Partnerships to Transform STEM Learning

A Case Study of a STEM Learning Ecosystem

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Science, technology, engineering, and mathematics—the disciplines known as STEM—are critically important for economic and societal development. STEM has increasingly been integrated in educational research and practice, as the national agenda has shifted in response to several high-impact reports, including *Rising Above the Gathering Storm* (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, 2007), which emphasized the need to increase STEM proficiency to prepare young people for the STEM workforce and to promote innovative capacity and prosperity.

One of the most notable transformations in the STEM educational landscape in the last decade is the rise of the out-of-school time (OST) sector as a leading provider of STEM enrichment (Krishnamurthi, Ottinger, & Topol, 2013; National Research Council, 2015). High-quality OST programs provide young people with rich, engaging learning experiences, coupling STEM concepts with hands-on activities that foster youth voice and choice and apply STEM

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to real-world social contexts (Lyon, Jafri, & St. Louis, 2012; Noam & Shah, 2014). A large and growing literature documents the positive effects of OST STEM on youth outcomes (e.g., Allen et al., 2019; Dabney et al., 2012; Young, Ortiz, & Young, 2017). Practitioners, researchers, and policymakers show increasing interest in strategic partnerships among OST providers, K–12 schools, and other community organizations (Anthony & Morra, 2016; Bevan et al., 2010; National Research Council, 2015) to improve access to quality STEM learning, especially among underserved youth, and to increase the number of young people who pursue STEM careers (National Research Council, 2015).

To better understand how communities can develop and leverage partnerships within and beyond OST to improve STEM programming, we conducted an in-depth case study of one of the first STEM learning ecosystems in the U.S.: the Tulsa Regional STEM Alliance in Oklahoma, which is working to improve STEM teaching and learning from its home base in the OST sector. This article begins by describing the STEM Learning Ecosystems Community of Practice (CoP), a national initiative that cultivates dynamic community partnerships to provide high-quality STEM learning. After presenting our research frame and outlining our methodology, we summarize key findings from the Tulsa alliance, focusing on how an OST-led STEM learning ecosystem forms, develops, acts, evolves, and sustains itself over time. Our conclusions focus on how the OST field can lead a national movement to transform STEM education by developing strong partnerships with schools, businesses, and STEM institutions; by investing in quality standards; and by building data systems and common measurements to support continuous improvement.

STEM Learning Ecosystems Community of Practice

The federal government's most recent five-year strategic plan for STEM education identified strategic partnerships through STEM learning ecosystems as a key to success (National Science and Technology Council, 2018). The STEM Learning Ecosystems CoP was developed to bridge the many political, cultural, pedagogical, financial, and logistical divides among the diverse sectors that are invested in STEM (Traphagen & Traill, 2014). Launched by the STEM Funders Network at the Clinton Global Initiative in 2015 and organized by the Teaching Institute for Excellence in STEM, the STEM Learning Ecosystems CoP promotes local collaborations among school districts, OST providers, businesses, cultural institutions, research organizations, and funders (Figure 1). The CoP's mission is to "spark young people's engagement, develop their knowledge, strengthen their persistence and nurture their sense of identity and belonging in STEM disciplines" (STEM Ecosystems, 2019b).

The STEM Learning Ecosystems CoP framework encompasses the four strategies shown in Table 1. All ecosystems are also provided with 10 aligned design principles (Traill, Traphagen, & Devaney, 2015), which include cultivating dynamic, diverse partnerships; experimenting with creative means of partnering across sectors; and increasing the quantity and quality of active, inquiry-based formal and informal STEM learning opportunities for all, including for young people historically underrepresented in STEM. Individual ecosystems are encouraged to adapt the strategies to suit their communities.

Now in its fifth year, the STEM Learning Ecosystems CoP has scaled rapidly, growing from 27 commu-

