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Article

A Proposed Conceptual Framework for K–12 STEM Master Teacher (STEMMaTe) Development

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Abstract: Recent reports from federal agencies and legislation call for explicit avenues to incorporate K–12 STEM master teacher voice into the policy space. National initiatives, federal legislation, and teacher recognition programs have sought to identify K–12 STEM master teachers and harness their potential. These efforts warrant a conceptual framework to quantify attributes of K–12 STEM master teachers, to foster pathways for the development of current and future leaders. Using a sample of 10 individuals from two extant programs of K–12 STEM master teachers (Albert Einstein Distinguished Educator Fellowship and Presidential Awards for Excellence in Mathematics and Science Teaching), data from their career trajectories (sourced from Curriculum Vitae) were sequenced to construct and confirm the STEM Master Teacher (STEMMaTe) conceptual framework. This framework may be used to guide programmatic development to increase national capacity for K–12 STEM master teachers. Recommendations are discussed for the creation of pathways to develop STEM master teachers and increase their participation in the broader education system.

Keywords: leadership development; situated learning theory; STEM education; teacher leadership

1. Introduction

Since the publication of *A Nation at Risk* [1], there has been an ongoing national discourse on the importance of Science, Technology, Engineering, and Mathematics (STEM) Education in the United States [2]. Whether that discourse is framed in economic terms focusing on shifting workplace demands, or in response to the complex, scientific/technological roots of 21st century problems like climate change [3], it is clear that STEM education is a critical component of our past, present, and future American education system.

Yet, this issue is not solely an American problem; countries such as Canada [4], Australia [5], Turkey [6] and international regions like Europe [7] and Latin America [8] report immediate needs to improve STEM education at all grade levels. The international pressure on STEM education hinges on global metrics like the Programme for International Student Assessment (PISA), and Trends in International Mathematics and Science Study (TIMSS) assessments, common benchmark examinations for 15-year-olds in cross curricular competencies and fourth and eighth graders in math and science achievement, respectively. Both PISA and TIMSS published rankings and consequent comparisons can serve as sources of pride, envy and shame for countries [9], directing national educational policy [10] and launching country-wide reform efforts [11]. In the American conversation on the importance of science education, discourse within the science education community has focused on reforming the formal K–12 education system to develop students' STEM-based practices and promote 21st century skills that improve global STEM competitiveness and align with workplace demands in a new economy [12,13]. This effort culminated in the creation of the National Research Council's (NRC), *A Framework for K–12 Science Education* in 2012 [14]. A year later, the Next Generation Science Standards

(NGSS) were established, building upon the principles of the aforementioned NRC framework [15] and representing an opportunity for major and meaningful reform in American science education [16]. Because of the importance of STEM for global economic stability, there is international interest in national and universal STEM education standards [17,18].

Reform efforts, such as those associated with the implementation of novel standards like the NGSS, may be successful if K–12 STEM teachers (mainly comprised of secondary teachers of science and mathematics in the United States), are provided professional development in high-quality instruction as one part of a comprehensive strategy [19]. This necessitates a significant, multi-layered policy infrastructure to support teachers in the implementation and execution of the NGSS, including professional development opportunities at district/school levels for teachers to translate the NGSS into classroom curriculum, opportunities for authentic science instruction, state-level assessment policies that will determine how to measure the implementation and achievement of the standards, and federal, accountability policies that determine how state-level assessment regimes align with federal policy frameworks like the Every Student Succeeds Act [20]. This impetus on developing teachers is found internationally; Thomas and Watters [21] have suggested that a fundamental part of Australasian STEM education reform should lie in developing an effective and engaged STEM teacher workforce. As with facilitating high-quality instruction, teachers also play an essential role in successful implementation of policy [22]. Yet teachers' inputs in the creation of policy and advocation of best practices in implementation have been relatively limited. An NRC report, *Exploring Opportunities for STEM Teacher Leadership: Summary of a Convocation* [23] has described the importance of K–12 STEM master teacher ***voice***, as these "best teachers need to have much more influence on the education system at every level, from districts to states to the federal government" (p. 14). Using this concept from the NRC, voice can be quantified as master or teacher leader participation (advocacy) in education policy, which necessitates a pipeline of teachers with the knowledge, skills, and experiences to contribute in these spaces. Yet, the NRC report continues by describing how both policy and research communities currently lack a coherent framework for identifying, developing, and empowering master K–12 teachers in the STEM content areas [23]. The National Academies of Sciences, Engineering, and Medicine [24] have echoed this need for STEM teacher leader development and study, as the "research base on teacher leadership is not robust" (p. 196).

To systematically advance K–12 STEM master teacher participation in policy advocacy (voice), we propose in this paper a conceptual framework to articulate the development of K–12 STEM Master Teachers—the *STEMMaTe* framework. This framework was inductively developed using situated learning theory and empirical data from the professional teaching and leadership experiences of ten nationally-recognized, K–12 STEM master teachers. The framework also merges extant constructs and theories of K–12 and STEM teaching, providing both theoretical and practical coherence for the elusive concept of a K–12 STEM master teacher. By developing a unifying framework to scaffold opportunities for specific and sequenced skill acquisition, we hope to provide a more coherent roadmap or mechanism to identify and develop K–12 STEM master teachers. Hence, the STEMMaTe framework relates extant individual, teacher-specific self-efficacy [25,26] and teacher-leadership constructs [27] within situative theory [28] to explore experiences (opportunities) to foster K–12 STEM teacher leaders. It should be noted that the latter (teacher leadership) continues to be ill-defined in the research space [29,30], yet it has become an increasingly popular term in national policy discourse [23].

We hope that this conceptual framework will be used to advance the discussion on STEM master teachers by providing researchers and policy makers a mechanism for identifying and understanding the skill sets of such master teachers; aiding professional development program providers in their design and implementation of experiences to develop the unique abilities and expertise of STEM master teachers; and ultimately, increasing the national capacity for K–12 STEM master teachers. Therefore, we begin this paper by exploring the rationale for such a model through substantiating the need for teacher participation in the policy making process, with an emphasis on why master teacher voice is an asset. Next, we lay out the theoretical foundations of the STEMMaTe framework, connecting those foundations to the results of a case study analysis of 10 nationally-recognized K–12 STEM master teachers. We conclude with an exploration of possible applications of the framework, including program evaluation, program development, and program sequencing designed to increase capacity for STEM Master Teacher development.

1.1. Teachers' Voices Matter in Education Policy

Historically, teacher voice has been left out of local, state, and federal policy conversations [31,32]. Only in the past twenty years has research shown that this exclusion has had demoralizing effects on teachers, affecting their sense of empowerment and professionalism [23,33]. Teachers' exclusion has also had negative impacts on the American education system at the highest levels, namely in the form of unintended and avoidable policy consequences.

Consider *No Child Left Behind* (NCLB), the 2003–2015 reauthorization of the *Elementary and Secondary Education Act* (ESEA), a federal law funding and governing American K–12 education since 1965. The underlying assumption of NCLB was that high-stakes accountability would increase student achievement, particularly for students living in poverty and students of traditionally disenfranchised groups including English-language learners, students with disabilities, and underrepresented minorities [34]. While noble in principle, the policy mechanics of NCLB resulted in negative practices like teaching to the test [35], and shifted instructional focus away from non-tested subjects (science and social studies) towards the tested subjects (math and reading) only [36,37]. In trying to meet the unrealistic mandate of one hundred percent student proficiency by 2014 [38], the law created a culture of *test-and-punish*, demoralizing teachers and schools [39]. These unintended consequences ran counter to the reauthorization's original intent and complicated the law's overall efficacy [40].

