoke to the joint enterprise of working to solve an educational problem that further strengthened the networks for fellows involved in such PLCs, often resulting in relationships that have been maintained well beyond the end of the Noyce program.

Teacher leader practice

This component attends to the particular features of the programs that worked to offer opportunities for Fellows to enact teacher leadership – or participate in the *practice* of teacher leadership. Results indicated that two elements were essential across the programs to address this component: Mentoring and External Sharing of Knowledge. This section addresses the second query of the research question (i.e., how do STEM teacher leader programs *structure* teacher leader programs) by sharing results from what components – what structures – programs included in each program.

Mentoring

Each project included a focus on mentoring. Mentoring occurred in many facets such as mentoring preservice STEM teachers or mentoring novice and other STEM teachers. Data consistently spoke to the need for STEM teacher leaders to mentor others as a means for developing their identities as teacher leaders. Mentoring also allowed fellows to experiment with provisional selves as teacher leaders (Ibarra, 1999) as they supported their mentees.

Preservice STEM teacher mentoring Projects consistently worked to match teacher leaders with preservice teachers in their university’s teacher education programs. STLPs tended to report having a higher number of fellow-intern placements, which may be a result of their program’s longevity and being more established. For example, program A’s final external evaluation noted that 56 student interns had been mentored by teacher leaders in their projects, with at least two project completers saying that such mentoring opportunities motivated them to remain in the classroom. One fellow noted that serving as a mentor gave her both a teacher and teacher educator role that impacted her professional identity. Projects F and E (DTLPs) also had teacher leaders serving as mentor teachers to interns. Interns spoke to the positive experience of the mentoring relationship. For example, interns consistently called ‘mentors reliable, experts in the field, providing a safety net and a positive atmosphere’ (project E, evaluation report).

Probationary or other STEM teacher mentoring As documented in interview, proposal, external evaluation, and project documentation data, projects also attended to the need to offer teacher leaders experiences mentoring other STEM teachers, such as including coach training and partnering fellows with preservice teachers during teaching internships. Although DTLPs included this type of mentorship, STLPs had more developed plans for this form of mentorship within their proposals. For example, project C (STLP) was committed to developing content experts to mentor other STEM teachers. Their proposal spoke to a goal to prepare teacher leaders ‘to serve as mentor trainers to work with mid-career STEM teachers to be strong

classroom mentors for pre-service and new STEM teachers.’ Further detail was shared describing the plan ‘to retain and provide continuous professional development to experienced, expert secondary STEM teachers in [our partner school district] to take on the role of [expert school-based teacher educator]’ (proposal) that included development and implementation of a mentoring curriculum. Project C’s external evaluation corroborated the actualization of this goal by stating that 16 teacher leaders in their program served as formal mentors to preservice or new STEM teachers potentially contributing to fellow’s teacher leader identities. Project G (DTLP) also had in place the plan for teacher leaders to mentor preservice teachers and follow them into their novice years of teaching to develop a sustained, committed mentor-mentee relationship (proposal).

Sharing of knowledge

All projects included a component for fellows to externally share their knowledge. Such sharing came in various forms such as conference or local presentations and participation in teaching university courses. DTLPs tended to have these opportunities later in the project timeline than STLPs. These experiences – presentations and teaching courses – of recognizing they have some valid knowledge to share, then sharing that knowledge and gaining recognition for that knowledge, builds their identity as a STEM teacher leader (Campbell et al., 2019).

Conference or local presentations Data indicated that projects viewed conference or local presentations as one way to support and encourage teacher leadership identity growth. Fellows participated in various aspects of professional presentations at conferences or local venues. All projects reported fellows taking content learned during the program and providing presentations to colleagues. In addition, projects A, D, and F (STLPs), and H (DTLP) included fellows co-presenting with program team leaders in professional presentations, as well as developing and presenting at professional conferences on their own – though project H’s presentations occurred later in the program timeline. In project H (DTLP), as a result of fellows’ experience in these required presentations, they subsequently presented at other conferences on their own (interview). Fellows also designed conferences and workshops for colleagues. For example, as a culminating final experience for fellows, projects E and H (DTLPs) included fellow-designed multi-day conferences for their colleagues, such as a three-day conference on project-based learning in mathematics and science (evaluation reports). Projects such as F (STLP) and H (DTLP) required fellows to plan and implement STEM Community Nights in their districts (proposal). These nights resulted in bringing students, parents, teachers, administrators, local businesses, and community members together to showcase STEM content at the school and within the community (evaluation reports).