Figure 1. STEM Learning Ecosystems Model

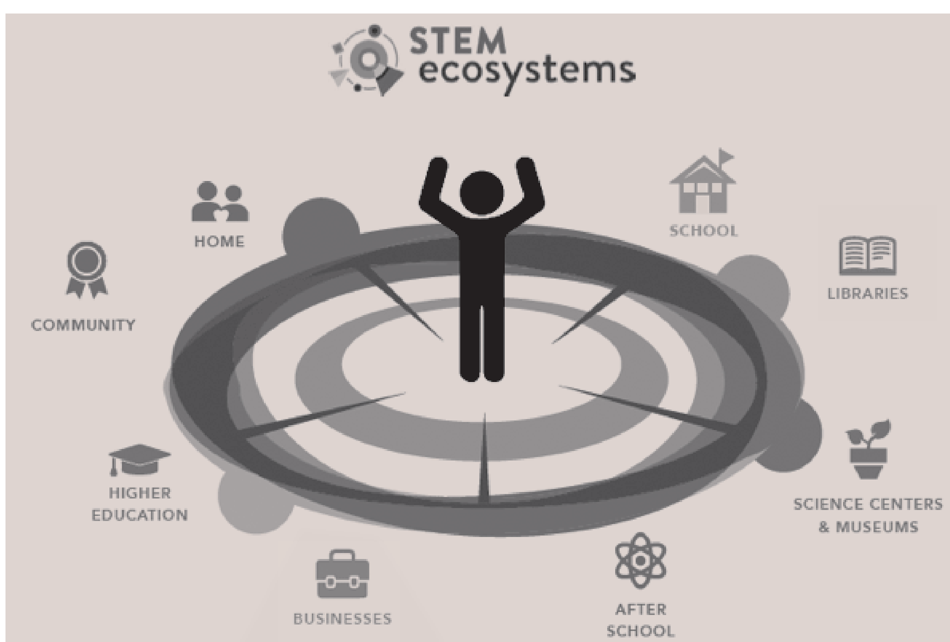


Table 1. STEM Learning Ecosystems CoP

Source: https://stemecosystems.org/strategies

Strategy	Definition	Examples of Actions
Cultivate cross-sector partnerships	Assess gaps, identify partners, and determine collective goals based on each community's needs, assets, and interests	Identifying a lead organization, engaging a broad range of stakeholders from key sectors, assessing the community's readiness to collaborate, and defining the landscape and potential gaps
Create and connect STEM-rich learning environments	Ensure that STEM learning opportunities are high quality, universally accessible, youth centered, and connected so learners can deepen their skills and interests and tackle increasingly complex challenges	Aligning with reputable and vetted national standards, connecting school and OST STEM learning, and employing evidence-based strategies to promote successful STEM learning for all, especially traditionally underserved students
Equip educators	Build educators' capacity through high-quality, relevant professional development, cross-sector experiences, and sharing of effective practices	Designing and implementing high-quality training, connecting educators with private and public sector STEM employees, and developing approaches to continuous improvement (e.g., data sharing to increase quality)
Support youth pathways	Enable young people to become engaged, knowledgeable, and skilled in the STEM disciplines as they progress from childhood into early adulthood	Connecting young people to STEM mentors, teaching about the range of STEM careers and opportunities starting at an early age, and creating new credential models (badging, certifications, etc.).

nities in the U.S. in 2014 to 89 communities in the U.S., Canada, and Africa in 2019. These 89 ecosystems, each consisting of an individual city or region, collectively serve tens of millions of young people by engaging school districts; informal programs; and philanthropic, business, and industry partners. Ecosystem leaders have invested thousands of hours to "cultivate the ecosystem," defined by initiative organizers as "collaborating across sectors in new and creative ways to increase equity, quality, and STEM learning outcomes for all" (STEM Ecosystems, 2019a).

Research Goals and Framework

Now that the STEM Learning Ecosystems CoP is well established, the field can begin to understand how communities have implemented its strategies to change STEM learning models. We conducted a case study of an established community that met the following criteria: It leads from the OST sector, has participated in the CoP since its launch in 2014, is representative of the partnership and demographic composition of the initiative, has established common assessment strategies that can be used within and across ecosystems, has evidence of observable change in the design and delivery of STEM learning in and out of school, and was able to engage in the case study research with full transparency. One ecosystem met all these criteria: the Tulsa Regional STEM Alliance (TRSA) in Oklahoma. In addition to meeting the criteria, TRSA is a credible, highly engaged organization committed to collaborative practice.

To explore how an ecosystem led by an OST-centered organization develops, acts, and sustains itself over time, we asked the following research questions:

- Why and how does a community come together to form an ecosystem?
- How are ecosystem aspirations transformed into action?
- How does an ecosystem measure the effectiveness of its efforts?
- What are indicators of ecosystem sustainability?

We began by reviewing the four STEM Learning Ecosystems CoP strategies and 10 design principles. To

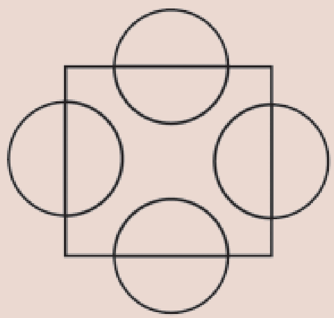
Figure 2. Partnership Typology

Source: Noam & Tillinger, 2004

OPPORTUNITY-BASED

Discovering overlapping interests

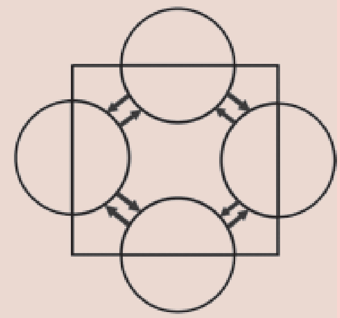
Member organizations maintain their autonomy. Collaboration is seen as functional. Members network to share knowledge and resources.



COLLABORATIVE

Joining forces

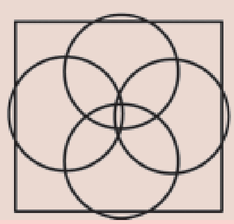
Member organizations develop common goals, benefit from one another's strengths and experiences, and establish some accountability.



