RESEARCH + PRACTICE COLLABORATORY

RESEARCH SYNTHESIS

Designing and Building Infrastructures to Support Equitable STEM Learning Across Settings

William R. Penuel
Tiffany R. Lee
University of Colorado Boulder

Bronwyn Bevan
Exploratorium

April, 2014

The purpose of this paper is to present a conceptual framework for initiatives focused on supporting learning across settings in the domains of science, technology, engineering, and mathematics (STEM). The conceptual framework emerges from ecological perspectives on learning that suggest a need to consider how learning develops across settings, through a range of supportive interactions and relationships (Barron, 2006; Bronfenbrenner, 1979). The framework presents initial *design principles* for organizing learning opportunities that connect people to practices in multiple settings. It also identifies *supporting infrastructures* that can help to scale and sustain these learning opportunities. Both the design principles and supporting infrastructures are grounded in successful efforts to support learning across settings.

The conceptual framework foregrounds goals for *equity and diversity* in STEM education. The examples used to identify initial design principles for cross-setting learning are ones that promote equity by

- Expanding access to STEM learning opportunities.
- Brokering continuing opportunities for participation in STEM learning opportunities, including through leveraging existing repertoires of practice from one setting to another.
- Helping young people appropriate STEM practices to address issues that they feel matter to their personal lives or communities.

Equity and diversity goals are central to contemporary visions for transforming STEM education, and their pursuit is essential for broadening participation in STEM fields and developing a science-literate citizenry (National Research Council, 2012).

I. The Importance of Supporting STEM Learning Across Settings

Becoming a scientist or engineer is a process that unfolds over many years, and across many different settings. It requires much more than doing well in a particular class, or even having a high grade point average in college. It involves finding mentors, who can help a person navigate different institutional settings and structures, and developing a strong identification with disciplinary practices or fields, which entails positioning oneself and being positioned as a future scientist or engineer (Stevens, O'Connor, Garrison, Jocuns, & Amos, 2008). It also depends on making successful transitions from one setting to another, both concurrently (e.g., home to school; Civil & Andrade, 2002) and over time (e.g., school to workplace; Eisenhart, 1996).

Similarly, the process of becoming a science-literate citizen or “competent outsider” (Feinstein, 2011) who can access and make use of STEM in daily life is one that spans multiple settings and unfolds over time. Learning about science and how it relates to and can be used to address everyday or community needs or opportunities is a complex endeavor that often involves self-initiated cycles of learning about topics that are not typically taught in school (Feinstein, 2011, in press; Polman et al., 2010). Cultural institutions, community-based programs for youth, and families are all settings where young people can engage in such pursuits (National Research Council, 2009). Making use of what one learns in these settings, however, often entails gaining recognition for one’s accomplishments and gaining access to new opportunities for further education, work, play, and civic engagement (Calabrese Barton & Yang, 2000).

All designed learning environments aim for some kind of transfer of what is learned in one situation to another (Bransford, Brown, & Cocking, 1999). In designing for learning across settings, the process of transfer is not one-way, and a key aim is to foster *connections* among people, settings, and practices (Ito et al., 2013). These connections serve varied purposes, including helping learners gain access to networks that can provide them with varied and rich opportunities for further learning, work, play, and citizenship (Brandt & Clinton, 2002). These connections may also help expand learners’ agency to imagine and co-create new possible futures for themselves and for society (Calabrese Barton & Tan, 2010). Learners play an active role in making these connections, though they also can benefit from guidance and structured opportunities to make sense of how different activities relate to one another, and how particular activities in one setting prepare them for participation in another. Of particular importance is guidance that enables participants to move easily across borders that separate different settings and contribute to practices in those settings (Dreier, 1999).

These findings point to two basic premises about STEM learning that guide this conceptual framework for designing and building infrastructures to support learning across settings:

1. STEM learning is life-long, life-wide, and life-deep.
2. Promoting equity and diversity in STEM learning requires
    a. expanding access to new opportunities for learning;
    b. providing opportunities for continuing and deepening learning; and
    c. designing learning opportunities that deeply connect with and reflect (and therefore invite) the lived experiences of children and young people.

STEM Learning as Life-Long, Life-Wide, and Life-Deep

The phrase "life-long, life-wide, and life-deep" refers to the idea that learning unfolds over time, across multiple settings, and in ways that are informed and shaped by deeply held human values (Banks et al., 2007; Bell, Tzou, Bricker, & Baines, 2012). "Life-long" learning refers to the ways in which the settings and opportunities that people experience in their life change over their lifespan. The term "life-wide" highlights the ways that learning is a cross-setting phenomenon at every point in a person's life. The diagram below (Figure 1), developed by researchers in the Learning in Informal and Formal Environments (LIFE) Center, shows that at every phase of school and work life, settings *outside* formal educational settings are where people spend the vast majority of their time. Without diminishing the importance and impact of time spent in schooling, the diagram suggests that designing for and leveraging learning in out of school settings is an important, and perhaps necessary, strategy for expanding participation in STEM education.

