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Designing and Building Infrastructures to Support Equitable STEM Learning Across Settings

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In recent years, it has become clear that STEM learning is a process that unfolds through dynamic interactions over time and across different settings. Formal learning in schools is not the only—or necessarily most significant—context for STEM learning. Important opportunities also occur in youth's out-of-school time, including during designed programs before and after school, through the support of mentors, and via online communities (Adams, Gupta, & Cotumaccio, 2014; Bell, Tzou, Bricker, & Baines, 2012; Ito et al., 2013). Collectively, these opportunities make up a "STEM learning ecosystem," which comprises the interactions among learners, the settings in which learning occurs, and the learners' communities and cultures (National Research Council, 2015).

Advancing equity in STEM requires providing young people with a rich array of resources for learning in and across the multiple settings of their lives—in school, in community organizations, in neighborhoods, in families, and in online communities. This is a key conclusion of a recent National Research Council (2015) report, which called out the need to map learning opportunities in communities, explore how youth navigate those opportunities, and promote equity by addressing gaps in the "STEM learning ecosystem" (p. ES-2) and by connecting youth more effectively to existing opportunities in the ecosystem. The report also called for building a lasting "STEM learning infrastructure" necessary to address inequities of opportunity that limit access of youth from under-resourced communities to STEM-related careers and academic pursuits (National Research Council, 2015, p. ES-2). This paper outlines principles for building a diverse and connected ecosystem and the features of a supportive STEM learning infrastructure needed to promote equity.

The recommendations presented here are derived from a review of literature that encompassed general strategies for leveraging diversity in STEM learning and studies of specific programmatic efforts to promote young people's learning across settings. The research on equity shares a premise that young people's diverse everyday experiences are a resource for—rather than a barrier to—their learning (Gutiérrez, & Rogoff, 2003; Nasir, Rosebery, Warren, & Lee, 2014). The goal of STEM education programs, then, should not be to eliminate perceived deficits of students' own thinking, their families, or their communities, but to find connections between each of these and disciplinary knowledge and practices (Warren, Ogonowski, & Pothier, 2003).

Because the literature on programs that make explicit attempts to promote learning across settings is relatively new and sparse, we sought to identify programs that were grounded in this premise and that had some evidence of positive youth outcomes. We included in our review designs that show at least some promise of expanding youth access to and STEM learning within and across different settings.

In the next section, we describe the design principles we developed from our review of the literature. We also provide a programmatic example for each principle.

Design Principles to Support Equitable Learning Across Settings

In this section, we describe *design principles* for translating ideas about supporting equitable STEM learning ecosystems into program structures or designs. Our review suggests that to promote equitable cross-setting learning, afterschool programs must:

(1) Draw on values and practices from multiple settings to articulate shared learning goals and to identify resources that can help to meet those learning goals;

(2) Structure partnerships to encompass multiple stakeholder groups that can co-design initiatives to promote learning across settings;

(3) Engage participants in building stories, imaginative worlds, and artifacts that make connections and have meaning across young people's different learning settings;

(4) Help youth identify with the learning enterprise by supporting and naming young people as contributors to authentic endeavors; and

(5) Intentionally broker youth learning across settings, including preparing educators and family members to be brokers.

A design principle is not a generalizable or replicated finding about how best to promote a particular kind of learning aim; rather, it is intended to be a useful guide for design that can be tested, refined, or even dropped through empirical study (Bell, Hoadley, & Linn, 2004). The design principles articulated in this framework likewise are intended to serve as provisional guides to be reflected on, tested and refined over time through research and development.

Principle 1: Draw on values and practices from multiple settings to articulate shared learning goals and to identify resources that can help to meet those learning goals.

Educational design research typically focuses on a set of goals established for a single learning environment selected by educational professionals and subject matter experts. Designing for inclusive and equitable learning across settings requires a more diverse set of perspectives for articulating learning goals, potential challenges to meeting those goals, and resources that can be leveraged to overcome those challenges. This is because practices for supporting learning in families and afterschool programs are organized differently than practices for supporting learning in schools (Rogoff et al., 2007). Afterschool programs need to understand young people's cultural norms so that they can be positioned as learning resources. This often requires building relationships with community and families (Brown & Nicholas, 2012).