And yet, there were early warning signs highlighting problematic elements of the law. Teachers had foretold that the punitive system in NCLB would not lead to improvement. A survey of teachers by Sunderman, Tracey, Kim, and Orfield [41] found that teachers had not only anticipated this type of reaction to NCLB's policies, but also reported policy recommendations that are only now being implemented a decade later, regarding the need for more resources, improved working conditions, and multiple measures for accountability structures. Had teacher voice been incorporated into the policy-making process from the start, that voice may have helped policymakers avoid these unintended consequences and achieved their intended goals of educational reform.

1.2. Differentiating Teachers' Voices in Policy Discussions: The Case for Master Teacher Voice

While incorporating teacher voice is an important step in building better policy, it is important to acknowledge that teacher voice is not a uniform construct, as it may vary as a function of teachers' experiences and situated expertise. Therefore, teachers' perspectives based upon experience can, and should, have varying levels of impact in the policy space. Novice teachers, defined as those with two years of experience [42], have different experiences and perspectives than veteran teachers, defined loosely as educators with approximately a decade or more of classroom teaching experience [43]. Hence, it may not be appropriate to engage a first-year teacher, with limited pedagogical or content knowledge, to participate in a statewide discussion of K–12 STEM standards. Conversely, experienced teachers may not provide the best perspective on the impact of recent teacher induction policies on a local district, where a novice teacher would hold more expertise. Other groups of teachers, STEM professionals who received alternative certification for a second career in teaching, for example, also possess content expertise that could benefit the policy-making process. Therefore, years of K–12 classroom experience may be a poor proxy for expertise, as expertise is developed through experiences, but not all experiences lead to expertise. While we acknowledge that teachers' development of expertise through experiences is underexplored, the relationship between experience and expertise should be clarified. As such, it is important to understand the landscape of teacher's experiences, but more importantly their expertise, so teachers' voices may be leveraged in a fashion that matches their expertise to the context of the specific policy discussion.

1.3. Teacher Experience and Teacher Expertise

The question then becomes, how best to identify master teachers with the sort of expertise required for high-level policy contributions? Traditional models of teacher development (see Figure 1) often focus on a direct relationship between time in the classroom (experience) and expertise. However, this sort of direct relationship is problematic [44]. Ben-Peretz and McCulloch [45] argued that conflating classroom experience and master teacher status belies the "distinctively different professional identities and characteristics from those [teachers] who have served in teaching for over 30 years" (p. 43). As indicated before, experience does not equate to expertise, as Shulman [46] warned that teacher's classroom management may cause classroom observers to make confuted judgements on that teacher's mastery of the craft. Empirical studies contend that teachers' effectiveness vis-a-vis student learning is significantly higher after a decade in the classroom [47,48], yet other work by Day, Sammons, Stobart, Kington, and Gu [49] suggest that experienced teachers were not more effective than their inexperienced peers in increasing student achievement. This debate extends national boundaries, as Ben-Peretz and McCulloch [45] found there are global disagreements between the "combinations of 'expertise' and 'experience' that constitute a veteran teacher" (p. 3).

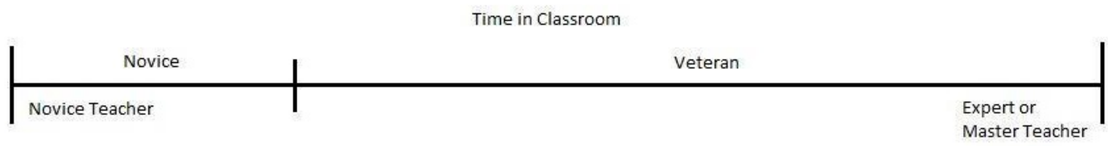

Figure 1. *Time in Classroom* Based Conceptual Representation of Developing Master Teachers.

Scholars in the field warn that teachers' professional development through their careers is not a linear movement from novice to expert [50–52] as seen in Figure 1. Complicating the matter further, some veteran teachers struggle to adapt their expertise when they encounter unfamiliar contexts (e.g., new curriculum, new pedagogical practices, new groups of learners); they "no longer display the thinking or behavior of an expert" [53] (p. 145). This may explain the hesitancy of many veteran teachers to participate in large or small-scale reforms [54–56], suggesting that there is additional expertise that has not matured for them to be effective in novel contexts or situations.

Given that experience (time) in the classroom is a problematic indicator for teaching excellence (expertise), it is critical to identify which group of teachers are best suited for large-scale policy involvement. The NRC [23] argues that master teachers have an expert voice that is vital for large-scale impact at the state and federal level. Specifically, these master teachers are recognized as leaders in their profession by regularly sharing their expertise, transforming pedagogical practices, and taking a more prominent role in decision making; they actively seek out leadership opportunities to step beyond the classroom domain to have a greater impact on students, colleagues, schools, and their community. The report goes on to state that by leveraging their ability as advocates and change agents, as well as their deep institutional knowledge of the craft of teaching, master teachers could serve as iterative bellwethers of educational education policy, and be a valuable resource for policy makers.

Master teachers demonstrate more abilities than veteran teachers in their classrooms, therefore, a new working hypothesis should be conceptualized to better understand master teacher qualities and skills. Establishing a conceptual framework of what skills and abilities K–12 STEM master teachers possess can inform professional development programs and professional learning opportunities to better provide experiences (professional development services or professional learning opportunities) to identify, leverage, and advance the expertise of this unique group in participating in and informing large-scale, federal education policy.

1.4. Identifying and Developing Master Teachers' Expertise and Voice

Matching teachers' expertise to the proper outlet for voice is paramount for teachers to be effective in conveying their expertise in the policy space. Complicating this issue is the present inability to identify the features of a K–12 STEM master teacher, quantify those characteristics, and come to a community-based consensus on a common definition. Given the lack of a common definition, master teachers are often identified based on their participation in leadership programs, which can be problematic when such programs are monetarily incentivized [57]. Such programs have varying levels of efficacy [58], creating a scenario where it may be difficult to distinguish a veteran teacher (who participates in a program for financial reasons) from a master teacher (an eager learner with leadership capacity) who could be an asset to policy makers. Again, since experience does not equate to expertise, it is unclear how teacher leaders, a somewhat ill-defined group in the literature [30], relate to master teachers or veteran teachers.

Yarger and Lee [59], York-Barr and Duke [30], and as recently as Wenner and Campbell [29] have called for the creation of theory-driven conceptual frameworks to describe teacher-leadership development. This call from the research community aligns with national efforts, like the US Department of Education's *Building STEM Teacher Leadership* Initiative [60]. Teacher-leadership continues to grow in importance to schools and students [61]; the newly reauthorized *Every Student Succeeds Act* [62] recommends developing teacher leadership to improve education outcomes [63,64]. To address this need, experiences in leadership are now being incorporated into teacher performance evaluation systems both domestically in North Carolina [65] and abroad in Singapore [66]. However, a study by Dozier [67] found that teachers reported they were eager to take on leadership roles, but lacked experiences to prepare for them, creating a gap between expectations and the reality of teacher-leadership opportunities, especially within STEM [24].

To address the needs and gaps in the research literature related to STEM master teacher and teacher-leadership conceptualization, we propose merging elements of teacher expertise and teacher leadership, through situated learning opportunities (experiences), into a new conceptual framework, the goal of which is to identify characteristics of and sequence opportunities to develop teachers' skills and abilities to obtain K–12 STEM Master Teacher (leader) status.