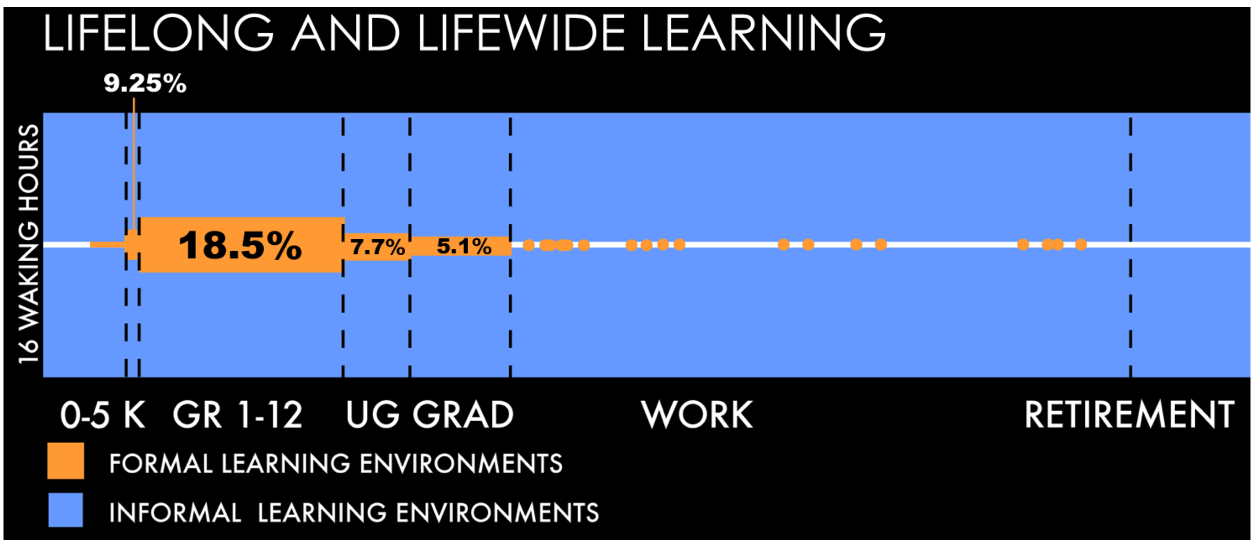

Figure 1. The LIFE Center's Lifelong and Lifewide Learning Diagram (LIFE Center: Stevens, Bransford, & Stevens, 2005)

In addition, values influence the ways in which learning resources in one setting may be recruited in another (Goldman et al., 2010; Pea & Martin, 2010), indicating one way that cross-setting learning is also "life-deep." Any given setting for learning sits at an intersection of different value systems, defined in part by the values that participants bring from other settings (Bell et al., 2012). STEM learning programs that recognize and value young people's familiar and everyday practices are inclusive and welcoming to young people who may or may not already identify as STEM learners. Programs like Urban Science Education for the Hip Hop Generation program in New York (Emdin, 2011) exemplify this feature by allowing students to approach science from a position of strength, where their personal resources (their knowledge or passion for hip hop music) is a means for participating in science class.

This conception of learning as life-wide, life-long, and life-deep has particular relevance for how we conceptualize interest and identity, two important strands of science learning (National Research Council, 2009). Though interest is often conceptualized from a social psychological perspective (e.g., Hidi & Renninger, 2006) or measured as an individual characteristic (e.g., Harackiewicz & Hulleman, 2010), interest might better be understood as something that develops over time, across settings, and in relation to values. This kind of approach is reflected especially in recent writings about interest from a sociocultural perspective, which emphasize the ways that interest develops through relationships within varied "lines of practice" (Azevedo, 2011) meaning the pursuit of a related set of activities focused on a single interest but that evolves, ebbs and flows, and involves a wide variety of practices or instantiations at different times and in different settings. A key idea is that one person's interest in a given subject matter may manifest itself quite differently than another's. For example, one person's interest in astronomy may involve extensive research, reading, and engagement with factual knowledge; whereas another person's engagement with astronomy might rely more on person-to-person engagements in the context of, for example, meet ups with telescopes or other more group-oriented activities. These dynamic and context-dependent views of interest challenge conventional measurement strategies. They also argue for the need to diversify opportunities and pathways to support more fluid conceptions of how interest and expertise develop.

Promoting Equity and Capitalizing on Diverse Strengths of Students in Science and Engineering

Promoting equity in STEM requires attention to providing young people access to powerful settings for learning; supporting them to make connections and take up opportunities across settings, and attending to how access to disciplinary practices is shaped by what goes on in particular learning settings (Hand, Penuel, & Gutiérrez, 2012). At present, most equity-oriented research on STEM learning focuses principally on young people's access to disciplinary practices as supported or hindered by classroom teaching (e.g., Greeno & Gresalfi, 2008; Sadker & Sadker, 1995; Shepardson & Britsch, 2006). Research on how to promote equitable access to informal learning environments is only now beginning to appear (see, Kafai & Peppler, 2011, for a review).

Out of school programs and the organizations that sponsor them—from community-based youth organizations to museums—often play critical roles in brokering opportunities for connecting learning opportunities across settings (Ito et al., 2013; Traphagen & Traill, 2014). For example, mentoring programs have helped young people find workplace internships that are closely linked to youth's interests (Schwartz, 2013). Other initiatives led by cultural organizations such as museums seek to connect learning opportunities across different institutions, making it possible for young people to engage in interest-driven activities across multiple settings (Traphagen & Traill, 2014).