Teaching university courses Fellows also participated in teaching university courses as a form of sharing their knowledge. The level of participation in teaching university courses was higher for STLPs. For example, project G (STLP) fellows reported having taught a number of university courses as well as co-teaching courses for preservice mathematics teachers (evaluation report). Proposal, interview and project documentation data showed other examples of university teaching. For example, in project H (DTLP), though not as substantial or sustained as project F’s (STLP) teaching experiences, fellows taught at least one STEM methods class where the methods course traveled to their school site (interview). Project C (STLP) not only had several fellows serve as adjuncts to teach mathematics and science methods courses, but also involved all fellows in re-designing those courses. One critical outcome of this work was that fellows realized the full extent of challenges facing novice teachers as they move into their first teaching assignments, especially in high-needs schools. This caused a shift in fellows’ thinking from viewing the high attrition rate of new teachers in their district as a failure of *the new teachers* to attributing it to *their own*

failures as mentors and teacher leaders (interview). Thus, project C fellows became more invested in mentoring new teachers in their district to try to ameliorate the rate of attrition.

Discussion

We noted Smylie and Eckert's (2018) distinction between the development of the teacher leader – the person – and of teacher leadership – the process. We reformulated that into the distinction between *developing* teacher leaders and *supporting* teacher leadership, with the understanding that the former would involve a transformation in the skillset and voice of individuals who were likely already accomplished teachers. The latter resonates with the work of Grootenboer (2018) who speaks to the work of 'school middle leadership' – leadership as practice and the important, complex work undertaken by teachers in schools who find themselves in the 'middle.' These teachers are not principals but not solely teachers, but teachers in the 'middle' responsible for the teaching of students as well as leading the professional learning of their colleagues. This distinction – between *developing* and *supporting* – provided a useful lens for analyzing the various features of the eight Noyce programs across the four relevant components of the Smylie and Eckert framework. What we uncovered from this analysis has numerous implications for programs associated with promoting teacher leadership, particularly those programs that might be external to the school system itself.

Teacher leadership outcomes

The difference in DTLPs and STLPs has implications for Teacher Leadership Outcomes. We noted that programs generally tended to focus their intended outcomes around instructional leadership, with less attention given to association leadership, and little attention given to policy leadership (Teacher Leadership Institute, 2018). This would seem appropriate for DTLPs, especially given the fewer years of teaching experience of their participants. However, even these programs should indicate a clear shift toward association and policy leadership later in the programs' timeline in order to expand their participants' spheres of influence (Lovett, 2018) and build more well-rounded teacher leader identities (Hite & Milbourne, 2018). For STLPs, there needs to be explicit goals related to association and policy leadership in order to meet the broader visions of teacher leadership laid out in documents such as the Teacher Leader Competencies (Teacher Leadership Institute, 2018). Additionally, both types of programs must be thoughtful about trying to align their goals with those of the school districts from which participants are drawn. While certain programmatic features – like pulling candidates from a wide spectrum of school districts – might limit the extent of such alignment, having overlap in program and school goals creates a synergy between the two different communities of practice that will allow ideas and processes to flow more freely and bidirectionally (Wenger, 2010).