An example of an effort to draw on values and practices from local communities to support STEM learning is the Ethno E-textile project (Kafai, Searle, Martinez, & Brayboy, 2014). In that project, researchers worked with a Native American community in the Southwest to guide teens' exploration of the intersections of local culture and computing. The project used electronic textiles that made use of traditional crafting and sewing practices to help students learn about engineering and computing as they also engaged with community cultural practices related to crafting. The project involved close collaboration with a teacher and members of the local Cultural Resources Department to identify linkages among computing practices, craft practices, and local knowledge.

The facilitators made explicit connections between computational principles already present in local crafting cultures. The facilitators also challenged youth to reflect on how computation could be useful in their community and reflective of their own interests and identities. Students created designs that reflect their hybrid experiences in both Western and indigenous communities, though they easily made comparisons between the e-textile project and what they were learning in their Native Arts class. The project underscores the possibilities for connecting with community value systems as a context for learning about computing and linking home and school spaces (Searle & Kafai, 2015).

Principle 2: Structure partnerships to encompass multiple stakeholder groups that can co-design initiatives to promote learning across settings.

Co-design in education is a highly-facilitated process that engages people with diverse expertise in designing, developing, and testing educational innovations (Penuel, Roschelle, &

Shechtman, 2007). In structuring partnerships to support equity, it is important not only to consider which stakeholder groups need to be involved, but also the history of communities and the relations among different stakeholder groups. This is so, because historical inequities can inadvertently be perpetuated when there is a history of disenfranchisement of people from non-dominant communities, but designers presume that everyone can and will participate equally.

A collaborative effort led by Megan Bang and colleagues (Bang, Medin, Washinawatok, & Chapman, 2010) with the Menominee people in rural Wisconsin and with Native peoples living in Chicago illustrates this intentional approach to co-design that accounts for historical inequities. This partnership aimed to increase science achievement of Native American students and their representation in science-related professions while deepening students' "community-based ways of knowing" that reflect their Indigenous scientific epistemologies and supporting "the vitality of Indigenous people" (Bang & Medin, 2010, p. 1009).

Because there is a long history of conducting research in Indigenous communities without consideration for their interests and cultural values, and without their active involvement in the research, Bang and colleagues designed a form of participatory action research that fully engaged Indigenous communities (Hermes, 1999). The approach included input from local elders, support from tribal institutions, use of traditional language, respect for cultural values, and broad community participation in the research activities. The inclusion of stakeholder groups throughout the research and development process was vital to the design of learning across settings and the successful youth outcomes they documented (Bang & Medin, 2010). Promoting equitable cross-setting learning should not be the job or role of just one person or organization. Partnerships working across settings need to make sure many voices are involved.

Principle 3. Engage participants in building stories, imaginative worlds, and artifacts that make connections and have meaning across young people's different learning settings.

To support equity by making connections across settings, several afterschool programs have engaged participants in co-constructing narratives or stories that include and have significance in multiple settings. *Transmedia storytelling* (Jenkins, 2010) is a design approach for creating a single story that audiences or learners can experience across different media. It typically involves building a "world" in which participants, characters in the narrative, and plots unfold across different media. Participants play an active role in shaping the story by not only adapting it in their own creative writing, as is common in fanfiction (Chandler-Olcott & Mahar, 2003).

Transmedia storytelling is increasingly common in the entertainment sector. In recent years, educational broadcasters have begun to use transmedia storytelling principles to design cross-setting innovations for young children. An example of such an initiative is a multi-year, collaborative effort by researchers and public media organizations to design and test a set of interventions designed to promote low-income children's mathematics and science learning across the settings of home and preschools (Pasnik & Llorente, 2013; Penuel et al., 2010). The interventions, which were implemented in schools, made use of characters and stories from public television programs targeting four- and five-year olds at home. The interventions included a mix of guided viewing of programs, game play, and hands-on activities to promote specific learning goals in mathematics and science. Because the interventions included resources for parents and programs appeared on broadcast television, families had access to opportunities to extend their children's learning at home. More parents in the intervention group reported that their children talked with them about ideas featured in the science curriculum than did parents of children that were not part of the intervention group (Penuel et al., 2010).