1.5. A Proposed Conceptual Framework of Identifying and Developing K–12 STEM Master Teachers (STEMMaTe)

Through the lens of situated learning theory, coupled with cases of nationally recognized K–12 STEM teachers, we can begin to conceptualize how to identify and potentially develop STEM Master Teachers. The proposed conceptual framework of K–12 STEM master teacher-leadership development, or STEMMaTe model, is informed by Lave and Wenger's [28] situated learning theory, where expertise is attained not by behaviorist conceptions of innate talent or linear developmental stages [68], but rather opportunities for legitimate peripheral participation (LPP) to foster the skills needed to obtain expertise. According to Lave and Wenger [28], when an individual commences a specific activity as a novice, they first engage in marginal activities, often apprenticing with a community-vetted skilled expert. These novices negotiate meaning through the practices of that community through increasing meaningful and practical (legitimate) participation. Mastery or expertise may be obtained through this process, provided the learner has truly legitimate and ample experiences to participate, there is transparency in community practices [69], and a desire on behalf of the learner to obtain the situated expertise [70]. The term situated is of particular importance as it implies that reticulated social practices are characteristics of all human activity, especially learning [71]. Therefore, this perspective ascribes that one's cognition is intrinsically coupled with specific experience/s, acknowledging the critical importance of one's environment for situated learning [72]. In the situated perspective, learning is thought to occur when the novice becomes more centrally involved in the practices of the community while becoming more aware of the nuance within the activities; this interaction may potentially alter their perception of self (identity) and recognition within that community of practice [28]. This perspective is compelling as it acknowledges the power of culturally embedded activity, where the "acquisition of knowledge is contextually tied to the learning situation" [73] (p. 1611). This may explain why the apprentice-based student-teaching experience has long been an important bulwark in teacher induction programs [74,75]. Thus, the situative approach has been lauded for illuminating how "classrooms and other learning environments afford opportunities for productive learning" [76] (p. 12). Hence, it has been applied for understanding situated knowledge development in medicine [72] and sports [77]. Specifically to education, prior studies have shown situated learning theory to be a meaningful framework for adult learning, especially with educators [78]. Regarding continuing learning, the literature has described that high quality and impactful teacher professional development are those that leverage aspects of this theory. Specifically, experiences that utilize active learning with collective participation over a sustained duration [79–84].

As teaching is an inherently social activity, situative perspectives are compelling conceptual frameworks for exploring teaching of K–12 STEM subjects [85,86] and delivering teacher professional development [87,88]. Building upon research where situative theory was utilized in STEM education and teacher professional development provides vital confirmability to explore a novel conceptual framework within a mutual context of STEM teaching and teacher learning. And so, in the context of this paper, STEM Master Teacher LPP can be described as performance within a scaling (classroom-building-regional-state-national) professional development/learning environment, whereby the learner's unique situated expertise (STEM teaching and learning) is applied incrementally through community practices (leadership, advocacy) in a novel activity space (policy). This LPP may be a fundamental aspect in how teachers learn, progress in, and refine their craft; whereby direct participation in experiential opportunities affords individuals the chance to engage in sense-making in new activities [89].

Each stage of a teacher's professional career develops in a situated fashion. First, pre-service teachers begin their study of the teaching craft through internships and practicums (professional formation) concurrent with coursework, often culminating in a student teaching experience with an experienced (mentor) classroom teacher. It is important that the pre-service teachers who desire to reflectively learn are paired with mentors willing to provide legitimate participation through transparent practices [90]. Research suggests that this practice is not pure socialization, rather situated learning [89], where there is ongoing negotiation between the novice and the educational environment around the multifaceted activity of teaching [75]. Second, the teacher induction continues for novice teachers throughout the early stages of their career, where "veteran teachers help beginners learn the philosophy, cultural values and established sets of behaviors expected by the schools where they are employed" [91] (para. 9). This reflects the idea that the novice teacher is not just learning information and practices, but is becoming a teacher and adopting a teacher identity [70]. It is recommended that novice teachers are provided administrative protections such as fewer outside the classroom responsibilities, smaller class sizes, or single preparations (or course loads) as compared to their experienced counterparts [92] to allow them to grow in knowledge and skills in a supportive environment [93], or perhaps mitigate the effects of their inexperience on classroom effectiveness [94]. These early professional formation LPP experiences are important in their development; as novice teachers progress in their profession, they may more readily adapt to new or additional course preparations, balancing out-of-classroom duties, and larger class sizes. Obtaining the ability to be flexible in changing contexts is important, not only as this flexibility furthers the development of their content and pedagogical skills [95,96], but also advances their identity [70] and connection to the community [97] through demonstration of increasingly complex competencies within the community of practice. This process is not unlike the Liberian-based Vai and Gola tailors' "reversing production" method [28] (p. 72), where novices learn to sew on buttons and stitch hems well before being introduced to the initial stages of suit production, like seaming the garment or cutting patterns from cloth. Furthermore, Lave and Wenger's ideas on reverse production can help to focus the learner on the outline of the activity, scaffolding logic and reasoning to how the larger activity is designed and fits together comprehensively.

Like teaching, policy novices are often provided the big picture first to understand how they can apply their situated knowledge to another context (e.g., STEM content to teaching or teaching to the policy or advocacy realm); this is reflected in numerous programs that place education [98,99], science [100,101], and military [102,103] experts into an apprenticeship role in federal policy settings. With a comprehensive understanding of the outputs of policy making, teachers can, through practice, delve deeper into how the former steps in the policy process inform or direct the latter steps. Therefore, a situated learning theory perspective lends well to teaching as well as policy and advocacy, as both domains possess an inherent socio-cultural structure requiring ongoing negotiation with stakeholders in the community, and discrete methods (practices).

The Five Components of the K–12 STEM Master Teacher (STEMMaTe) Framework

This paper contends that K–12 teachers, especially those within the STEM disciplines, progress towards master teacher level expertise through tiered LPP opportunities, or professional development/learning experiences, in: (1) establishing *scholastic effectiveness* in teaching (i.e., K–12 STEM content and pedagogy); (2) developing *institutional knowledge and memory* of educational structures and reform efforts; (3) garnering leadership abilities and mindsets to decontextualize their experiences, so they may move between contexts as an *adaptable and flexible* educator; (4) demonstrating *emergent leadership* at the local level to effect change as advocates for themselves or within their communities; (5) performing *strategic leadership* through distribution of their leadership and expertise in national advocacy and reform arenas. Non-concentric rings (see Figure 2) reflect the nonequivalence of experience and expertise, where some novices may require more LPP than others within the various communities of practice within the STEMMaTe conceptual framework. Inductively created and aligned with exemplars of STEM master teachers, the inherently social aspect of teaching and learning [104], and the importance for teachers to network and learn from one another [105,106] especially teachers in STEM [107], the STEMMaTe framework provides the conceptual foundations to understand how social opportunities provide learning experiences that develop the qualities of a STEM master teacher within the career trajectory of a K–12 teacher. The progression of experiences where skills may be acquired to progress from K–12 STEM novice teacher to K–12 STEM master teacher is shown in Figure 2. An onion (model) representation was selected to indicate the nature of shifting boundaries reflected in newer iterations of situated theory [70,108], where some learners may progress towards expertise at different rates, despite similar LPP experiences.