Teacher leadership capacity

In relation to Teacher Leadership Capacity, programs need to carefully consider their criteria and mechanisms for selecting participants. DTLPs in this study sought participants with fewer years of classroom experience, individuals who would be labeled as early- to mid-career teachers (Berl, 2005); STLPs sought participants with more years of experience, who would be labeled as mid- to late-career teachers. There is great value to the educational system in having programs geared toward both groups of teacher demographics, but consideration must be given to how to best draw candidates from each. For early- to mid-career teachers, programs must select based on *potential*, and these programs will need to rely to a certain extent on school recommendations to judge that potential. Such recommendations should be guided by the identification of teacher leader skills and dispositions in formative stages and, as such, there would be value in pulling descriptions of appropriate skills and dispositions from documents such as the Teacher Leader Model Standards (Teacher Leadership Exploratory Consortium, 2011). We did not find such information

provided in application materials sent out to schools from any of the programs. For mid- to late-career teachers, programs must select based on *performance*, which would include at least some demonstration of informal/formal teacher leadership actions (Anselmus Dami, 2021). Given that school leaders can have narrow definitions of teacher leadership, often confined to more managerial roles such as department chairs (Angelle & Schmid, 2007), application materials can strengthen the recommendation process by including lists of representative teacher leader activities from documents such as the Teacher Leader Competencies (Teacher Leadership Institute, 2018). We did find some such lists in the application materials, but they were often not comprehensive in terms of including examples of association and policy leadership.

Developmental activities and experiences

In terms of Developmental Activities and Experiences, both DTLPs and STLPs require consideration of the impact of such activities and experiences on participants' teacher leader identities and on their communities of practice. These considerations should inform programmatic features discussed herein, such as the nature of professional development, graduate coursework, and networking. When developing teacher leaders, professional development and graduate coursework will likely need to focus initially on content and instructional expertise, as these are of greater concern to less experienced teachers (Beijaard et al., 2004); this will impart greater self-efficacy for these individuals regarding their capacity to function as teacher leaders. When supporting teacher leadership, there is still likely to be value in professional development and graduate coursework with a content focus, but there should be a shift toward research-based instructional strategies (Henderson & Dancy, 2007), as well as more sophisticated aspects of leadership, such as working with adult learners (Merriam, 2008) and understanding organizational change (Hussain et al., 2018). There was not significant evidence of foci on either of these latter two areas in the programs reviewed. Further, these professional development and graduate coursework experiences, much like program goals, need to be complementary to what is being done in participants' school contexts, as with project C (STLP) that allowed fellows to choose professional development pathways that were identified in the school district action plan. Finally, networking activities need to be thoughtfully structured to address teacher leader identity and community of practice concerns. As noted in the Results section, specific attention to strengthening the internal network of the program is likely very important for DTLPs; this can create a strong community of practice which can lead to greater teacher retention and reduced isolation. STLPs still need to give attention to this internal networking, but need to quickly shift their emphasis to external networking. This external networking took the form of participation in Noyce conferences in several programs, which allowed fellows to build *awareness* of what they had to offer as teacher leaders (strengthening teacher leader identities), as well as a *recognition* that there were others dealing with problems similar to those that the fellows faced. An important form of external networking illustrated by programs geared toward developing teacher leaders was to bring fellows in contact with recognized teacher leaders and having them share the stories of their journey into leadership (e.g., project E, DTLP); this provided a foundation for the fellows to build their own narrative identities as teacher leaders (McAdams, 2011).

Teacher leader practice

Thoughtfully structuring opportunities related to Teacher Leader Practice can have a significant positive impact on both the professional identities and communities of practice of participants involved in programs such as those reviewed in this paper. Mentoring is recognized by several researchers as a foundational aspect of teacher leadership (Gehrke, 1988; Gul et al., 2019; Lambert, 2003). As Lambert (2003) notes, mentoring 'can develop efficacy in problem solving and decision making, offer both support and challenge, and facilitate a professional vision' (p. 427). For both developing teacher leaders and supporting teacher leadership, mentoring provides an opportunity to learn to work with adult learners. For developing teacher leaders, it makes sense to have participating teachers with fewer years of experience work with preservice

teachers initially, shifting to mentoring novice teachers later in the program timeline; for supporting teacher leadership, there is value in having participating teachers serve as induction mentors for novice teachers (if they have not engaged in significant mentoring previously), then shift to roles such as instructional coaches later. For developing teacher leaders, carefully structured mentoring experiences can provide legitimacy to their forming identities; for those being supported in their teacher leadership, more advanced mentoring experiences can validate more established identities.