Principle 4: Help youth identify with the learning enterprise by supporting and naming young people as contributors to authentic endeavors.

Learning always involves becoming a certain kind of person, that is, developing an identity. Identity development involves appropriating or "making one's own" the tools and practices of a discipline (Hand & Gresalfi, 2015; Nasir, 2010). Young people who identify as successful successful science learners are more likely to access, persist, and succeed in science learning. But historical patterns of who participates in STEM exclude women and members of particular racial groups, including Latinos, African Americans, and Native Americans. Therefore, intentionally developing positive science learning identities is critical for expanding equity in science education.

Designing for identity development requires that activities be organized such that young people have opportunities to make contributions to authentic endeavors and to have their contributions recognized. In authentic endeavors, young people have a say in the purposes of the designed learning activities in a particular setting, which in turn prepares them for action in another setting (Ito et al., 2013; Zeldin, 2004; Zeldin, Camino, & Mook, 2005). Authenticity is evident when young people participate in planning, flexible role taking, and strategic thinking (Heath, 2001, 2005), and when the boundaries between school and community are blurred (Gutiérrez & Vossoughi, 2010; Polman & Hope, 2014).

A good example of such an approach is the Green Energy Technologies in the City (GET City) Program at the Boys & Girls Clubs in a downtown Midwestern city (Calabrese Barton & Tan, 2010). The program primarily serves middle school-aged youth from non-dominant communities. Like many other science education programs that take place in or outside schools, youth have the opportunity to learn how to engage in key science practices, such as planning and conducting investigations, analyzing and interpreting data, and communicating scientific information. For example, in GET City, youth learn how to plan experiments to model the effects of different kinds of roofing materials on surface temperatures in urban areas. In contrast to many other programs like it, however, youth in GET City have a considerable say in the activities: adult staff regularly enlist them to help co-plan activities and adjust course when youth propose new courses of action. In addition, at the insistence of the youth themselves, the project investigations brought them into the community, where they conducted interviews with people on the street about their experience of urban heat islands, and where they also had opportunities to present results of their investigations to city officials. As Calabrese Barton and Tan (2010) document, a number of GET City youth participants have appropriated identities as “community science experts” (p. 21), that is, as persons who are capable in science and knowledgeable about how to generate evidence related to culturally-relevant, environmental concerns in their communities.

Principle 5. Intentionally broker youth learning across settings, preparing both educators and family members to be brokers.

Youth from low-income, immigrant, and marginalized communities may have less access to the social networks commonly leveraged by middle class families to broker (organize and make happen) students’ experiences and learning across multiple opportunities such as internships, summer camps, and advanced coursework (Duncan & Murnane, 2011). *Brokering* as we define it here refers to acts of helping people move from one setting into another that might otherwise be inaccessible to them (Ching, Hoadley, Santo, & Peppler, 2015). Brokering can be as simple as telling an acquaintance about a job opportunity (Granovetter, 1974), or it can involve extended, deep interaction necessary to help someone master a complex new work practice (Hargadon &

Sutton, 1997). Because people who act as brokers often occupy positions between different networks of people and practices, brokering is sometimes called "boundary spanning" (Tushman, 1977). Brokering facilitates a form of learning that comes about from expanding personal networks. Effective brokering expands "know who," that is, knowledge of a particular person or group of people who can provide personal or social support, or who have knowledge, skills, or resources they are willing to share (Wellman & Frank, 2001). Of course, the broker must be knowledgeable both about the aims of learners and opportunities available to them to be effective.

Brokering also can be important to becoming employed in a STEM field, because it helps people navigate educational requirements, bureaucratic procedures, and implicit expectations regarding successful career pathways (Stevens, O'Connor, Garrison, Jocuns, & Amos, 2008). In addition to "know-who," brokering requires the capacity to "know where," that is, to know networks of people and places where learners can pursue deeper learning opportunities—whether in formal educational settings, work, play, or civic institutions.