INTERCONNECTED

Developing an inclusive system

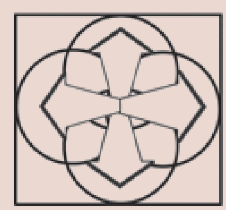
Member organizations develop clear communication and a level of intimacy. They engage in joint decision-making, shared programming, and group celebrations of accomplishments.



TRANSFORMATIONAL

Changing all partners

Member organizations accomplish more together than they do independently. Relationships are equal, not hierarchical.



explore how community sectors join in an ecosystem to transform STEM education, we used the partnership typology shown in Figure 2 (Noam & Tillinger, 2004) to track the ecosystem from opportunity-based to collaborative to interconnected to transformational partnership, acknowledging that systems, like people, can function at more than one developmental level at the same time.

Our in-depth analysis of an established ecosystem examines how community stakeholders collaborate to support student learning, how the programming helps young people develop STEM skills and knowledge, and how other ecosystems can use this model.

Research Methods

We used a mixed-methods approach to understand how Tulsa's OST-centered community used the STEM Learning Ecosystems CoP network to begin to transform STEM learning.

Data Sources

Multiple data sources were used to build evidence for the case study. All study procedures were approved by an institutional review board.

Document Review

To understand the historical context of the Tulsa STEM ecosystem, we conducted an extensive review of documents, archival records, and physical artifacts, including the ecosystem design blueprint, the STEM Learning Ecosystems CoP membership application, and the TRSA website. These secondary data helped us understand the timeline and allowed us to map the landscape of the community. The data also allowed us to explore evidence of ecosystem impact on academic achievement, the quality of programming, and the learning experiences of youth.

Focus Group and Interviews

We conducted one focus group with 10 people and 15 individual interviews with key ecosystem stakeholders. In total, 21 individuals participated in the focus group, individual interviews, or both. They represented various sectors of Tulsa's ecosystem, including afterschool, business, local government, philanthropy, K–12 schools, STEM professionals, and community alliances. Several participants were also parents whose children participated in TRSA OST or in-school programming. Some had STEM experience as teachers or as staff of STEM-based organizations.

The focus group was designed to spur conversations among participants from diverse sectors. Individual interviews, by contrast, allowed more time to delve into individuals' perspectives. They also allowed individuals to surface challenges facing the ecosystem or its sectors that they might be hesitant to raise in a group setting. Both the focus group and individual interviews used a semi-structured format. The discussions were guided by predetermined questions based on the CoP strategies and the partnership typology, but respondents were encouraged to talk freely and ask questions.

After each interview, we emailed the participant a link to a follow-up questionnaire, in which we asked for demographic information such as gender and race/ethnicity and enabled respondents to share anonymously their thoughts about the well-being and sustainability of the ecosystem. Of the 11 people who completed this survey, nine identified as White/Caucasian, and seven were female. All 11 were college educated; just over half held a master's degree.

Observations

Direct observations of OST STEM activities were performed using Dimensions of Success (DoS), a validated observation tool designed to assess levels of quality of informal STEM activities (Peabody, Browne, Triggs, Allen, & Noam, 2019; Shah, Wylie, Gitomer, & Noam, 2018). This evidence-based tool captures 12 dimensions of STEM program quality along four organizing domains. Strength of evidence for each dimension is quantified using a 4-point rubric ranging from 1, *evidence absent,* to 4, *compelling evidence*. Rigorous training and certification are required to perform DoS observations. Certified observers performed 37 observations in 12 school- or community-based OST programs. The psychometric properties of DoS and descriptions of its dimensions can be found in Shah et al. (2018) and Allen et al. (2019).

Student Surveys

Students enrolled in OST programs supported by TRSA were invited to complete a validated self-report survey called the Common Instrument Suite for Students (CIS-S). The CIS-S measures five attitudes predictive of future STEM participation—engagement, career interest, career knowledge, activity participation, and identity—and assesses four 21st century skills: critical thinking, perseverance, relationships with adults, and relationships with peers (Allen et al., 2019; Malti, Zuffianò, & Noam, 2017; Noam, Allen, Shah, & Triggs, 2017). The psychometric properties and descriptions of the survey scales can be found in Allen et al. (2019). A total of 7,713 young people in grades K–12 who participated in TRSA-supported programming took the survey. For validity reasons, only surveys from respondents in grades 4 and above were used in this case study.

Ecosystem Leader Survey

We also used data from the TRSA leader's STEM Learning Ecosystems Indicator Tool. Leaders of all CoP communities complete this self-report survey each year. Developed by CoP organizers, the survey measures ecosystem progress in five domains aligned with the CoP strategies and design principles: cross-sector partnerships, architectural and organizational features required for sustainability, alignment of learning in and out of school with evaluation, equipping educators with tools and training, and college and career readiness and development of articulated career pathways.

Data Analysis

Qualitative data from interviews and the focus group were transcribed, categorized, and organized thematically. We also assembled key events and outcomes into a chronology to examine the ecosystem's development over time.