There is a strong tradition of research that investigates how organizing learning to reflect and leverage students' cultural resources to address meaningful problems in the world is strong in out-of-school contexts. For example, programs that enlist student thinking, design, and STEM skills to build and cultivate community gardens (Fusco, 2001; Rahm, 2002), to investigate community health and environmental conditions (Calabrese Barton & Tan, 2010), to calculate the amount for tithes to church (Taylor, 2013), or to monitor basketball statistics and scoring (Nasir, 2002) illustrate how students who may not already self-identify as STEM learners can be supported to take up the tools of STEM in order to investigate questions or issues that appeal to them on civic, faith-based, personal, or aesthetic grounds. These programs provide students ways into STEM learning that may not be available to them otherwise, leveraging interests or concerns developed in other contexts, and in the process developing STEM skills and conceptual understanding that can be extended to and expanded on in school and other settings.

There is also an important, small, but growing body of research that examines STEM teaching that leverages everyday cultural practices for classroom learning (Brown & Spang, 2008; Civil, 2007; Emdin, 2011; Rosebery, Ogonowski, DiSchino, & Warren, 2010). In this line of research, a key strategy is to identify forms of practice that can serve as touchstones for engaging and extending disciplinary learning. For example, researchers have demonstrated the ways in which cultural practices of a form of interaction *bay odyans* in Haitian communities can be leveraged to engage young people in science argumentation (Hudicourt-Barnes, 2003; Warren, Ogonowski, & Pothier, 2003).

II. Design Principles for Initiatives to Support Learning Across Settings

In the conceptual framework we posit here, we conceptualize learning broadly as processes of being, doing, knowing and becoming that unfold over place and time (Herrenkohl & Mertl, 2010). On this view, learning is a deeply social and dynamic process that involves not just appropriation but transformation of STEM practices, skills, and tools in the pursuit of meaningful goals (Stetsenko, 2010). In the process of learning across settings, young people create hybridized identities, tools, and practices that have distinct meaning and utility in specific contexts (e.g., rapping at home versus rapping in a math class) but which all operate as a means for engaging their world (Gutiérrez, Baquedano-Lopez, & Tejada, 2000; Gutiérrez, Morales, & Martinez, 2009).

In this section, we describe strategies for translating ideas about life-long, life-wide, and life-deep learning and for expanding participation in and access to STEM practices. We intend these to be an initial set of *design principles* for organizing learning opportunities across settings. Design principles are claims about how to organize learning environments abstracted from particular projects or initiatives. Key design principles to promote cross-setting learning we articulate here are:

(1) Draw on values and practices from multiple settings to articulate learning goals and identify resources to meet those learning goals.
    a. Search for goals that reflect diverse values of stakeholders.
    b. Identify practices in one setting that can be used in another as a resource to support learning in that setting.

(2) Structure partnerships to encompass multiple stakeholder groups as a way of supporting co-design of initiatives focused on promoting learning across settings
(3) Engage participants in building stories, imaginative worlds, and artifacts that span contexts and that facilitate meaning making across contexts
(4) Help youth identify with the learning enterprise by supporting and naming them as contributors to authentic endeavors.
    a. Support the development of practice-linked identities by providing with opportunities to contribute to authentic endeavors
    b. Support the development of practice-linked identities by naming youth as contributors or potential contributors to current and future endeavors
(5) Use intentional brokering to facilitate movement across settings, preparing both educators and parents to be brokers.

A design principle is not a generalizable or replicated finding about how best to promote a particular kind of learning aim; however, it is something that 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 conceptual framework are intended to serve as provisional guides to design, to be tested and refined over time through research and development.

Principle 1: Draw on values and practices from multiple settings to articulate learning goals and identify resources 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 learning across settings requires a more diverse set of perspectives for articulating learning goals, identifying potential challenges to meeting those goals, and identifying and leveraging resources that can overcome those challenges. This is because non-school actors are typically responsible for some aspects of implementation of designs, and these actors may prize different goals from those of classroom educators. In addition, practices for supporting learning in families and afterschool programs are organized differently from practices for supporting learning in schools (Rogoff et al., 2007). Attempting to import new practices from one setting into another without consideration of differences in the organization of practice and values of actors in each setting may actually cause harm (Ares, 2010).

Principle 1a. Search for goals that reflect diverse values of stakeholders. Effective designs need not resolve differences in values held by actors in different settings (Binder et al., 2011; Björgvinsson, Ehn, & Hillgren, 2012; DiSalvo, 2012). Sometimes, design can identify learning goals that are mutually prized by actors who hold different value systems, or designs can produce learning resources that actors in different settings may prize, because they see possibilities for realizing their own values. An example in the literature is the *Math in a Minute* project at Stanford University. The project began as a research study focused on eliciting the everyday activities of a diverse group of families that involved mathematics with a goal of developing supports for mathematical learning across different contexts of family life. The team sought to take into account the concerns of different stakeholders. These included a concern with demonstrating the value of mathematizing everyday experiences (researchers' values) and taking into account the values that occasioned mathematical problem solving in families in *Math in a Minute* stories (children's and parents' values). The team also sought to create designs that could complement school mathematics (educators' values). Based on the families' report of the use of mathematics on road trips, the project designed a mobile application that accommodated the different stakeholder goals called *Go Road Trip*. The app encompassed multiple challenges, organized around a central challenge in which family members could estimate when they would arrive, using tools like route planning that could help them develop their estimates.