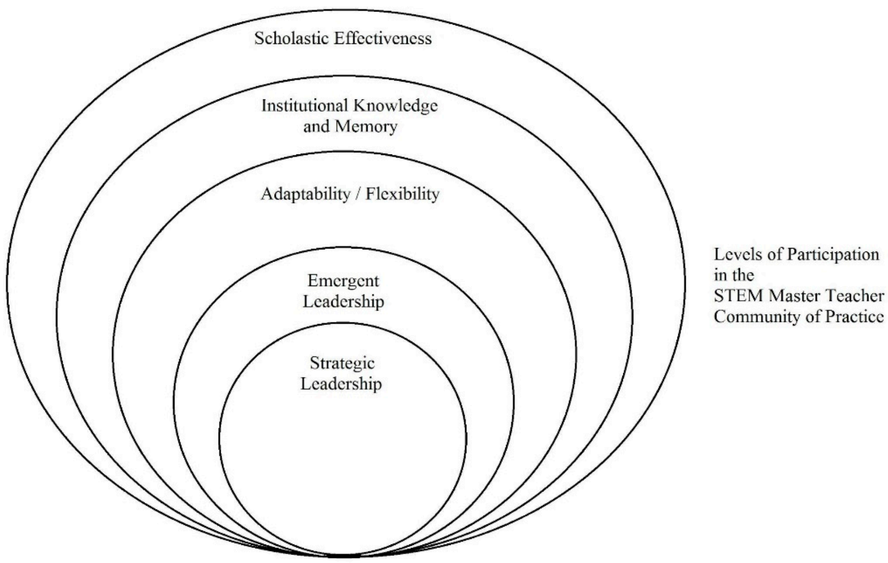

Figure 2. Preliminary Conceptual Framework for K–12 STEM Master Teachers (STEMMaTe) adapted from Lave and Wenger [28].

To explore the STEMMaTe conceptual framework, we consider the hypothetical development of a K–12 STEM master teacher, mapped to the five framework elements. Starting in the outermost, or first ring, in the fast-changing realm of primary and secondary STEM education, K–12 STEM master teachers must not only be aware of current trends in the STEM teaching and learning, but also be able to effectively translate that information into authentic learning experiences in their classrooms [109]. This expectation is corroborated by the requirement for STEM teachers to possess and implement discipline-specific content knowledge described in the NGSS [15]. A K–12 STEM teachers' content preparation has been evidenced to have a positive effect on students' learning gains [110], whereas poorly prepared teachers in STEM subjects are empirically linked to poor student performance [111]. To foster these skills, there is a common agreement among researchers that teacher self-efficacy, defined as one's personal beliefs as a teacher and abilities in teaching a particular subject like STEM, is vital [112]. Originally established by Bandura [25], cultivating self-efficacy in teachers has evidenced significant improvements in student achievement [113–115] and teaching satisfaction [116]. As teachers develop positive self-efficacy, they continually improve and expand their practice throughout their teaching career [117,118]. One means of facilitating this skill development is colleague interaction via Professional Learning Communities (PLCs); a report by Fulton and Britton [107] found that STEM teachers participating in rigorous and well-structured STEM-based PLCs had improved content knowledge and more effective pedagogical practices, which led to improved student performance in STEM subjects. Thus, it makes logical sense that teachers who master this stage are more effective in teaching vis-à-vis students' test scores; not only for their expertise in content, but also in non-cognitive and 21st Century skill development that improves learning outcomes [119] for a global STEM workforce [12], recommended by the NGSS [15]. These two experiential junctures separate what the literature describes as novice teachers from experienced or veteran teachers; moving from transmission of knowledge to cultivating knowledge in students [45,120,121]. This suggests that emergent STEM master teachers acknowledge the importance of non-cognitive skills because of their awareness and appreciation of life-long learning.

As teachers progress to the second ring, equipped with the ability to sustain classroom activities, they are afforded both time and access to a greater view of the structures that shape their classroom. It is here where they begin to ground themselves in a specific and immersive context, through repeated interactions with their peers and administrators, developing an understanding of their school culture, community stakeholders, and district level policy structures. This knowledge may be cultivated through a variety of means, including service as department head or content level leader, serving on district level committees, engaging in community events, and attending school board meetings [122]. This institutional knowledge serves as a pre-requisite for leadership skill building, as Smylie and Eckert [27] described in their model for teacher leadership as "building capacity for teacher leadership" (p. 6). In a supportive environment (e.g., principal supportive of leadership, avenues for leadership work), teachers may shift their locus of concern away from their classroom teaching towards a greater field of view, exploring how relationships in the school and the district influence or even mediate classroom activity. Research by Silva, Gimbert, and Nolan, [123] found that emergent teacher leaders learned the structure of schools, so they could navigate the system and advocate for the needs of their students. This activity sets the stage for future leadership practice.

Research suggests that mastery of a particular context, even of a single school, is not enough to achieve mastery; as per Rich [53], veteran teachers lose their expertise when placed in novel teaching contexts. The third ring of the STEMMaTe framework suggests that this occurs due to a lack of experiences for specific skill development to adapt to changes in the curriculum, engage in flexible teaching strategies, and converse with colleagues to firmly develop institutional knowledge and memory [53]. This lack of opportunity may stem from policies that prohibit flexibility in teaching of the curriculum [124], an unsupportive principal [27], or little time in the school day for professional teacher to teacher collaboration and talk [125].

Yet, from Lampert's work [126], some experienced teachers may engage in (teaching) practices that are successful and adaptable to meet success with a myriad of learners in a variety of contexts. This ability to adapt and shift contexts is a watershed moment for K–12 STEM teacher leaders:

it is here where they begin to consider larger and different contexts of education, moving beyond their own personal locus of concerns towards the larger community of education. This is when anecdotally-sourced teacher talk (e.g., *In my classroom, I do this ...*) transitions into rich conversations of research into practice. It is also in this experiential ring that there is an opportunity for experiences where teachers may explore broader issues of equity and diversity, a critical component and deficit in the teacher-leadership development literature [29]. The STEMMaTe model aligns with prior research indicating that flexible teaching is a result of an emergent STEM master teachers' ongoing commitment to their own professional knowledge and growth; not only impacting student achievement, but also an instrumental attribute for educational reform, teacher quality and advancing the teaching profession [30,127,128]. Critical to this growth is the research by Margolis and Doring [129] indicating that new teachers who are learning these emergent leadership skills are afforded time and space to experiment with their understanding and use of leadership skills beyond just sharing best practices. Similarly, Snell and Swanson [128] found in their research of teacher-leaders that "as they [teachers] developed high levels of skill in each of these domains [expertise, collaboration, reflection, flexibility, empowerment] these teachers emerged as leaders" (p. 19). Per the STEMMaTe model, this intermediate phase is instrumental in presenting experiences for the teacher to garner new professional knowledge and skills, and then act upon them in novel educational spaces. This phase too fosters decontextualization of the individual teacher's experience, so they may understand and appreciate experiences of other teachers and students (at scale). This realization, coupled with experiences to develop their knowledge base and leadership skills, equips teachers to navigate within new spheres of education beyond the purview of his or her own classroom or school-based duties. This may include participation in career-advancing experiences like a master's degree program, a Research Experiences for Teachers (RET) opportunity, or first-level leadership in local organizations or district committees. As teachers cultivate leadership skills, in particular adaptability and flexibility, they are ready to move beyond areas of their current expertise and into tiered leadership [130]. Katzenmeyer and Moller [131] defined teachers engaged in leadership as those who "lead within and beyond the classroom, influence others towards improved educational practice, and identify with and contribute to a community of teacher leaders" (p. 6). Moving beyond their current roles, emergent master teachers play a critical role in the leadership and success of PLCs [132]; this progression into scaled leadership is a critical experience for the development of a STEM master teacher, especially in STEM communities of practice [133]. It is unsurprising that these STEM master teachers may serve as vital reform agents provided their situated knowledge of teaching and school culture [134]. Also, as an exercise of their newly acquired leadership skills, these teachers engage in state, regional, or larger-scale advocacy activities; especially prized for their ability to understand the larger landscape, "professional societies, university researchers, administrators, and other experts" [23] (p. 12) can benefit from these teachers' expertise.