Programs like the Lang Science Program at the American Museum of Natural History, which helps to broker access to college and STEM fields for groups that are underrepresented in STEM, are purposeful about building personal and institutional links among middle and high schools, community colleges, and 4-year institutions of higher education. Participants in the Lang Science Program (Adams, et al., 2014) commit to seven years of coursework throughout the school year and during summers, where they have opportunities to engage in ongoing research at the American Museum of Natural History in fields such as zoology, genetics, paleontology, and astrophysics. The program is an intentional effort to support long-term engagement of youth by helping to develop youth's initial interests in STEM, fostering STEMlinked identities, brokering access to high school and college opportunities, and ultimately supporting pursuits of STEM careers. In addition, the program team has engaged in a retrospective analysis to better understand how long-term participation in out-of-school programs such as the Lang Science Program shapes young women's interest, motivation, and ability to pursue and persist in STEM majors. Findings from the retrospective study of six alumni show that the program played a significant role in the young women's STEM identities and career trajectories. The program helped to broker access to places such as the physical museum and to program curriculum and subjects that likely would have been otherwise inaccessible. It also facilitated interactions between the young women and science-related professionals that broadened their awareness of the many science-related professions.

Ideally, program designers draw on all five principles to design for equitable learning across settings and seek to integrate components so that they work toward common aims. For example, a program might integrate principle 1 with principle 5 by encouraging mentors to elicit youth's values and interests and then link them to activities in the community where they can engage in value- and interest-driven pursuits. The same program could integrate means for recognizing youths' accomplishments in those pursuits through a digital badge system that is shared across multiple partner institutions (integrating principle 2 and 4). The badge system might rely on a story or "pathway" metaphor to encourage youth to pursue more and more challenging activities, so that their knowledge and skill develop in tandem with their interests (integrating principle 3). As we outline below, integrating these elements can benefit from infrastructures that facilitate youth participation and adult coordination of learning opportunities.

Elements of Successful Supporting Infrastructures for Learning Across Settings

To implement cross-setting equity-oriented design principles, programs and communities need to build infrastructures that can help to connect and span different organizations and communities (National Research Council, 2015). In this section, we describe some elements of successful *supporting infrastructures* to facilitate learning across settings. By supporting infrastructures, we refer to those material resources and processes that are "behind-the-scenes" but that are critical to any functioning STEM learning ecosystem and that must be built and maintained over time.

Focusing on infrastructures is critical to diagnosing inequity of opportunity and for promoting equity (Hall & Jurow, 2015). By making visible the infrastructures that enable many economically advantaged youth to engage in coherent pursuits of STEM learning opportunities, we can highlight what must be put into place to afford such opportunities for youth from under-resourced communities. A challenge is that most infrastructures are largely invisible; it takes deep investigation to recover and make explicit the work infrastructures do, let alone redesign them. But redesigning infrastructures is a core task of changing systems, and instantiating design principles outlined above in a wide range of contexts with a diverse range of youth people in different historical and material circumstances will require new infrastructures for supporting learning across settings.

Adequate Material Resources

One reason more advantaged youth can pursue varied opportunities in their communities is that their parents can afford to pay for participation in extra-curricular programs. Further, the gap between low-income and more advantaged families in spending on extra-curricular programs is large and growing (Duncan & Murnane, 2011).

Nearly all of the programs described above were supported by grants but had almost no additional funding for scaling and none for sustaining programs. Unstable funding sources for informal organizations may limit their ability to plan, staff, and sustain innovations. Further, research suggests that one reason young people from lower-income families suspend interest-related pursuits in STEM is that their access to material resources needed for participation ends (Van Horne, Van Steenis, Penuel, & DiGiacomo, in press). Thus, to promote equity, material resources are needed for sustaining programs and lowering or eliminating costs of participation for low-income youth. One way to accomplish this aim is to provide base funding at the city- and state levels for equity-focused STEM initiatives.

Supports for Parents to Become Integral Parts of Youths' Learning Ecologies

In middle- and upper-income families, parents often play a wide variety of roles in supporting their youth's learning, including brokering their access into out-of-school learning opportunities. Brokering is facilitated by parents' relationships to their own peers who may be able to support their child's pursuit of a STEM-related interest (Barron, 2010). The brokering may be driven, too, by a desire of more economically advantaged parents to secure the future of their children through participation in enrichment activities (Lareau, 2003). Beyond brokering, parents can play many different roles in supporting their children's STEM-related learning from collaborator to teacher to co-learner (Barron, Martin, Takeuchi, & Fithian, 2009), provided they have the opportunity and support for learning how to take on new roles. Designing opportunities for parents to participate together in STEM-related learning activities holds promise as a means for expanding parents' repertoires for supporting their children's learning (Roque, Lin, & Luizzi, in press). Additionally, intentional efforts to raise parent awareness of learning opportunities that can allow their children to persist in STEM activities may be a crucial function of developing robust learning ecologies.