Principle 1b. Identify practices in one setting that can be used in another as a resource to support learning in that setting. Supporting learning across settings requires thoughtful use of practices identified in one setting to inform the design of learning opportunities in another setting. One of the most well-developed traditions of research and development related to identifying practices in one setting that can be used as a resource for school learning is focused on identifying family and community *funds of knowledge* (González, Andrade, Civil, & Moll, 2001; Moll, Amanti, Neff, & González, 1992). In this tradition, designers of educational experiences are expected to engage in a variety of activities to identify funds of knowledge. These include participating in community activities in order to learn about cultural resources and practices relevant to the subject matter they teach (Ayers, Fonseca, Andrade, & Civil, 2001; Maher, Epaloose, & Tharp, 2001), conducting household visits and meetings with family members (Andrade, Carson, & Gonzales, 2001; González et al., 1993), and using questionnaires for parents to identify cultural and community funds of knowledge (Ayers et al., 2001; Kahn & Civil, 2001). The BRIDGE (Linking Home and School: A Bridge to the Many Faces of Mathematics) Project is an example where researchers worked with teachers, families, and community members to design projects in elementary mathematics that leveraged funds of knowledge in a working class, Mexican-American community (Civil & Andrade, 2002). As part of the project, teachers documented students' home and community activities in which they participated (Andrade et al., 2001). A key goal was to identify the kinds of skill and resources students used to successfully accomplish home or community activities in order to design school programs that could leverage these skills and resources as starting points for academic work.

Principle 2: Co-design in initiatives focused on promoting learning across settings requires carefully structured partnerships that encompass multiple stakeholder groups.

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 many research and development efforts, co-design is a primary means for organizing partnerships between researchers and practitioners or among groups from different youth sectors (Coburn, Penuel, & Geil, 2013; Penuel, Coburn, & Gallagher, 2013). In structuring partnerships, it is important not only to consider what stakeholder groups need to be involved, but also the history of communities and the relations among different stakeholder groups. An effort that illustrates an intentional approach to composing and structuring co-design in this way is a collaborative effort led by Megan Bang and colleagues (Bang, Curley, Kessel, Marin, & Suzokovich, 2012; Bang & Medin, 2010; Bang, Medin, Washinawatok, & Chapman, 2010) with the Menominee people in rural Wisconsin and with Native peoples living in Chicago. This partnership aimed to increase science achievement of Native Americans and their representation in science-related professions and to deepen students' "community-based ways of knowing" that reflect their Indigenous scientific epistemologies and to support "the vitality of Indigenous people" (Bang & Medin, 2010, p. 1009). There is a long history of conducting anthropological and educational research in Indigenous communities without consideration for these communities' interests and without their active involvement in the research. In this project, learning scientists adapted a form of participatory action research (Hermes, 1999) to their work in particular Indigenous communities. The approach included input from local elders, gaining support from tribal institutions, use of traditional language and respect for cultural values, and broad community participation in the research agenda, staff selection, and budget.

Principle 3. Engage participants in building stories, imaginative worlds, and artifacts that span contexts and that facilitate meaning making across contexts.

One strategy for facilitating meaning making across activities in different settings is to engage participants in co-constructing narratives or stories that span multiple settings. *Transmedia storytelling* (Jenkins, 2007, 2010) is a design approach for creating a single story or story 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, as well, not just adapting it but extending it into new realms. 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 one involving the Detroit Science Center, Henry Ford Museum, and local science teachers in Detroit Public Schools. The initiative involved coordination of museum staff, teachers, and researchers in a collaborative design effort aimed at increasing the "contextual permeability" (Quintana, 2012, p. 80) between formal and informal settings for science learning. Designers generated an overall challenge for youth participants, namely to design a way to use exhibits at the museum to create electrical energy to charge their mobile phones. The team designed a range of tools for posing questions, recording observations, and developing explanations for their observations. The tools helped learners bring up or recall questions and ideas developed in one setting (e.g., the classroom) in another (e.g., the museum), and they also helped to structure learners' observations in ways that could facilitate learning (e.g., providing them with scaffolds for constructing explanations that included a claim, evidence, and reasoning).

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

Learning is deeply rooted in participation in cultural practices through which individuals come to understand specific ways of being and develop identities as developing experts in science who can make use of science in their ongoing activities. We define identity as the attributes (e.g., goals, virtues, values, and habitual patterns of action) of persons drawn from practice that one claims as one's own and that are recognized by others (Penuel & Wertsch, 1995). These attributes include images of possible *future* action as well, situated within worlds or settings that the learner imagines (Holland, Lachiotte, Skinner, & Cain, 1998). Identity, from this perspective, develops as people transform their participation in culturally valued activities and come to imagine new possible futures for themselves and others (New London Group, 1996; O'Connor & Allen, 2010). Recognition is an essential aspect of identity development in these activities: identity development requires others to confirm and support a learner's self-image and imagined future (Erikson, 1968; Gee, 2000-2001; Nasir, 2010; Nasir & Hand, 2006; Penuel & Wertsch, 1995).