As they progress through scaffolded leadership opportunities, K–12 STEM master teachers can begin to develop the skills and knowledge needed to exert their influence at larger scales, including federal education policy. Based upon the knowledge they possess of classroom excellence (1), institutional knowledge of education (2), the adaptability and flexibility to fluidly move between contexts (3) and experiences with leadership to build their knowledge and skills (4), they may emerge as advocates and change agents, supporting policies like inquiry-based and collaborative STEM classrooms [135], or advocating for the inclusion of the more controversial topics in STEM education [136]. It is at this level where experienced and expert K–12 STEM master teachers may serve as advisors to state boards of education, serve as leaders for national organizations like the National Science Teachers Association, or inform teacher-leadership campaigns like the American Association of Physics Teachers *Aspiring to Lead* initiative [137]. The STEMMaTe model itself is agnostic to whether the K–12 STEM teacher leaders are retained in the classroom; this depends largely on authentic experiences for developing expertise and teacher leadership [138] and the teacher's context of being locally valued to continue in their trajectory of teacher leadership [27].

Given this model's theoretical foundations, it is important to explore how the STEMMaTe framework aligns not only with the extant research literature, but also with the experiences of exemplar K–12 STEM master teachers. As such, a case study analysis was conducted of 10 nationally-recognized STEM educators who had won either the Presidential Award for Excellence in Mathematics and Science Teaching (PAEMST) award, and/or received the Albert Einstein Distinguished Educator Fellowship (AEF). The PAEMST award is the United States' highest honor for K–12 STEM Teachers [139], whereas the AEF selects accomplished K–12 master STEM teachers to live in Washington, D.C. to work on federal STEM education policy in Congress or an Executive Branch agency (e.g., the National Science Foundation, Department of Energy) for 11 months [98]. The selection criteria for including AEF and PAEMST as programmatic exemplars were based upon The National Science Foundation's recognition of both programs in a national call for research related to STEM Teacher leadership [140], and inclusion of both programs as case studies in a NRC report on leveraging K–12 STEM teacher voice in policy making [23].

2. Materials and Methods

This study examined the career development of nationally recognized (PAEMST and/or AEF) K–12 STEM master teachers. In order to maintain the focus on K–12 STEM master teacher development, only a select group of individuals were considered who have progressed through the five rings of the model to obtain master teacher status. To explore career development, Curriculum Vitae (CVs) (which included extended Resumes) from ten K–12 STEM master teachers were solicited for a qualitative document analysis to verify the theoretical underpinnings of the STEMMaTe conceptual framework. The research questions for this study are as follows:

1. What series or sequence of opportunities and experiences shaped and developed sampled individuals towards the status of a K–12 STEM master teacher (to AEF and/or PAEMST and beyond)?
2. In what ways do themes and trends in common collective experiences shape and develop these sampled individuals towards K–12 STEM master teacher status (to refine a STEMMaTe conceptual framework)?

Over a period of two months, PAEMST awardees and AEF recipients were recruited for the study through PAEMST and AEF listservs and email. Through these avenues, K–12 STEM master teachers from all experience levels (e.g., years of classroom experience, content area expertise) and background (e.g., race, ethnicity, gender, geographic location, age, academic level, etc.) were invited to participate in the study. Ten individuals remitted a blinded CV or extended resume to researchers. This document was chosen as it provides a detailed historical record of the sequence of opportunities and experiences an individual has in their professional life. This sequenced chronicle of job-relevant information provides a means to explore the ability of the STEMMaTe framework to sequence experiences and find commonalities of experiences across the sample. Participants were asked to provide information regarding their education, qualifications (classroom experience), and other relevant experiences they had in becoming a K–12 STEM master teacher. In addition, participants provided details of their leadership activities including mentoring teachers, service to the STEM education community, and scholarly activity. This pool of participants included five males and five females, who identified as Caucasian ($N = 6$), Latino or Hispanic ($N = 3$), and African American ($N = 1$). Eight participants had served as an AEF and four participants had won the PAEMST award; two individuals had received both recognitions. Among these teachers, one identified their content area expertise in primary science, seven in secondary science, two in secondary technology and computer science, and two in secondary mathematics. In sum, this sample had 122 years of K–12 STEM classroom teaching experience (5, 10, 23, 6, 17, 20, 9, 10, 13, and 9 years respectively) and two were currently serving in the classroom. Additional information on the participant sample is found in Table 1.

Table 1. Demographics and Background of Sampled K–12 STEM Master Leaders.

Participant Descriptor	Frequency (N)	Percentage or Average (SD)
Gender		
Male	5	50.0
Female	5	50.0
Race/Ethnicity		
White	6	60.0
African-American	1	10.0
Latino or Hispanic	3	30.0
Education [a]		
Undergraduate degree in STEM Content Area	9	90.0
Undergraduate degree in STEM Education	2	20.0
Master's degree in STEM Content Area	2	20.0
Master's degree in STEM Education	9	90.0
PhD degree/work in STEM Content Area	2	20.0
PhD degree/work in STEM Education	7	70.0
Classroom Experience		
Total Years of Classroom Teaching (SD)	122	12.2 (6.0)
Currently a K–12 Classroom Teacher	2	20.0
Content Area Expertise		
Elementary STEM	1	
Middle Grades STEM	0	10.0
High School STEM	9	0
Science	7	90.0
Technology (including Computer Science)	2	70.0
Engineering	0	20.0
Mathematics	2	0
Teacher-Leadership Experience [b]		20.0
Presidential Awardee (PAEMST)	4	40%
Albert Einstein Distinguished Educator Fellow (AEF)	8	80%
Awards and Recognition [c]		
Prior to PAEMST and AEF recognition	29	3.6 (2.6)
Post PAEMST and AEF recognition	28	3.5 (3.0)

[a]—One participant had two undergraduate degrees in STEM and Education. (N = 11); [b]—Two participants were awarded (both) the PAEMST and selected as an AEF. (N = 12); [c]—Two participants did not report awards outside of PAEMST and AEF. (N = 8).

The collected CVs were coded using a deductive content analysis approach [141], based upon the working conceptual understanding that there may be common LPP experiences along a similar career trajectory of these sampled teachers that facilitated their development as K–12 STEM master teachers. Categories were established using the common groupings found on the sampled CVs: education, employment history, K–12 teaching experience, service, awards or recognition, publications, and presentations. In the first pass of initial coding, data from individuals' CVs were populated into each category. Frequency counts were completed for these categories including the number of years of classroom teaching, publications, conference presentations, level of service (local, state, national, or international), level of awards (local, state, national, international) received both before and after PAEMST and/or AEF recognition. Descriptive information was recorded regarding whether they had written curriculum, dates and types of presentations and publications (when and whether they were for researcher or practitioner audiences). Each participant's employment history and service to the profession was sequenced into a chronology, starting after the completion of their undergraduate education, to explore how the sequence of their career experiences culminated to their K–12 STEM master teacher status. Once established, these timelines were further coded into subcategories to explore the types of STEM and education experiences including working in STEM, research (RET programs), consulting, coaching, mentoring, being a department chair, advising, etc. The first pass coding may be found in Appendix A for participants 1–5 (Table A1) and 6–10 (Table A2), respectively. In the second pass, subcategories informed by the five parts of the STEMMaTe framework [142] were used to further visualize the data. Subcategories included detailed information on the discipline area of undergraduate, graduate degree(s), (see Table 1), K–12 teaching experiences (number of different STEM courses taught, teaching of STEM field, higher education teaching experiences) and types of STEM education service (mentoring student teachers, writing curriculum, providing professional development). From individuals' timelines, common sequences of experiences emerged among sampled teachers from early, mid to late education career which were mapped on the five sequenced categories of the STEMMaTe framework. Again, frequency counts were completed to explore common experiences across the framework. Individuals who did not provide information in a certain category (e.g., did not mention they were a mentor teacher or provide a list of conference presentations or publications) were not counted. To ensure trustworthiness of the data processing, an audit trail is provided to the reader in Appendices A and B; also, coding and frequency counts were verified by a second researcher. After the second coder's review was complete, intercoder agreement was 100%.