Quantitative data from observations, youth surveys, and the leader survey were analyzed using data analysis software. We tested for statistical significance to examine any differences in survey ratings between Tulsa youth and a national sample of peers in similar OST programming. We could not analyze differences over time because data were de-identified and represented different cohorts of programs and children.

Findings on the Tulsa STEM Ecosystem

We synthesized six categories from the qualitative and quantitative data: the ecosystem's landscape, origin and evolution, theory of action, impact, partnerships, and sustainability.

Landscape

The document review and the interview and focus group discussions helped us map the distinctive features of the ecosystem's location and community. As in many other U.S. cities, STEM employment opportunities in Tulsa are growing, but employers struggle to hire local people with adequate technical skills and experience. Oklahoma is home to a wide variety of STEM-related industries including oil, natural gas, energy, manufacturing, and aerospace. Many STEM-related businesses are collaborating with TRSA, providing financial and other resources and co-organizing STEM events. A few public schools have been praised by national media for their innovative approaches to STEM education (Kirp, 2017; Thompson, 2017). However, progress has been stymied by recent financial crises and teacher strikes, and performance on math and science assessments has been consistently low (Oklahoma State Department of Education, 2018; Nation's Report Card, 2017). Tulsa's STEM challenges have the potential to resonate in communities throughout the U.S.

TRSA grew out of several area organizations that had similar intentions to support STEM by addressing educational and workforce gaps. It took five years, from 2013 to 2018, to move from incubation to independence.

Origin and Evolution

We used qualitative data to trace the origin and evolution of Tulsa's STEM learning ecosystem. TRSA is an intermediary organization—a self-described "dynamic mesh network"—that advocates for education policies to give every student "access to the best possible STEM education" (Tulsa Regional STEM Alliance, 2019). TRSA provides training and professional development for STEM educators, collaborates with other organizations in and out of OST to implement STEM programs and events, and designs and delivers STEM programming to children and adolescents.

TRSA grew out of several area organizations that had similar intentions to support STEM by addressing educational and workforce gaps. It took five years, from 2013 to 2018, to move from incubation to independence. As of 2018, the organization was an active, independent 501(c)(3) nonprofit enterprise with well-defined organizational structures, goals, and programming. The sole STEM intermediary in Tulsa, TRSA has a board of directors, an advisory council, over 140 diverse STEM partners, and seven paid staff, including a dynamic leader.

Theory of Action

Document review, the ecosystem leader survey, and the focus group and interviews provided evidence for how TRSA has been putting the four STEM Learning Ecosystems CoP strategies into action.

TRSA is establishing and sustaining cross-sector partnerships by collaborating with more than 140 local STEM partners and working to establish new partnerships. Of the 40 events that TRSA organized in 2018, half involved partners representing four or more sectors, and two out of three involved partners from three or more sectors.

To create and connect STEM-rich learning environments in diverse settings, TRSA has been working to increase diversity in two areas: learning environments and populations served. Ecosystem partners we interviewed said that TRSA is promoting STEM learning throughout the city and county. It has been scaling its efforts to reach all young people, especially low-income youth, youth of color, and youth with special needs.

To equip educators to lead active learning in diverse settings, TRSA has worked with Teaching Institute for Excellence in STEM (TIES) and Tulsa area school districts to identify STEM priorities. It has piloted grade-level STEM lessons in schools, led professional development in which teachers developed inquiry- and problem-based pedagogy, and offered STEM in school-

Table 2. Tulsa Ecosystem Growth, 2017–2018

Activity	Participants in 2017*	Participants in 2018*
Events, programs, and camps for youth	177,858	194,914
Mentorship opportunities with participating STEM professionals	229	301
Professional development events for educators	1,232	1,310

* Values do not represent unique cases; TRSA may serve the same young person more than once per year.

based OST settings such as clubs and competitions. Records showed that 1,432 students, 41 teachers, 59 classrooms, and 27 schools from several districts were engaged in these efforts. In addition, TIES and TRSA spent substantial time helping one school district design a process to integrate STEM into curriculum.

For the fourth strategy, TRSA has fostered STEM interest and workforce development by partnering with area businesses and industry to offer programs that support youth access to STEM learning and careers. Examples include mentorships with local professionals, engineering competitions, visits to local businesses, and "STEM cafés" in which STEM experts visit schools to discuss their areas of expertise.

Impact

Evidence for ecosystem impact—such as improvements in funding, equity, access, and STEM teaching and learning—was provided by TRSA documents, such as budget and finance information and program attendance logs, and by the focus group and interviews. Evidence for impact falls into three categories: activities and participation, student outcomes, and program quality outcomes.

Activities and Participation

TRSA led significant growth in STEM engagement in Tulsa, as shown in Table 2. Based on documented levels of student impact between 2013 and 2018, TRSA expects to serve more than 250,000 children and youth by 2020. "Student impact" includes direct student engagement in programs, events, camps, and mentoring opportunities as well as indirect student engagement through professional development, materials, and other financial support.