Principle 4a. Support the development of practice-linked identities by providing opportunities to contribute to authentic endeavors. Designing for identity development requires that activities be organized such that young people have opportunities to make contributions to authentic endeavors and to have these contributions recognized and acknowledged. Authentic endeavors are ones in which young people have a say in the purposes of the activity and in which the designed learning activities in one setting support action in another setting, such as a young person's family and community (Ito et al., 2013; Zeldin, 2004; Zeldin, Camino, & Mook, 2005). Authenticity is evident when young people engage in planning, flexible role taking, and strategic thinking (Heath, 2001, 2005), and when the boundaries between school and community are blurred (Engeström, 1991; Gutiérrez & Vossoughi, 2010). A good example of such an approach is the Green Energy Technologies in the City Program (GET City; Calabrese Barton & Tan, 2010). The program is housed in a downtown Boys & Girls Club in a mid-sized city, and it serves principally middle school-aged youth. Like many other science education programs that take place in or outside schools, youth who participate 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 matters of environmental concern in their communities.

Principle 4b. Support the development of practice-linked identities by naming youth as contributors or potential contributors to current and future endeavors. In GET City and other cross-setting programs based in the community, a key aspect of adult roles is naming youth as current and future contributors to shared endeavors. Parents, teachers, mentors, and peers, all play a role in shaping the expectations of a learner, so it is important to consider how they can intentionally place, or "position", youth as participants in a cultural practice (Harré, Moghaddam, Cairnie, Rothbard, & Sabat, 2009). Positioning includes providing access to three kinds of resources: material, relational, and ideational (Nasir & Cooks, 2009). Material resources include the tools, artifacts, and physical space in which group activity occurs, whereas relational resources refer to the creation of a sense of belonging for members within the group. Ideational resources refer to the orientation of members into the specific value systems associated with the practice, helping members understand how actions and are privileged by the group. Adult positioning young people as contributors through talk and the activation of each of the three kinds of resources are important acts of *recognition* for practice-linked identities within designs for learning across settings. An example from the YouthScience (Polman & Miller, 2010) program illustrates how important naming is for the development of practice-linked identities and youth's identity development. This community-based program provided opportunities for underserved high school youth to work as employees at a science museum and to help promote the community's understanding of STEM. On the first day of the summer program, the director named potential futures for youth within the program as she welcomed the teens to the program. She encouraged teens to "identify where you want to go today, tomorrow, and in the future" and then went on to acknowledge the multiple identities that she carries as a program director, a mother, and other roles (Polman & Miller, 2010, p. 890). Her self-introduction served as a way of identifying multiple identities an individual can claim. But she also named youth as people who can envision and think about their futures and connect present to future in an imagined trajectory or pathway.

Principle 5. Use intentional brokering to facilitate movement across settings, preparing both educators and parents to be brokers.

Brokering as we define it here refers to acts of helping people move from one setting into another setting that might otherwise be inaccessible to them. 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). People who act as brokers often occupy positions between different networks of people and practices, and so brokering is sometimes called "boundary spanning" (Tushman, 1977). Brokering facilitates a form of learning that comes about from expanding personal networks. Brokering expands "know who," that is, knowledge of what a 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). Brokering often also is important to becoming a professional in a STEM field, because brokering helps people navigate educational requirements, bureaucratic procedures, and implicit expectations regarding successful career trajectories (Stevens et al., 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 MESA (The Mathematics, Engineering, and Science Achievement; http://mesausa.org/), which for decades have helped broker access to college for many students from non-dominant backgrounds who are the first in their families to attend college, are purposeful about building personal and institutional links among high schools, community colleges, and 4-year institutions of higher education. As in other programs, the professional development of MESA educators is key to their success in helping provide strategic supports throughout a student's educational career (Belfield & Levin, 2007; Gándara & Contreras, 2009).

The Synergies project (Falk et al., 2013) is an intentional effort to support partnerships among different youth-serving institutions related to STEM; it is a project that illustrates how community organizing can help to broker connections among those institutions to support cross-setting learning. In Synergies, researchers are working collaboratively with more than a dozen community organizations in an urban neighborhood in the Pacific Northwest to improve coordination of STEM-related learning opportunities, with the aim of increasing youth's interest in science. In that project, a community organizer devotes her time to increasing mutual awareness of opportunities among providers of activities and helping youth to find those opportunities. In addition, the team is facilitating a community process, informed by data from a longitudinal study of children's interest in STEM, to identify and implement strategies to improve coordination around program offerings. The research evidence the team is developing is intended to serve as a key support to the design process, informing the identification of key areas for improving coordination and also providing a means of monitoring progress toward the project's goals.

There are also some examples of programs that prepare parents to be brokers of educational opportunities within their schools. In the Primes project, for example, researchers partnered with parents to identify mathematics practices in the home and to help parents recognize linkages between these home-based practices on the one hand and school mathematics practices on the other. A key aim in building this recognition was to provide a critical support that could enable parents to become advocates for their children with respect to their access to school-based math programs and to challenging coursework in mathematics (Goldman & Booker, 2009).

III. Elements of Successful Supporting Infrastructures for Learning Across Settings

In this section, we describe some elements of successful *supporting infrastructures* that help to facilitate learning across settings. We focus on infrastructures that help to bring designs for supporting learning across settings to *scale.* For our purposes, scale encompasses deliberate efforts to expand designs from one or a few settings to multiple settings (Stringfield & Datnow, 1998), while ensuring depth and quality of implementation and sustainability (Coburn, 2003). With others who study and promote learning across settings, we presume scaling and sustainability requires principled adaptation of designs to fit local contexts and that "replication" often involves significant innovation rather than implementation with fidelity (Coburn, Catterson, Higgs, Mertz, & Morel, 2013). In this section, we have included examples from outside STEM fields to illustrate key elements, with the aim of identifying concepts and strategies that could be useful for re-designing STEM-related educational infrastructures.