3. Results

This research explored the sequence and types of LPP experiences of identified K–12 STEM master teachers throughout their professional teaching career. When using the STEMMaTe conceptual framework, common experiences along their career trajectory were found among the sample that led to their development as a K–12 STEM master teacher. For example, 9 of the 10 participants had undergraduate degrees in STEM, 9 of the 10 had advanced degrees, and 9 of the 10 had served as instructional coaches, STEM specialists, and/or curriculum development specialists.

Submitted CVs were then mapped using the STEMMaTe framework. First, each participant's career milestones (teacher-leadership-focused LPP) were recorded into columns chronologically (see Appendices A and B). Then, each milestone was provided a relationship to the STEMMaTe conceptual framework (see Table 2). Table 2 explores the data in more depth, showing how the STEMMaTe model maps to the coded CV data. And, the resulting career trajectories are shown in Tables 3 and 4.

Table 2. Sequence and Types of LPP Experiences Reported by K–12 STEM Master Teachers.

Category	Performances	Frequency (N)	Percentage or Average (SD)
Scholastic Effectiveness	Undergraduate STEM Degrees	9	90.0
	Undergraduate Teaching or Research Assistant	2	20.0
	Local, Regional Awards and Novice Teacher Fellowships [a]	13	1.6 (1.1)
Institutional Knowledge and Memory	Advanced Teaching Certification and Training	3	30.0
	School-based Leadership (Department Chair)	7	70.0
	Mentoring (Student Teachers, New Teachers)	7	70.0
	Leading Practitioner-focused Professional Development	9	90.0
Adaptability and Flexibility	STEM-based Research Experiences (including RET Programs) [b]	42 (years)	4.2 (3.6)
	Advanced Degrees (Masters)	9	90.0
	Graduate Teaching or Research Assistant	5	50.0
	Teaching out of Field or More than a Single Discipline in STEM (Informal teaching)	4	40.0
	Teaching New and Varied STEM Courses (Adjunct)	62	6.2 (2.9)
	Office/Committee in Local, District Level Professional Organizations [c]	16	2.7 (1.2)

Table 2. *Cont.*

Category	Performances	Frequency (N)	Percentage or Average (SD)
Emergent Leadership	STEM Specialists/Instructional Coaching/Curriculum Development/Curriculum Provider	9	90.0
	State Awards and Fellowships [a]	19	2.4 (1.7)
	Office/Committee in State Professional Organizations [d]	17	2.1 (1.6)
	Conference Presentations in STEM education Practitioner (teacher) venues [e]	108	13.5 (12.9)
	Publications in STEM education Practitioner (teacher) venues [f]	36	5.1 (3.3)
Strategic Leadership	Advanced Degrees (Doctoral) Focusing on STEM Education Research or Policy	7	70.0
	Professor or Researcher in Higher Education	7	70.0
	National Awards and Fellowships (including PAEMST, AEF)	41	4.1 (3.7)
	Office/Committee in National, International Professional Organizations	62	6.2 (2.8)
	Consulting/Advising to Governmental Agencies, Think tanks, National and International Teacher Professional Organizations	6	60.0
	Conference Presentations in STEM education research venues [g]	71	14.2 (11.1)
	Publications in STEM education research venues [h]	20	3.3 (2.6)

[a]—Two participants did not report awards and recognition other than PAEMST/AEF. (N = 8); [b]—Only two participants did not report having STEM-based research experiences; [c]—Four participants did not report local, district level activities; [d]—Two participants did not report State Level organizations, which included the District of Columbia and Guam; [e]—Two participants did not report practitioner presentations; [f]—Three participants did not report practitioner publications; [g]—Five participants did not report research presentations; [h]—Four participants did not report research publications.

Table 3. K–12 STEM Master Teachers Career Trajectories Mapped to STEMMaTe Framework, Participants 1–5.

Participant Number	1	2	3	4	5
Early Career	Scholastic Effectiveness	Scholastic Effectiveness	Scholastic Effectiveness	Scholastic Effectiveness	Scholastic Effectiveness
	Scholastic Effectiveness	Scholastic Effectiveness ¥	Scholastic Effectiveness ¥	K–12 Teaching **(6 years)**	Scholastic Effectiveness ¥
	Adaptability and Flexibility	K–12 teaching **(11 years)**	Scholastic Effectiveness ¥	Institutional Knowledge and Memory	Scholastic Effectiveness ¥
	K–12 Teaching **(5 years)**	Institutional Knowledge and Memory	Adaptability and Flexibility	Adaptability and Flexibility	Institutional Knowledge and Memory
	Emergent Leadership	Adaptability and Flexibility	K–12 Teaching **(20+ years)** *	Strategic Leadership **	K–12 Teaching **(27 Years)**
	Adaptability and Flexibility	Adaptability and Flexibility	Emergent Leadership	Emergent Leadership	Strategic Leadership**
	Emergent Leadership	Strategic Leadership **	Strategic Leadership **	Strategic Leadership	Emergent Leadership
	Strategic Leadership **	Emergent Leadership	Emergent Leadership	Strategic Leadership	Strategic Leadership
	Adaptability and Flexibility	Strategic Leadership	Emergent Leadership	Adaptability and Flexibility ***	
	Adaptability and Flexibility ***	Strategic Leadership	Strategic Leadership	Strategic Leadership	
	Strategic Leadership		Strategic Leadership	Strategic Leadership	
Late Career			Strategic Leadership		

* Individual is still teaching in a K–12 classroom at the time of the research study; ** Indicates Strategic Leadership was AEF or PAEMST experience; *** Adaptability and Flexibility category related to Graduate Research Teaching or Research; ¥ Relates to Holding STEM Job or STEM Master's degree (unrelated to STEM Education).

Most teachers had early career experiences that bolstered their content knowledge (e.g., degree in STEM), presumably aiding in their development of scholastic effectiveness. Most of these teachers also served in school-wide leadership positions (e.g., department chair, facilitating PD), to develop their institutional knowledge memory. Next, many teachers had experiences that would support their development of adaptability/flexibility (e.g., teaching out of field, teaching new STEM courses). And finally, most had emergent leadership experiences (e.g., instructional coaching, publishing in peer-reviewed journals) prior to receiving AEF or PAEMST which led to strategic opportunities for leadership. There are notable exceptions for participants 1, 4, 9 and 10. Upon further examination, participants re-entered the adaptability and flexibility category as graduate research or teaching assistant, as these teachers changed careers from K–12 classroom teaching to earn a doctorate as a full time graduate student. Analyses of the CV data set suggest that these master teachers' experiences align with the proposed STEMMaTe framework.

Table 4. K–12 STEM Master Teachers Career Trajectories Mapped to STEMMaTe Framework, Participants 6–10.