Student Outcomes

Tulsa's ecosystem has made significant investments to make sure that youth have positive STEM experiences. Results from the CIS-S survey for TRSA-supported afterschool and summer programs from 2016 to 2018 showed that, at the end of programming, Tulsa students reported significantly more growth in all STEM-related attitudes and 21st century skills measured (except STEM activity participation) than did students in the national sample. For example, 79 percent of Tulsa students reported growth in STEM career interests, compared to 70 percent of students nationwide, a statistically significant difference. In 21st century skills, 85 percent of Tulsa youth reported growth in perseverance, while 66 percent of youth nationwide reported growth, another statistically significant difference. The areas in which Tulsa youth reported the most growth between 2016 and 2018 were STEM engagement, critical thinking, perseverance, relationships with peers, and relationships with adults, with more than 80 percent reporting positive changes in these outcomes.

In baseline results, Tulsa youth began their programs with significantly higher ratings than their peers nationwide in all four 21st century skills and in four of the five STEM attitude measures. For example, Tulsa youth rated an average of 2.98 out of 4 on the self-reported measure of STEM identity before programming, while youth in similar OST STEM programs nationwide scored an average of 2.72. Similarly, Tulsa youth rated an average of 2.27 on self-reported quality of relationships with adults, compared to 1.82 for comparison youth. Both differences are statistically significant.

Examined together, the baseline and final results indicate that Tulsa youth both started with more positive beliefs about their STEM attitudes and skills and reported more growth after their TRSA-supported STEM programming than youth in similar programming nationwide. Typically, a lower baseline is associated with a higher likelihood of improvement and vice versa. The baseline trend may be influenced by an increasingly positive STEM culture in Tulsa or investments in integrating STEM curriculum in schools. The finding that Tulsa students were more likely than others to report that their program experiences affected their beliefs about themselves in relation to STEM could be related to the ecosystem's investments in educator professional development and program quality; this suggestion is consistent with recent findings that investments in STEM program quality improve youth outcomes (Allen et al., 2019). Although these explanations are plausible, more evidence is needed to clarify causality.

Program Quality Outcomes

Tulsa's ecosystem has made significant investments in the quality of STEM programming. Evidence indicates that young people participating in high-quality afterschool STEM programming are more likely to report positive changes in STEM-related attitudes than those in lower-quality programming (Allen et al., 2017).

Since 2015, TRSA has used DoS to evaluate informal STEM activities. Figure 3 displays average ratings of STEM program quality for the 37 DoS observations of TRSA-supported programs. Average ratings of at least 3, *reasonable evidence,* were achieved for organization, materials, space utilization, participation, and relationships. Another way to look at the data is to examine the proportion of observations that showed reasonable to compelling evidence of quality—that is, they scored 3 or 4 on the 4-point scale. At least 80 percent of observations activities met this criterion for quality for organization (86 percent), materials (84 percent), space utilization (89 percent), inquiry (81 percent), and relationships (100 percent).

From 2016 to 2018, levels of quality in Tulsa improved for three dimensions: organization, participation, and relevance. However, different programs participated each year, so we cannot state that programs improved.

Partnerships

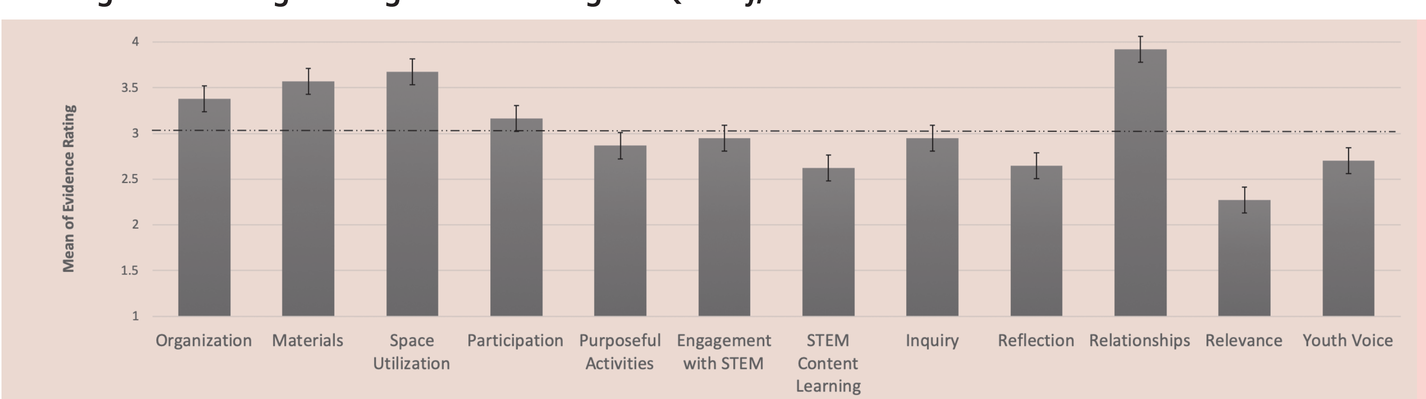
Evidence on partnerships was provided by documents and archival records, by the focus group and interviews, and by the follow-up survey sent to interviewees. The number and quality of activities and events TRSA conducted shows that its work relies on partnerships. Considering the ecosystem as a whole, most interviewees reported that ecosystem members know one another well, tend not to compete, agree on common goals, and share information.