In selecting examples to include, we purposefully focused attention on *supporting infrastructures* rather than specific program models. Supporting infrastructures are all the things that are necessary for any system of cross-setting learning activities to function well. A challenge is that most infrastructures are largely invisible; it takes deep investigation to recover and make visible the work infrastructures do, let alone redesign them (Bowker & Star, 1999; Star & Ruhleder, 1996). 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.

Social Media for Linking Youth to Interest Related Activities

Social media provide a potential platform for linking individuals with common interests and causes and for organizing change. There is some evidence, moreover, that engagement online is related to traditional forms of civic and political participation (Kahne, Lee, & Feezell, 2013). The opportunity afforded by social media to link to others who share interests and to develop solidarity and friendship across geographic distances can foster a sense of agency among youth (Ito et al., 2013). Online networks also offer means for developing coordinated campaigns and for sharing local strategies for change that can be adapted and appropriated elsewhere (Cohen, Kahne, Bowyer, Midddaugh, & Rogowski, 2012; Zimmerman, 2012). One example of an interest-driven network that supports both community service and activism is the Harry Potter Alliance (HPA; http://thehpalliance.org/). The HPA, as its name suggest, is an organization that is closely connected to the *Harry Potter* franchise; however, it is a grassroots, networked organization that is focused on issues related to access to literacy, equality, and human rights. Most—but not all—of the members of local chapters are Harry Potter fans. Themes and storylines from Harry Potter infuse and anchor different HPA campaigns and projects (Slack, 2010), a hallmark of transmedia storytelling. The common media experiences, sense of community, and strong motivation to help among members of HPA are characteristics shared by other successful "fan activist" infrastructures (Kligler-Vilenchik, McVeigh-Schultz, Weitbrecht, & Tokuhama, 2012).

Networks That Connect Adults and Youth in Shared Endeavors

A number of youth organizations today have sought to support youth initiative in activities where they have opportunities to act with and learn alongside professionals. One such organization is Youth Speaks of San Francisco (http://youthspeaks.org/), which began as a single program and now claims nearly 50,000 youth as participants in some 50 cities across the United States. Youth Speaks supports youth expression, literacy development, and social action through the arts by serving as the presenter of local and national youth poetry slams, festivals, and reading series (Weiss & Herndon, 2001). Youth Speaks is an example of a network that provides multiple settings for young people to develop, express themselves, and take action through oral and written poetry. These settings' formats are varied, and include classroom activities, after school clubs, youth-initiated projects, social activism, open mic sessions, and performances. An important format for Youth Speaks is its poetry slams, competitions among youth poets that bring young people from different schools, regions, and outside the United States together. Different Youth Speaks participants are drawn to some formats more than others. As such, the network provides many entry points and pathways to developing as young poets, creating important settings for young people to identify themselves as producers of text and as poets (McCormick, 2000) and for imagining new possible futures for themselves and their communities (Jocson, 2006). And in contrast to traditional youth development programs that are isolated both from schools and the world of work, Youth Speaks purposefully connects school and community, and it positions professional artists as key mentors and teachers to youth and as partners to classroom teachers.

Systems for Recognizing Learning Across Settings

Some supporting infrastructures are organized around means for recognizing and making visible youth accomplishments and skill across settings. Young people's interests and accomplishments in one setting are not always visible to teachers, parents, supervisors, and mentors in other settings. New kinds of certification systems, or badging systems as they are often called, provide a means for different organizations in a community to recognize knowledge and skill developed in one setting in another (Baker, 2007; Riconscente, Kamareinen, & Honey, 2013). The idea of badging systems is not new: it is a familiar form of recognition to children and parents involved in Scouting. What is new is the use of *digital* badges that can be shared across organizations and made visible online for a wide range of adult mentors and teachers to see. One purpose for such badges is to help adults and youth alike

> …recognize and visualize the learning that happens in diverse contexts, making porous the boundaries between formal and informal settings. Moreover, through linking formal and informal spaces, instructors may be able to better tailor instructional materials to match the background and interests of their students. (Riconscente et al., 2013, pp. 7-8)

An example of such a badging system is the Chicago Summer of Learning, piloted for the first time in summer 2013. The Summer of Learning was a citywide effort to engage young people in science, technology, engineering, arts, and technology activities. More than 100 organizations participated, joining together myriad summer camps, art centers, and leadership activities for youth in a coordinated effort. Through the program's web site, youth and their families could identify activities based on their interests. The web site was also a place for recording and recognizing youth's accomplishments in programs, for which they could earn different kinds of badges, such as "Science Research," "Robot Instructions," and "Peer Mentor." The web site explains what the badge is and how the badge can be earned in youth-friendly terms. Researchers are now investigating how this platform might be used to trace young people's interest development and how educators might use the badges to identify and recognize the interests and experiences of young people across settings. To avoid codifying current educational inequities, it will be essential to tie such systems of badging to the existence of robust and equitable learning opportunities. The creation of badging systems without leveling the playing field could otherwise serve to exacerbate recognized forms of educational achievement, where children who regularly participate in robust educational systems or are supported by adults who carefully broker their learning opportunities are more regularly rewarded and recognized through badging systems than their peers without such supports.