A similar progression can be envisioned for sharing of knowledge. Developing teacher leaders can start more locally by working within their program-based communities of practice to engage in joint enterprise (Wenger, 2010) that can then be shared with school communities of practice (e.g., professional learning communities). This could evolve into participating in local conferences – or hosting them, as with project H (DTLP). Participants being supported in teacher leadership could be exposed to state and national conferences in the early stages of their program, could collaborate with program team members in presenting at such conferences in middle stages, and finally, could be encouraged to prepare and deliver their own presentations in later stages. For both groups, explicit training on action research and writing about leadership, as program D (STLP) provided, may offer ways to help fellows develop their teacher leader identities. The goal in either case would be to expand strong communities of practice within the program to broader communities of practice within the larger educational system, as well as to incrementally expand participants' sphere of influence.

Conclusion

This study focused only on the structure of these eight programs as opposed to the outcomes of the teacher leaders who participated in the programs. Hence, further research is needed that connects program structures with the effects and outcomes of the teacher leader participants. Studies such as this would address a limitation of this study – helping determine how well the participants progressed through program content to actualize teacher leadership and develop teacher leader identities.

Programs in this study tended to emphasize content development, given that was a requirement from the funder, but also because fellows strongly indicated their desire to improve their content knowledge coupled with the call for content development as part of teacher leadership development (Berg et al., 2014; Wenner & Campbell, 2017). Programs were structured to encourage fellows to develop professional identities as more than just content-focused, *instructional* teacher leaders – to move beyond that to see themselves as *association* and *policy* leaders as well, especially with regards to issues related to STEM education (Beijaard et al., 2000; Caza & Creary, 2016). Teacher leadership is a complex construct and most teacher leadership models (e.g., Poekert et al., 2016; Teacher Leadership Institute, 2018) recognize various forms of teacher leadership. Furthermore, others have noted that teacher leader programs may not be able to address all teacher leader competencies in one program (Berg et al., 2014). The design of the multi-year programs in this study – professional development, graduate coursework, networking, mentoring, and sharing knowledge – intended to advance the teacher leader identity of fellows over time through the programs' communities of practice that engaged the teachers in prolonged leadership and knowledge-building experiences. These programs intended to develop thick teacher leader identities as teachers engaged in the described activities and gained knowledge that empowered them to take on additional teacher leadership roles (Wenner & Campbell, 2018).

Limitations in the study included the challenges associated with qualitative research. For example, the researchers were part of the data collection and analysis so elimination of all biases is impossible. As noted earlier, strategies such as multiple research team members reviewing data and member checking were used to minimize research bias (Galdas, 2017; Morse et al., 2002), but complete bias cannot be eliminated. Additionally, the notion of bracketing – a qualitative method to reduce the impact researcher preconception on data analysis (Tufford & Newman, 2012) – was not used based on Heidegger's (1962, 1972) ideas that

understanding lived experiences is inherently an interpretive process and removing preconceptions is 'neither possible nor desirable' (Gearing, 2004).

This study adds to the literature in two ways. First, this analysis attends to the call for learning more about content-focused teacher leadership programs (Berg et al., 2014; Wenner & Campbell, 2017). Second, this study demonstrates an emerging distinction between initial teacher leader programs – programs that are developing teacher leaders and advanced teacher leader programs – programs that are supporting teaching leaders. For example, greater focus on association and policy leadership (Teacher Leadership Institute, 2018) within future STEM teacher leader programs is important to the development of more well-rounded teacher leaders capable of expanding their influence. Furthermore, The results offer insights for teacher leader program developers when thinking about program structures tailored to meet the needs of diverse program participants as well as key program features included in funded STEM teacher leader programs. This distinction also includes implications for international work in teacher leadership development, especially in light of the recent pandemic, which forced most work to move to virtual settings. With these virtual offerings, access to teacher leader programs, for example, from various parts of the world may now be accessible to a wider, international, more culturally diverse audience. Thinking of ways to apply these prominent five STEM teacher leader components (professional development, graduate coursework, networking, mentoring, and sharing knowledge) across more international audiences – both general teacher leader and STEM teacher leader programs – would be a fruitful endeavor.

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