The data suggest that the ecosystem has largely moved beyond Type 1, opportunity-based partnership, in the typology of Figure 2. TRSA has established collaborative partnerships (Type 2) with K–12 and business sectors and is beginning to show early signs of interconnected partnerships (Type 3) within the OST sector. As expected, there were few signs of transformational partnership (Type 4), which is is characterized by partners benefiting equally from funding and resources, changing practices to align with others, and adopting a shared framework to understand the community. This type is rarely seen in practice.

Sustainability

Evidence for the sustainability of the ecosystem and its ability to meet the needs of the community was provided by documents and archival records, focus group and interview discussions, student surveys, and DoS observations. Evidence of success includes the significant inroads TRSA has made toward developing strong partnerships in all sectors; generous funding from the Charles and Lynn Schusterman Family Foundation

Figure 3. Average Ratings of STEM Program Quality, 2016–2018



and the foundation's encouragement of other area funders to support TRSA; a landscape rich with STEM businesses and industries; close proximity to many STEM-rich institutions; and deep partnerships with several public school districts to promote quality STEM education, professional development, and funding. DoS findings and student surveys provide evidence that program quality is high and that youth participants are having positive experiences. Respondents said that the ecosystem has an established data system with common assessments and a community of practice focusing on use of data for continuous improvement.

Lessons Learned

This in-depth case study was designed to examine how ecosystems form and develop, using a partnership framework to explore one of the first STEM learning ecosystems in the U.S. Our study can help other communities, funders, and policymakers to guide or support STEM ecosystems.

Paradigm for the Field

Our study highlights the impact that cross-sector collaborations and the concentrated efforts of many partners can have on an ecosystem with strong leadership, established staff members, and well-defined organizational and governance structures. Tulsa's ecosystem provides a powerful example of how individuals, groups, and organizations can create a system of strong partnerships to improve access to quality STEM learning. TRSA is an exemplary OST-led model for the national STEM Learning Ecosystems CoP; evidence shows that it has implemented all four CoP strategies and most of the design principles. By applying national CoP strategies to partners—OST programs, businesses, funders, school districts, and community organizations—TRSA has grown and scaled, suggesting that others may benefit from its implementation approach. Evidence of success in the past five years includes:

- A 7,000 percent increase in funding from a substantially larger number of funders
- A 188 percent increase in the numbers of partners and advisory council members
- Growth of 1,800 percent in the numbers of children and youth engaged in TRSA-sponsored STEM activities

Focus group and interview respondents said that the STEM Learning Ecosystems CoP has benefited the Tulsa ecosystem by bringing more awareness to STEM and by improving the community's ability to obtain funding, build partnerships, and improve STEM achievement. Other ecosystems have the opportunity to learn from Tulsa's lead organizers at biannual CoP events, where members network, share best practices, and brainstorm solutions to common challenges (Traill et al., 2015; Traphagen & Traill, 2014). Although it is not possible to make a causal statement, converging evidence suggests that TRSA's success is due in part to its consistent and active engagement in the CoP and the way it has translated CoP strategies in practice—especially by using strategies to develop and deepen partnerships.

Partnerships and Culture

Application of the partnership typology in Figure 2 (Noam & Tillinger, 2004) to Tulsa's ecosystem helped us to identify partnerships within and between sectors and to trace their growth and depth. Other ecosystems can apply this framework to understand partnerships in their own communities.

In Tulsa, partnerships were foundational to the ecosystem's growth and development. Early design and planning sessions fostered cohesion among a diverse group of people who would soon take on leadership roles in TRSA. From these early meetings emerged a champion organizer and a dedicated funder who worked closely together to connect partners and sectors. Though funding initially brought like-minded partners together in opportunity-based partnerships (Type 1 in the typology), the "can-do" culture of TRSA's leaders created camaraderie among the partners so that many began sharing common goals and planning STEM-rich programs and events together in collaborative partnerships (Type 2); some even engaged in interconnected partnership (Type 3). Many of these partners are still at the table today.

TRSA avoided the trap that can emerge when opportunity-based partnerships form in response to a funding opportunity. If the organizations postpone the foundational work of developing relationships, the system will experience problems once the funding becomes available. If, by contrast, ecosystem leaders do the necessary groundwork and keep focusing on partner relationships, the system can develop deeper partnerships, as TRSA has done.

Evidence-Based Approach

Early on, TRSA decided to engage the research community, adopt a common framework and language to understand STEM quality and outcomes, and invest in evidence-based assessments to ensure the quality of STEM activities delivered to young people. Data collection pervades TRSA activities, especially in informal STEM programming but increasingly also in schools. TRSA adopted widely used tools with national comparison samples, the DoS observation tool and the CIS-S student survey, to determine whether activities are providing meaningful learning experiences that promote cognitive, emotional, and social growth.