IV. Making Use of Design Principles and Building Supporting Infrastructures

Design principles are useful to the extent that they can inform decisions about particular program goals and strategies. No doubt, the principles articulated here are underspecified and will need to be elaborated more fully by developers of cross-setting initiatives. Moreover, some of the specific programmatic examples included themselves have limited or unstable supporting infrastructures. Some programs with strong efficacy data are entirely dependent upon grant funding. Without more stable funding and purposeful attention to building supporting infrastructures, designs intended to support learning across settings may have a limited social impact. Infrastructure must be an important object of design (Penuel & Spillane, in press).

In addition, there are many policy barriers that work against intentional coordination of resources and infrastructure development to support young people's learning across time and settings. Among them are basic economic issues such as the relatively low pay rates for educators in afterschool and informal settings, which creates both a hierarchy of professionalism when contrasted with formal educators, and also creates a disincentive for educators to move across boundaries. Additionally unstable funding sources for non-formal organizations may limit the ability for these organizations to plan, staff, and sustain innovations (Halpern, 2006).

State standardized testing policies may limit the ability of schools to identify and leverage students' skills and interests that do not align to the tests. Similarly, they may place pressure on afterschool and even informal settings to narrow their offerings to support activities that either directly align with state standardized tests or which directly support modes of learning related to recapitulation of correct answers on paper-and-pencil tests.

Finally, a lack of generative evaluation and assessment tools that can effectively document how learning develops across settings and time and is supported by various and diverse sources leads to an undervaluing of opportunities that may not be aligned to standardized measurement tools. Evaluation tools that posit one set of measures relevant to a diverse set of programs and opportunities will tend to constrict program offerings, possibly negatively affecting goals of expanding participation in STEM fields.

In short, there remain significant challenges ahead for efforts to design and build supporting infrastructures for learning across settings. Of particular concern is the fact that many designers are likely to claim that their particular designs have great potential for expanding access to STEM practices and careers. Initially, some activities may have appeal because they appear to have a low barrier to entry for participants from a wide variety of backgrounds. But becoming readily engaged in such activities when supported to do so in a single context is not sufficient to develop skill and proficiency necessary to be recognized in ways that are essential to becoming a scientist, mathematician, or engineer. In addition to brokering access to opportunities to deepen one's interest and expertise, gatekeeping and practices of exclusion must be identified and addressed. Organizing for more expansive futures for all youth requires the kind of life-long, life-wide, and life-deep perspective that animates calls for greater attention to designing for learning across settings.

V. References

Andrade, R., Carson, C., & Gonzales, N. (2001). Creating links between home and school mathematics practices. In E. McIntyre, A. Rosebery & N. Gonzales (Eds.), *Classroom diversity: Connecting curriculum to students' lives* (pp. 100-114). Portsmouth, NH: Heinemann.

Ares, N. (2010). Political and cultural dimensions of organizing learning around funds of knowledge. In W. R. Penuel & K. O'Connor (Eds). *Learning research as a human science. National Society for the Study of Education Yearbook, 109*(1), 192-206.

Ayers, M., Fonseca, J. D., Andrade, R., & Civil, M. (2001). Creating learning communities: The "Build Your Dream House" unit. In E. McIntyre, A. Rosebery & N. Gonzales (Eds.), *Classroom diversity: Connecting curriculum to students' lives* (pp. 92-99). Portsmouth, NH: Heinemann.

Azevedo, F. S. (2011). Lines of practice: A practice-centered theory of interest relationships. *Cognition and Instruction, 29*(2), 147-184.

Baker, E. L. (2007). The end(s) of testing. *Educational Researcher, 36*(6), 309-317.

Bang, M., Curley, L., Kessel, A., Marin, A., & Suzokovich, E. (2012, April). *Muskrat theories, tobacco in the streets, and living Chicago as indigenous land.* Paper presented at the Annual Meeting of the American Educational Research Association, Vancouver, British Columbia.

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.

Banks, J. A., Au, K. H., Ball, A. F., Bell, P., Gordon, E. W., Gutierrez, K. D., . . . Zhou, M. (2007). Learning in and out of school in diverse environments: Life-long, life-wide, life-deep. Seattle, Washinton: The LIFE Center (The Learning in Informal and Formal Environments Center), University of Washington, Stanford University, and SRI International and Center for Multicultural Education, University of Washington.

Barron, B. (2006). Interest and self-sustained learning as catalysts of development: A learning ecology perspective. *Human Development, 49*(4), 193-224.

Belfield, C., & Levin, H. (2007). *The price we pay: Economic and social consequences of inadequate education*. Washington, DC: Brookings Institution Press.

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.

Binder, T., de De Michelis, G., Ehn, P., Jacucci, G., Linde, P., & Wagner, I. (2011). *Design things*. Cambridge, MA: MIT Press.

Björgvinsson, E., Ehn, P., & Hillgren, P.-A. (2012). Agonistic participatory design: Working with marginalised social movements. *CoDesign, 8*(2-3), 127-144.

Bowker, G., & Star, S. L. (1999). *Sorting things out: Classification and its consequences*. Cambridge, MA: MIT Press.

Brandt, D., & Clinton, K. (2002). Limits of the local: Expanding perspectives on literacy as a social practice. *Journal of Literacy Research, 34*(3), 337-356.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (1999). *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academy Press.

Bronfenbrenner, U. (1979). *The ecology of human development: Experiments by nature and design*. Cambridge, MA: Harvard University Press.