Strong Ties Among Organizations

Strong social relationships and links between organizations in neighborhoods are important for educational attainment in schools (Johnson, 2012). They are also important resources for brokering access to opportunities in STEM. For an adult to broker a young person's access to a new STEM-related learning opportunity and deepen their expertise, that adult needs to know about the opportunity (Ching et al., 2015). Adult leaders' own social ties to other adults in the community with relevant expertise are important sources of information about such opportunities.

Systems for Linking Youth to Opportunity

One of the greatest challenges for young people to overcome is the lack of access to and information about specific out-of-school opportunities that would allow them to discover or deepen STEM-related interests. One reason for this difficulty is that neighborhoods vary in the abundance and diversity of programs they offer to youth (Kehoe, Russell, & Crowley, 2016).

The Chicago City of Learning is a citywide partnership initiated by the mayor that includes more than 170 organizations to engage young people in roughly 4,000 out of school time activities, many of which involve STEAM (STEM and Arts) learning. It is also a technical system that provides a means for linking young people to opportunities. Through the program's web site, youth and their families identify activities based on their interests. The website is also a place for recording and recognizing youth's accomplishments in programs, for which they could earn digital badges for such skills as "Science Research," "Robot Instructions," and "Peer Mentor." Researchers have mapped the locations of STEAM-related opportunities using data for the platform, identifying neighborhoods where more accessible opportunities are needed (Pinkard et al., 2016). This research builds on smaller-scale studies that underscore the challenges low-income youth face in accessing out-of-school learning opportunities due to transportation barriers (Chin & Phillips, 2004). The partnership is using the citywide maps generated by Pinkard and colleagues to explore where to expand opportunities for youth.

Partnerships and Coalitions

Long-term partnerships among organizations in a community, as well as coalitions that advocate for more equitable access to educational opportunities can be an important supporting infrastructure for designing learning opportunities across settings. The Hive Learning Networks across several cities in the U.S. (e.g., New York City, Pittsburgh) are an example of partnerships of youth organizations that are focused on enhancing interest-related learning opportunities (Larson et al., 2014). At Network meetings, organizations share strategies they are developing and engage in joint design work to build new pathways for youth in their communities. Community-wide partnerships can also facilitate young people's access to learning opportunities across settings or, when organizations collaborate, to design pathways for developing deeper and deeper expertise in an area (Falk et al., 2016). Coalitions and advocacy organizations can also play a role in equity-focused educational initiatives by building commitment to change and a broad base of support for expanding opportunity for youth (Renée, Welner, & Oakes, 2009).

Applying Principles to Design Learning Opportunities and Building Supporting Infrastructures

The examples presented in this paper illustrate the possibilities for designing for equitable STEM learning across settings. They elaborate on a vision presented in the National Research Council (2015) report that calls for building resilient STEM learning ecosystems – where youth can access multiple opportunities for learning that are coherent and build upon one another. The components of a supporting infrastructure for design and implementation we have identified point to some of the conditions for building such ecosystems at the scale of a neighborhood or city. That such supports exist in some areas already provides hope that an ecosystem approach can expand opportunity for youth from under-resourced communities.

Our framework articulates broad design principles that developers of cross-setting initiatives will elaborate more fully to address the specific needs and concerns in their communities. Taking into account home and community values and practices when identifying learning goals, structuring partnerships to co-design learning opportunities with non-dominant communities, and engaging youth in storytelling to facilitate meaning-making across contexts all serve as ways to more equitably engage youth from underrepresented groups in STEM learning across settings. Similarly, it is important to purposefully identify youth as contributors to the scientific enterprise and to intentionally broker their access and interactions across multiple settings.