In addition, TRSA has already done exemplary work to build an integrated data collection system. With technical assistance and support from researchers, these systems are used in a continuous improvement process that informs programs of their strengths and areas for improvement so they can set goals and modify facilitation, curriculum, activities, or materials (Noam et al., 2017; Peabody et al., 2019; Sneider & Noam, 2019). For example, program observation data and youth data are channeled into a comprehensive online database, visualized, and correlated using a dynamic virtual dashboard that is accessible to participating schools and programs. TRSA works with partners to help them understand their data and put their findings into action. National work with DoS and CIS-S has shown that investments in STEM program quality translate to better outcomes for youth (Noam et al., 2017; Sneider & Noam, 2019). A lesson for all ecosystems is that data collection should be intentional, transparent, and evidence-based; should involve multiple sources; and should be applied to practice quickly and constructively.

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Action for Sustainability

This case study shows how Tulsa's ecosystem translated the principles of the STEM Learning Ecosystems CoP into growth and sustainability. The lessons learned in Tulsa—both the successes and the challenges—are applicable to all ecosystems and to STEM education as a field. The successes have been outlined above: strong partnerships, high-quality programming, positive youth experiences, stable funding, and use of data for continuous improvement. Challenges include developing stronger partnerships with schools and businesses and improving quality in the areas of reflection, relevance, content learning, and inquiry. More professional development is needed to facilitate activities that help young people to reflect on learning, connect content to their everyday lives, deepen their STEM knowledge and understanding, and practice inquiry skills used by STEM professionals in the real world. These challenges are not unique to Tulsa, but in fact have been observed nationwide, underscoring the need for collective action by the whole field (Allen et al., 2019; Shah et al., 2018).

The Tulsa example suggests that STEM ecosystems can benefit from the following actions:

- Developing strong partnerships with many organizations in key community sectors, including K–12 schools and businesses
- Improving communications to raise awareness of ecosystem efforts
- Diversifying funding streams and balancing the goals of funders with the goals of other members of the community
- Changing leadership and inviting new voices to join or lead the initiative, especially people who represent the diversity of the community
- Encouraging stakeholders to align their actions to the ecosystem's mission and aspirations
- Involving all members equally in goal setting or decision-making
- Developing and implementing new strategies to increase reach and capacity while minimizing burden on staff
- Expanding STEM learning opportunities to underrepresented and underserved youth
- Expanding use of data for continuous improvement
- Making sure that all sectors, not just schools or OST programs, are collecting and using data

To measure sustainability indicators, ecosystems must use a common database to track data over time and across sectors, asking questions such as these: What percentage of youth are considering STEM careers? What percentage of college students select STEM majors? Do percentages differ by student characteristics, such as socioeconomic status? Ecosystems need a holistic, longitudinal approach to understand whether they are "moving the needle" in terms of math and science performance and of persistence in the pathway toward STEM college majors and careers.

STEM learning ecosystems are just beginning to progress. There is more than one path toward growth, sustainability, and success. Further research is needed to understand the many approaches ecosystems can take to translate STEM Learning Ecosystems CoP theory into practice. As a starting point, case studies built on ecosystem evaluations can provide valuable insight into pathways ecosystems can take to transform STEM education models. They can also help to generate hypotheses to inform future larger-scale studies.

The established model used in Tulsa, applied to other ecosystems, could enable them to explore all aspects of their communities, tell their own unique stories, and set their future paths. Used as an exemplar, the model could catalyze dynamic partnerships among OST programs, schools, businesses, and other sectors. The ecosystem initiative—in Tulsa and beyond—must end not with improvements to OST STEM opportunities but with a core transformation of STEM education across all learning environments. This vision includes fostering project- and engagement-oriented learning opportunities with support from the home, the community, schools, and OST programs.

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References

Allen, P. J., Chang, R., Gorrall, B. K., Waggenspack, L., Fukuda, E., Little, T. D., & Noam, G. G. (2019). From quality to outcomes: A national study of afterschool STEM programming. *International Journal of STEM Education, 6*, 1–21. https://doi.org/10.1186/s40594-019-0191-2

Allen, P. J., Noam, G. G., Little, T. D., Fukuda, E., Gorrall, B. K., & Waggenspack, L. (2017). *Afterschool & STEM system building evaluation 2016*. Belmont, MA: The PEAR Institute.

Anthony, K., & Morra, J. (2016). Creating holistic partnerships between school and afterschool. *Afterschool Matters*, *24*, 1–10.

Bevan, B., Michalchik, V., Bhanot, R., Rauch, N., Remold, J., Semper, R., … Park, M. (2010). *Out-of-school time STEM: Building experience, building bridges*. San Francisco, CA: Exploratorium.