Participant Number	6	7	8	9	10
Early Career	Scholastic Effectiveness	Scholastic Effectiveness	Scholastic Effectiveness	Scholastic Effectiveness	Scholastic Effectiveness
	K–12 Teaching **(21 years)**	Scholastic Effectiveness	Scholastic Effectiveness	Scholastic Effectiveness	K–12 Teaching **(9 years)**
	Institutional Knowledge and Memory	K–12 Teaching **(10+ Years)** *	Adaptability and Flexibility	Adaptability and Flexibility	Institutional Knowledge and Memory
	Strategic Leadership **	Institutional Knowledge and Memory	K–12 Teaching **(10 years)**	K–12 Teaching **(13 years)**	Adaptability and Flexibility
	Adaptability and Flexibility	Emergent Leadership	Adaptability and Flexibility	Institutional Knowledge and Memory	Adaptability and Flexibility
	Adaptability and Flexibility	Adaptability and Flexibility	Institutional Knowledge and Memory	Institutional Knowledge and Memory	Adaptability and Flexibility
	Emergent Leadership	Adaptability and Flexibility	Adaptability and Flexibility	Adaptability and Flexibility	Adaptability and Flexibility
	Strategic Leadership	Strategic Leadership **	Adaptability and Flexibility	Adaptability and Flexibility	Adaptability and Flexibility
	Strategic Leadership	Strategic Leadership	Adaptability and Flexibility	Adaptability and Flexibility	Adaptability and Flexibility
		Strategic Leadership	Emergent Leadership	Emergent Leadership	Strategic Leadership **
			Strategic Leadership **	Strategic Leadership **	Strategic Leadership **
			Strategic Leadership	Adaptability and Flexibility ***	Strategic Leadership
			Strategic Leadership **	Strategic Leadership	Adaptability and Flexibility ***
			Strategic Leadership	Strategic Leadership	Strategic Leadership
Late Career			Strategic Leadership	Strategic Leadership	

* Individual is still teaching in a K–12 classroom at the time of the research study; ** Indicates that Strategic Leadership was AEF or PAEMST experience; *** Adaptability and Flexibility category related to Graduate Research Teaching or Research.

4. Discussion

The STEMMaTe framework provides a mechanism for identifying important experiences for STEM master teacher development. Contrary to traditional conceptions that conflate veteran and master teachers, the framework posits that STEM master teacher status is a product of LPP and mastery of pedagogical self-efficacy (scholastic effectiveness), institutional understandings (institutional knowledge and memory), contextual malleability (flexibility/adaptability), and scaled leadership capacity (both emergent and strategic). By addressing the need for understanding K–12 STEM teacher-leadership development, we may sequence extant or cultivate new teacher-leadership experiences and programs to address the dearth of K–12 STEM teachers at policy-influencing levels.

While the framework provides coherence to concepts like experience, leadership, and expertise, it also provides a mechanism for program development that specifically targets K–12 STEM master teacher development. Recognizing that K–12 STEM Master Teacher development is a lengthy and complex process, it may be unrealistic to expect a single program to address every dimension of the framework. Rather, teachers need a continuum of experiences that address different needs at different stages of their career. The STEMMaTe framework provides a mechanism for sequencing existing programs into such a continuum of experiences. The idea of a continuum creates space for a progression of activities (LPP) within each community of practice, each of which provides meaningful professional development to the developing STEM master teacher. Just as an experienced teacher would not benefit from a program like the Knowles Science Teacher Fellowship [143], which targets early career teachers (years 1 to 5), a novice teacher would not benefit from a program like AEF [98], which requires previous experiences to acquire and demonstrate mastery of STEM content and pedagogy. However, the framework suggests sequencing LPP experiences (programs) to provide pathways for teachers to achieve STEM master teacher status, to possess the knowledge, skills, and experiences to participate at policy-influencing levels of local, state, and national K–12 STEM education.

To provide context, a sequence might look like the following: A novice teacher begins his/her career in a program that targets early-career teachers, perhaps within the Knowles Science Teaching Foundation's Fellowship program. This type of program could provide support for the teacher as s/he develops his/her scholastic effectiveness and help him/her cultivate a leadership mindset. Next, s/he builds institutional knowledge by serving on building or district-level committees, or by participating in a Professional Learning Community (PLC). As teacher identity builds [70], s/he may seek new ways to demonstrate knowledge of the teaching craft by applying for National Board Certification [144]. This recognition would validate his/her scholastic effectiveness by providing evidence of his/her institutional knowledge of teaching and learning. To cultivate experiences in flexibility and adaptability, s/he could apply for a RET program like the Grosvenor Teacher Fellows [145], NOAA's Teacher at Sea [146], or PolarTrek [147], which provide opportunities to teachers to spend a portion of their non-academic year studying in remote, STEM-focused locations. These programs select for learners who wish to engage in LPP for flexibility (education in non-school settings) and adaptability (experience translated into classroom curricula). For STEM teachers, RET programs are vital for advancing content knowledge and leadership [148]. Next, a statewide leadership development program can help him/her develop a statewide network of colleagues to begin participating in leadership activities at a larger scale. One such example is the Kenan Fellowship for Teacher Leadership [149], a North Carolina program that networks teachers with industry leaders, academics, and educational policy organizations. Such programs could also be supplemented with leadership positions in STEM-based teacher organizations, like the National Science Teachers Association, International Society for Technology in Education, the International Technology and Engineering Educators Association or National Council of Teachers of Mathematics. At this point, s/he could apply for PAEMST, or even the Teacher of the Year Program [150], which would provide recognition at both the state and national levels and increase the scale of her/his professional network. S/he could conclude her/his master teacher progression with a program like the AEF [98], after which s/he would have the skills, recognition, and professional networks to influence policy at the local, state, and national levels. Table 5 shows a potential pathway for STEM master teacher development using extant STEM teacher opportunities and programs.

Table 5. Potential Pathway for STEM Master Teacher development through the STEMMaTe Conceptual Framework and Teacher Professional Development Opportunities and Programs.

Levels of Participation in STEM Master Teacher Community of Practice	LPP Program Experiences
Scholastic Effectiveness	Novice Teacher Focused Fellowship Mentoring
Institutional Knowledge and Memory	Advanced Teaching Recognition/Certification School-based Leadership Role Department Chair
Adaptability and Flexibility	RET Program
Emergent Leadership	Kenan Fellowship for Teacher Leadership Participation in STEM Teacher Professional Organizations
Strategic Leadership	Albert Einstein Distinguished Educator Fellows Holding Office in National or International STEM Teacher Professional Organizations

While the proposed program continuum emphasizes national programs, it is important to acknowledge that professional development continuums can, and should, exist at the local and state levels, at least for early stages in the framework (scholastic effectiveness, institutional memory, adaptability/flexibility). This is particularly true for some professional formation experiences, that build both teachers' competency and pedagogy, and have minimal monetary costs. Clearly, not all K–12 STEM Master Teachers need to participate in the Knowles program; requiring so would put significant constraints on who is identified as a K–12 STEM Master Teacher. However, intentional, programmatic development at the state and local level targeting early-career teachers, consistent with a program like Knowles [143], would help increase national capacity for STEM Master Teacher development. In one sense, national programs could help provide a 'roadmap' for program development at the local/state level. Given the importance of STEM in the national education discourse, it is critical to develop, identify, and empower STEM master teachers.

The proposed STEMMaTe framework builds on the traditions of situated learning theory, which has proven success in informing adult learning with educators [78,151] by applying Lave and Wenger's [28] notions of legitimate peripheral participation (LPP) to cultivating expertise in STEM teacher leadership. The STEMMaTe framework also provides mechanisms for conceptualizing both what a STEM master teacher can do (practices) and the continuum of (LPP) experiences necessary to develop that teacher. The framework has the potential to evaluate existing programs, sequence those programs into the larger continuum of experiences, and provide guidance for new program development. The document analysis conducted of the 10 sampled K–12 STEM teacher leaders suggests that the STEMMaTe framework does map onto the continuum of experiences of these participants on their way to K–12 STEM master teacher status. While not explicit, this framework offers a remedy to the teacher retention problem; providing new teachers sequenced and developmentally appropriate professional development experiences may incentivize them to remain in the profession [152–154].