In addition, the supporting infrastructures described above must be considered when designing for cross-setting learning. There is a need to address the lack of funding to scale and sustain programs in order to reduce barriers to youth's access to STEM learning across settings. There is also a need to consider opportunities to involve lower-income parents and families in STEM activities with their children, enabling them to better support their children's learning. Adults need support in identifying and connecting youth with expertise in the community; similarly, youth need better access to information about out-of-school learning opportunities available to them. Partnerships and coalitions that bring together community organizations to develop relevant and accessible equity-focused educational initiatives can serve as a way to increase cross-setting STEM opportunities for youth.

We are hopeful that application of these principles to design and test new strategies for promoting equity, as well as efforts to build more supporting infrastructures to link youth to new opportunities, will help develop the understanding we need to expand STEM learning opportunities for all youth.

References

Bang, M., & Medin, D. (2010). Cultural processes in science education: Supporting the navigation of multiple epistemologies. *Science Education, 94*(6), 1008-1026.

Bang, M., Medin, D., Washinawatok, K., & Chapman, S. (2010). Innovations in culturally based science education through partnerships and community. In M. S. Khine & M. I. Saleh (Eds.), *New science of learning: Cognition, computers, and collaboration in education* (pp. 569-592). New York, NY: Springer.

Barron, B. (2010). Conceptualizing and tracing learning pathways over time and setting. In W. R. Penuel & K. O'Connor (Eds). *Learning research as a human science. National Society for the Study of Education Yearbook, 109*(1), 113-127.

Barron, B., Martin, C. K., Takeuchi, L., & Fithian, R. (2009). Parents as learning partners in the development of technological fluency. *International Journal of Learning and Media, 1*(2), 55-77.

Bell, P., Hoadley, C., & Linn, M. C. (2004). Design-based research in education. In M. C. Linn, E. A. Davis, & P. Bell (Eds.), *Internet environments for science education* (pp. 73-88). Mahwah, NJ: Erlbaum.

Bell, P., Tzou, C., Bricker, L. A., & Baines, A. D. (2012). Learning in diversities of structures of social practice: Accounting for how, why, and where people learn science. *Human Development, 55*, 269-284.

Brown, D., & Nicholas, G. (2012). Protecting indigenous cultural property in the age of digital democracy: Institutional and communal responses to Canadian First Nations and Maori heritage concerns. *Journal of Material Culture, 17*(3), 307-324.

Calabrese Barton, A., & Tan, E. (2010). 'We be burnin'! Agency, identity, and science learning. *Journal of the Learning Sciences, 19*(2), 187-229.

Chandler-Olcott, K., & Mahar, D. (2003). Adolescents' anime-inspired "fanfictions": An exploration of Multiliteracies. *Journal of Adolescent and Adult Literacy, 46*(7), 556-567.

Chin, T., & Phillips, M. (2004). Social reproduction and child-rearing practices: Social class, children's agency, and the summer activity gap. *Sociology of Education, 77*(2), 185-210.

Ching, D., Santo, R., Hoadley, C., & Peppler, K. A. (2015). *On-ramps, lane changes, detours and destinations: Building connected learning pathways in Hive NYC through brokering future learning opportunities.* New York, NY: Hive Research Lab.

Coburn, C. E., Penuel, W. R., & Geil, K. (2013). *Research-practice partnerships at the district level: A new strategy for leveraging research for educational improvement*. Berkeley, CA and Boulder, CO: University of California and University of Colorado.

Duncan, G. J., & Murnane, R. J. (Eds.). (2011). *Whither opportunity? Rising inequality, schools, and children's life chances*. New York, NY: Russell Sage Foundation.

Falk, J. H., Dierking, L. D., Staus, N., Wyld, J., Bailey, D., & Penuel, W. R. (2016). The Synergies research-practice partnership project: A 2020 Vision case study. *Cultural Studies of Science Education, 11*(1), 195-212.

Gee, J. P. (2000-2001). Identity as an analytic lens for research in education. *Review of Research in Education, 25*, 99-125.

Granovetter, M. S. (1974). *Getting a job*. Cambridge, MA: Harvard University Press.

Gutiérrez, K. D., & Rogoff, B. (2003). Cultural ways of learning: Individual traits or repertoires of practice. *Educational Researcher, 32*(5), 19-25.