Dabney, K. P., Tai, R. H., Almarode, J. T., Miller-Friedmann, J. L., Sonnert, G., Sadler, P. M., & Hazari, Z. (2012). Out-of-school time science activities and their association with career interest in STEM. *International Journal of Science Education, Part B*, *2*(1), 63–79. https://doi.org/10.1080/21548455.2011.629455

Kirp, D. L. (2017, April 1). Who needs charters when you have public schools like these? *The New York Times*. Retrieved from https://www.nytimes.com/2017/04/01/opinion/sunday/who-needs-charters-when-you-have-public-schools-like-these.html

Krishnamurthi, A., Ottinger, R., & Topol, T. (2013). STEM learning in afterschool and summer programming: An essential strategy for STEM education reform. In T. K. Peterson (Ed.), *Expanding minds and opportunities: Leveraging the power of afterschool and summer learning for students.* Retrieved from http://www.expandinglearning.org/expandingminds/article/stem-learning-afterschool-and-summer-programming-essential-strategy-stem

Lyon, G. H., Jafri, J., & St. Louis, K. (2012). Beyond the pipeline: STEM pathways for youth development. *Afterschool Matters*, *16*, 48–57.

Malti, T., Zuffianò, A., & Noam, G. G. (2017). Knowing every child: Validation of the Holistic Student Assessment (HSA) as a measure of social-emotional development. *Prevention Science*, *19*(3), 306–317. https://doi.org/10.1007/s11121-017-0794-0

National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. (2007). *Rising above the gathering storm: Energizing and employing America for a brighter economic future*. Retrieved from https://doi.org/10.17226/11463

National Research Council. (2015). *Identifying and supporting productive STEM programs in out-of-school settings*. Washington, DC: National Academies Press. https://doi.org/10.17226/21740

National Science and Technology Council. (2018). *Charting a course for success: America's strategy for STEM education*. Retrieved from https://www.

whitehouse.gov/wp-content/uploads/2018/12/STEM-Education-Strategic-Plan-2018.pdf

Nation's Report Card. (2017). *Oklahoma.* Available from https://www.nationsreportcard.gov

Noam, G. G., Allen, P. J., Shah, A. M., & Triggs, B. B. (2017). Innovative use of data as game changer for afterschool: The example of STEM. In H. J. Malone & T. Donahue (Eds.), *The growing out-of-school time field: Past, present, and future* (pp. 166–176). Charlotte, NC: Information Age.

Noam, G. G., & Shah, A. (2014). Informal science and youth development: Creating convergence in out-of-school time. *Teachers College Record*, *116*(13), 199–218.

Noam, G. G., & Tillinger, J. R. (2004). After-school as intermediary space: Theory and typology of partnerships. *New Directions for Youth Development*, *2004*(101), 75–113. https://doi.org/10.1002/yd.73

Oklahoma State Department of Education. (2018). Oklahoma School Testing Program (OSTP) Summary Results: 2018. Available from https://sde.ok.gov/assessment-administrator-resources-administrators

Peabody, L., Browne, R. K., Triggs, B., Allen, P. J., & Noam, G. G. (2019). Planning for quality: A research-based approach to developing strong STEM programming. Retrieved from http://csl.nsta.org/2019/07/planning-for-quality

Shah, A. M., Wylie, C., Gitomer, D., & Noam, G. G. (2018). Improving STEM program quality in out-of-school-time: Tool development and validation. *Science Education*, *102*(2), 238–259. https://doi.org/10.1002/sce.21327

Sneider, C., & Noam, G. G. (2019). *The Common Instrument Suite: A means for assessing student attitudes in STEM classrooms and out-of-school environments.* Retrieved from csl.nsta.org/2019/07/the-common-instrument-suite

STEM Ecosystems. (2019a). Charting a course for success: America's strategy for STEM education. Retrieved from http://stemecosystems.org

STEM Ecosystems. (2019b). STEM learning ecosystems overview. Retrieved from https://stemecosystems.org/about

Thompson, J. (2017). With schools as great as Tulsa Union, who needs to despair? Retrieved from https://www.huffingtonpost.com/entry/with-schools-as-great-as-tulsa-union-who-needs-to_us_5a107cb5e4b023121e0e9346

Traill, S., Traphagen, K., & Devaney, E. (2015). Assessing the impacts of STEM learning ecosystems: Logic model template & recommendations for next steps. Retrieved from http://stemecosystems.org/wp-content/uploads/2015/11/Assessing_Impact_Logic_Model_Template_STEM_Ecosystems_Final.pdf

Traphagen, K., & Traill, S. (2014). How cross-sector collaborations are advancing STEM learning. Retrieved from https://stemecosystems.org/resource/how-cross-sector-collaborations-are-advancing-stem-learning

Tulsa Regional STEM Alliance. (2019). About TRSA. Retrieved from https://tulsastem.org/about

Young, J. R., Ortiz, N., & Young, J. L. (2017). STEMulating interest: A meta-analysis of the effects of out-of-school time on student STEM interest. *International Journal of Education in Mathematics, Science and Technology*, *5*(1), 62. Retrieved from https://files.eric.ed.gov/fulltext/EJ1124815.pdf