The framework does have limitations. Its capacity for program development and evaluation is coarse grained at best, enabling programs to classify their activities but not rate the efficacy of those activities. For example, a program could use the STEMMaTe framework to uncover a deficiency in strategic leadership, but the framework may not necessarily provide information on the quality of its work in the emergent leadership space. The framework is also agnostic with respect to obstacles that may impede STEM master teacher development. Because the learner has a strong desire for LPP, it does not mean that the teacher's administration shares this enthusiasm. They may either not support or actively dissuade the teacher's participation in the program, delaying or preventing the teacher from starting down the continuum of STEM master teacher development experiences. While the situated nature of the framework acknowledges the powerful, social component of leadership development, the framework does not offer guidance on negative community relationships or school climate issues that may impede development. Addressing the above limitations could be a first step in continuing research on both the STEMMaTe framework and the larger issue of identifying and cultivating attributes of STEM Master Teachers.

Moreover, the goal of any potential framework is to create a strong, empirical theory-setting model with testable hypotheses. Therefore, more work is warranted to build in capacity for evaluating the quality of teacher-serving programs. Creating more gradations within each phase of the framework could create that capacity. In parallel, future research could better explore characteristics of existing STEM master teachers, possibly through the use of cohort studies for groups like AEF or PAEMST awardees. While this study's document analysis certainly provides evidence in support of the framework, the case study does not add significant descriptive depth, nor does it provide causal connections between particular experiences and the development of skills requisite for master teacher status; future cohort analyses could do just that, further refining the framework. For example, a future case study analysis could explore how school-wide leadership positions like department chair support development of both institutional memory and/or emergent leadership. Another study could explore how much experience/time is sufficient before a teacher moves into emergent leadership experiences.

Currently, programs like PAEMST and the AEF do have experience minimums (5 years for both), but it is unclear how that requirement maps to master teacher development. In addition, qualitative case studies exploring the trajectory of STEM master teachers can explore potential external challenges or barriers, not captured by the framework, to STEM master teacher status.

5. Conclusions

Recent works have focused on the importance of involving teacher voice in policy-level discussions [23,155]. Educational policy-making is a political process, which means competing groups must engage in dialogue to decide how to use public resources [156]. While teachers are not the only group involved in this political process, they have a valuable perspective as the instruments of policy-level decisions. Master teachers in particular, have a critical perspective, as they can foresee systemic issues in funding processes for STEM programs, program implementation, and appropriate levels of support for programmatic efficacy [23]. The proposed STEMMaTe framework provides a mechanism for advancing avenues for teacher voice by developing such master teachers in STEM and guiding their (programmatic) development to increase national capacity for K–12 STEM master teachers.

Future work could explore this idea of program sequencing in more depth, at different scales (state, local, national) by surveying existing professional development programs at the local, state, and national levels. Using best practices in professional development design and execution recommended by van Driel, Meirink, van Veen, and Zwart [157] and Wilson [158], such work could create a series of roadmaps for teachers interested in master teacher development, potentially targeting specific regions/states. Smylie and Eckhart [27] recently argued for intentional development of teacher-leadership capacity; we would extend that argument further to incorporate all components of the STEMMaTe framework, creating opportunities for program development at multiple stages of a teachers' developmental journey. Therefore, the framework may potentially serve as an external evaluative tool, providing programs a mechanism for determining how they address different elements of master teacher development, through identification of program strengths, gaps, or providing guidance for new program development efforts. Through programmatic evaluation, the model may be useful in targeting state and/or federal dollars towards programs for K–12 STEM master teacher development, especially in under-resourced areas.

Finally, future research could explore how segments of this framework might apply to other disciplines like the humanities, creating frameworks to develop master teachers in Literacy or the Social Sciences. While this particular framework was a response to calls from the National Research Council [23,155] and the US Department of Education [60] to develop capacity for master teachers in STEM specifically, the authors acknowledge that master teacher development in other disciplines is just as important to a functioning education system. The STEMMaTe framework could provide a starting point for that development process, as concepts like adaptability and flexibility may be generalizable across disciplines.

While not a limitation of the framework, an important question remains related to STEM master teacher development: how can individual schools, and school systems, leverage the skills of teachers once they achieve STEM master teacher status? Traditional school structures often provide little time for leadership activities during the school day, so future research could explore alternative structures like distributed leadership [159] that capitalize on the unique practices of STEM master teachers. In a similar fashion, it may be prudent to expand connections between policy makers and teachers, so that policy makers can tap master teachers' expertise when implementing new policies like NGSS [15]. While programs like the AEF provide such connections at the federal level, those connections depend upon teachers leaving the classroom; future work could identify programs that allow teachers to work with policy makers while remaining in the classroom.

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Appendix A

Table A1. K–12 STEM Master Teachers Career Trajectories for Participants 1–5.

Participant Number	1	2	3	4	5
Early Career	Undergraduate Degree (STEM)	Undergraduate Degree (STEM)	Undergraduate Degree (STEM)	Undergraduate Degree (STEM)	Undergraduate Degree (STEM)
	UTA/URA	STEM Job	STEM Job	K–12 Teaching **(6 years)**	STEM Job
	Masters' Degree (Education)	K–12 teaching **(11 years)**	Masters' Degree (STEM)	School Leadership	Masters' Degree (STEM)
	K–12 Teaching **(5 years)**	Department Chair	HE Teaching	RET	Practitioner PD in STEM
	Specialist/Coach/PD Provider	Masters' Degree (Education)	K–12 Teaching **(20+ years)** *	AEF	K–12 Teaching **(27 years)**
	HE Teaching	RET	Specialist/Coach/PD Provider	Specialist/Coach/PD Provider	AEF
	Curriculum Developer	AEF	PAEMST	National Leadership	Specialist/Coach/PD Provider
	AEF	Curriculum Developer	Curriculum Developer	Consultant (Education)	PhD
	Master's Degree (Education)	Consultant (Education)	Regional Leadership	GRA/GTA	
	GTA/GRA	PhD	National Leadership	PhD	
	PhD		International Leadership	University Faculty/Researcher	
Late Career			PhD		

* Individual is still teaching in a K–12 classroom at the time of the research study.

Appendix B

Table A2. K–12 STEM Master Teachers Career Trajectories for Participants 6–10.

Participant Number	6	7	8	9	10
Early Career	3	Undergraduate Degree (STEM)	Teaching Fellowship	Teaching Fellowship	Undergraduate Degree (Education) **
	K–12 Teaching (21 years)	UTA/URA	Undergraduate Degree (STEM)	Undergraduate Degree (STEM)	K–12 Teaching (9 years)
	School Leadership	K–12 Teaching (10+ Years) *	Masters' Degree (Education)	Masters' Degree (Education)	School Leadership
	AEF	School Leadership	K–12 Teaching (10 years)	K–12 Teaching (13 years)	RET
	RET	State Leadership	Informal Teaching	School Leadership	Masters' Degree (Education)
	RET	Masters' Degree (Education)	School Leadership	Regional Leadership	Informal Teaching
	Specialist/Coach/PD Provider	HE Teaching	RET	RET	RET
	Consultant (Education)	PAEMST	RET	RET	RET
	Director	National Leadership	RET	RET	RET
		PhD	State Leadership	State Leadership	AEF
			AEF	AEF	PAEMST
			National Leadership	GTA/GRA	National Leadership
			PAEMST	National Leadership	GTA/GRA
			PhD	PhD	PhD
Late Career			University Faculty/Researcher	University Faculty/Researcher	

* Individual is still teaching in a K–12 classroom at the time of the research study; ** An elementary teacher.

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