Gutiérrez, K. D., & Vossoughi, S. (2010). Lifting off the ground to return anew: Mediated praxis, transformative learning, and social design experiments. *Journal of Teacher Education, 61*(1-2), 100-117.

Hall, R., & Jurow, A. S. (2015). Changing concepts in activity: Descriptive and design studies of consequential learning in conceptual practices. *Educational Psychologist, 50*(3), 173-189.

Hand, V., & Gresalfi, M. S. (2015). The joint accomplishment of identity. *Educational Psychologist, 50*(3), 190-203.

Hargadon, A., & Sutton, R. I. (1997). Technology brokering and innovation in a product development firm. *Administrative Science Quarterly, 42*(4), 716-749.

Heath, S. B. (2001). Three's not a crowd: Plans, roles, and focus in the arts. *Educational Researcher, 30*(7), 10-17.

Heath, S. B. (2005). Strategic thinking, learning environments, and real roles: Suggestions for future work. *Human Development, 48*, 350-355.

Hermes, M. (1999). Research methods as a situated response: Toward a First Nations' methodology. In L. Parker, D. Deyle, & S. Villenas (Eds.), *Race is...race isn't: Critical race theory and qualitative studies in education* (Vol. 4, pp. 83-100). Boulder, CO: Westview.

Holland, D., Lachiotte, W., Skinner, D., & Cain, C. (1998). *Identity and agency in cultural worlds*. Cambridge, MA: Harvard University Press.

Ito, M., Gutiérrez, K. D., Livingstone, S., Penuel, W. R., Rhodes, J. E., Salen, K., Schor, J., Sefton-Green, J., & Watkins, S. C. (2013). *Connected Learning: An agenda for research and design*. Irvine, CA: Digital Media and Learning Research Hub.

Jenkins, H. (2010). Transmedia storytelling and entertainment: An annotated syllabus. *Continuum: Journal of Media and Cultural Studies, 24*(6), 943-958.

Johnson, O. (2012). A systematic review of neighborhood and institutional relationships related to education. *Education and Urban Society, 44*(4), 477-511.

Kafai, Y. B., Searle, K., Matrtinez, C., & Brayboy, B. (2014). Ethnocomputing with electronic textiles: Culturally responsive open design to broaden participation in computing in American Indian youth and communities. In J. D. Dougherty, K. Nagel, A. Decker, & K. Eiselt (Eds.), *SIGCSE '14: Proceedings of the 45th Technical Symposium on Computer Science Education* (pp. 241-245). New York, NY: Association for Computing Machinery.

Kehoe, S., Russell, J. L., & Crowley, K. (2016, April). *Finding brokering opportunities and challenges in a learning ecosystem: A case study of a regional environmental education landscape*. Paper presented at the Annual Meeting of the American Educational Research Association, Washington, DC.

Lareau, A. (2003). *Unequal childhoods: Class, race, and family life.* Berkeley, CA: University of California Press.

Larson, K., Riemer, N., Ackerman, C., Mishel, E., Trent, R., Bradley, E., & Arum, R. (2014). *AY2013-14 Hive Networks final report: Connecting youth: Digital Learning Research Project*. New York, NY: New York University.

Nasir, N. S. (2010). Studying identity in learning contexts from a human sciences perspective. In W. R. Penuel & K. O'Connor. *Learning research as a human science. National Society for the Study of Education Yearbook, 109*(1), 53-65.

Nasir, N. S., Rosebery, A., Warren, B., & Lee, C. D. (2014). Learning as a cultural process: Achieving equity through diversity. In R. K. Sawyer (Ed.), *Cambridge Handbook of the Learning Sciences* (2nd ed., pp. 686-706). New York, NY: Cambridge University Press.

National Research Council. (2015). *Identifying and supporting productive STEM programs in out-of-school settings*. Washington, DC: National Research Council.

Pasnik, S., & Llorente, C. (2013). *Preschool teachers can use a PBS KIDS transmedia curriciulum supplement to support young children's mathematics learning: Results of a randomized controlled trial.* Waltham, MA and Menlo Park, CA: EDC and SRI International.

Penuel, W. R., Bates, L., Pasnik, S., Townsend, E., Gallagher, L. P., Llorente, C., & Hupert, N. (2010). The impact of a media-rich science curriculum on low-income preschoolers' science talk at home. In K. Gomez, L. Lyons, & J. Radinsky (Eds.), *Learning in the disciplines: Proceedings of the 9th International Conference of the Learning Sciences* (pp. 238-245). Chicago, IL: International Society of the Learning Sciences.

Penuel, W. R., Roschelle, J., & Shechtman, N. (2007). Designing formative assessment software with teachers: An analysis of the co-design process. *Research and Practice in Technology Enhanced Learning, 2*(1), 51-74.

Pinkard, N., Penuel, W. R., Dibi, O., Sultan, M. A., Quigley, D., Sumner, T., & Van Horne, K. (2016, April). *Mapping and modeling the abundance, diversity, and accessibility of summer learning opportunities at the scale of a city*. Paper presented at the Annual Meeting of the American Educational Research Association, Washington, DC.

Polman, J. L., & Hope, J. (2014). Science news stories as boundary objects affecting engagement with science. *Journal of Research in Science Teaching, 51*(3), 315-341.

Renée, M., Welner, K., & Oakes, J. (2009). Social movement organizing and equity-focused educational change: Shifting the zone of mediation. In A. Hargreaves, A. Lieberman, M. Fullan, & D. Hopkins (Eds.), *Second International Handbook of Educational Change* (pp. 158-163). London: Kluwer.

Rogoff, B., Moore, L., Najafi, B., Dexter, A., Correa-Chavez, M., & Solis, J. (2007). Children's development of cultural repertoires through participation in everyday routines and practices. In J. E. Grusec & P. D. Hastings (Eds.), *Handbook of socialization: Theory and research* (pp. 490-515). New York, NY: Guilford Press.

Roque, R., Lin, K., & Luizzi, R. (in press). “I’m not just a mom”: Parents developing multiple roles in creative computing. In *Proceedings of the 12th International Conference of the Learning Sciences*. Singapore: ISLS.

Searle, K., & Kafai, Y. B. (2015). Boys' needlework: Understanding gendered and indigenous perspectives on computing and crafting with electronic textiles. In B. Dorn, J. Sheard, & Q. Cutts (Eds.), *ICER '15: Proceedings of the eleventh annual International Conference on International Computing Education Research* (pp. 31-39). New York, NY: Association for Computing Machinery.

Stevens, R., O'Connor, K., Garrison, L., Jocuns, A., & Amos, D. M. (2008). Becoming an engineer: Toward a three dimensional view of engineering learning. *Journal of Engineering Education, 97*(3), 355-368.

Tushman, M. L. (1977). Special boundary roles in the innovation process. *Administrative Science Quarterly, 22*(4), 585-605.

Van Horne, K., Van Steenis, E., Penuel, W. R., & DiGiacomo, D. (in press). Disruptions to practice: Understanding suspensions of youths' interest-related activities. In *Proceedings of the 12th International Conference of the Learning Sciences.* Singapore: ISLS.

Warren, B., Ogonowski, M., & Pothier, S. (2003). "Everyday" and "scientific": Rethinking dichotomies in modes of thinking in science learning. In A. Nemirovsky, A. Rosebery, J. Solomon, & B. Warren (Eds.), *Everyday matters in mathematics and science education: Studies of complex classroom events* (Vol. 119-152). Mahwah, NJ: Erlbaum.

Weiss, J., & Herndon, S. (2001). *Brave new voices: The Youth Speaks guide to teaching spoken word poetry*. Portsmouth, NH: Heinemann.

Wellman, B., & Frank, K. (2001). Network capital in a multi-level world: Getting support from personal communities. In N. Lin, R. Burt, & K. Cook (Eds.), *Social capital: Theory and Research*.

Zeldin, S. (2004). Youth as agents of adult and community development: Mapping the processes and outcomes of youth engaged in organizational governance. *Applied Developmental Science, 8*(2), 75-90.

Zeldin, S., Camino, L., & Mook, C. (2005). The adoption of innovation in youth organizations: Creating the conditions for youth-adult partnerships. *Journal of Community Psychology, 33*(1), 121-135.

Zimmerman, A. M. (2012). Documenting DREAMs: New media, undocumented youth, and the immigrant rights movement. Los Angeles, CA: Annenberg School for Communication and Journalism, University of Southern California.