Brown, B. A., & Spang, E. (2008). Double talk: Synthesizing everyday and science language in the classroom. *Science Education, 92*, 708-732.

Burt, R. S. (2005). *Brokerage and closure: An introduction to social capital*. New York: Oxford University Press.

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

Calabrese Barton, A., & Yang, K. (2000). The culture of power and science education: Learning from Miguel. *Journal of Research in Science Teaching, 37*(8), 871-889.

Civil, M. (2007). Building on community knowledge: An avenue to equity in mathematics education. In N. i. S. Nasir & P. Cobb (Eds.), *Improving access to mathematics: Diversity and equity in the classroom* (pp. 105-117). New York: Teachers College Press.

Civil, M., & Andrade, R. (2002). Transitions between home and school mathematics: Rays of hope amidst passing clouds. In G. Abreu & N. C. Presmeg (Eds.), *Transitions between contexts of mathematics practices* (pp. 149-169). New York, NY: Kluwer.

Coburn, C. E. (2003). Rethinking scale: Moving beyond numbers to deep and lasting change. *Educational Researcher, 32*(6), 3-12.

Coburn, C. E., Catterson, A. K., Higgs, J., Mertz, K., & Morel, R. (2013). Spread and Scale in the Digital Age: A Memo to the John D. and Catherine T. MacArthur Foundation. Evanston, IL: Northwestern University.

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.

Cohen, C., Kahne, J., Bowyer, B., Midddaugh, E., & Rogowski, J. (2012). Participatory politics: New media and youth political action. Oakland, CA: Youth and Participatory Politics Research Network.

DiSalvo, C. (2012). *Adversarial design*. Cambridge, MA: MIT Press.

Dolle, J. R., Gomez, L. M., Russell, J. L., & Bryk, A. S. (2013). More than a network: Building professional communities for educational improvement. In B. J. Fishman, W. R. Penuel, A.-R. Allen & B. H. Cheng (Eds.), *Design-based implementation research: Theories, methods, and exemplars. National Society for the Study of Education Yearbook.* (pp. 443-463). New York, NY: Teachers College Record.

Dreier, O. (1999). Personal trajectories of participation across contexts of social practice. *Outlines: Critical Social Studies, 1*(1), 5-32.

Eisenhart, M. (1996). The production of biologists at school and work: Making scientists, conservationists, or flowery bone-heads. In B. A. Levinson, D. E. Foley & D. C. Holland (Eds.), *The* *cultural production of the educated person: Critical ethnographies of schooling and local practice* (pp. 169-186). Albany, NY: SUNY Press.

El-Nasr, M. S., & Smith, B. K. (2006). Learning through game modding. *Computers in Entertainment, 4*(1), 7.

Emdin, C. (2011). Dimensions of communication in urban science education: Interactions and transactions. *Science Education, 95*(1), 1-20.

Engeström, Y. (1991). Non scolae sed vitae discimus: Toward overcoming the encapsulation of school learning. *Learning and Instruction, 1*, 243-259.

Erikson, E. H. (1968). *Identity: Youth and crisis*. New York: Norton.

Falk, J. H., Dierking, L. D., Staus, N., Haun-Frank, J., Penuel, W. R., Wyld, J., & Bailey, D. (2013, April). *Viewing STEM learning through a community-wide lens: The Synergies Project.* Paper presented at the NARST Annual International Conference, Rio Grande, Puerto Rico.

Feinstein, N. (2011). Salvaging science literacy. *Science Education, 95*(1), 168-185.

Feinstein, N. (in press). Making sense of autism: Progressive engagement with science among parents of young, recently diagnosed autistic children. *Public Understanding of Science*.

Fusco, D. (2001). Creating relevant science through urban planning and gardening. *Journal of Research in Science Teaching, 38*(8), 860-877.

Gándara, P., & Contreras, F. (2009). *The Latino education crisis: The consequences of failed social policies*. Cambridge, MA: Harvard University Press.

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

Gee, J. P. (2003). *What video games have to teach us about learning and literacy*. New York: Macmillan.

Goldman, S., & Booker, A. (2009). Making math a definition of the stuation: Families as sites for mathematical practices. *Anthropology and Education Quarterly, 40*(4), 369-387.

Goldman, S., Pea, R. D., Blair, K. P., Jimenez, O., Booker, A., Martin, L., & Esmonde, I. (2010). *Math engaged problem solving in families.* Paper presented at the Proceedings of the 9th International Conference of the Learning Sciences-Volume 1.

González, N., Andrade, R., Civil, M., & Moll, L. (2001). Bridging funds of distributed knowledge: Creating zones of practices in mathematics. *Journal of Education for Students Placed at Risk, 6*(1-2), 115-132.

González, N., Moll, L. C., Floyd-Tenery, M., Rivera, A., Rendon, P., Gonzales, R., & Amanti, C. (1993). Teacher research on funds of knowledge: Learning from households. Berkeley, CA: Center for Research on Education, Diversity and Excellence, University of California.

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

Greeno, J. G., & Gresalfi, M. S. (2008). Opportunities to learn in practice and identity. In P. A. Moss, D. C. Pullin, J. P. Gee, E. H. Haertel & L. J. Young (Eds.), *Assessment, equity, and opportunity to learn* (pp. 170-199). New York: Cambridge University Press.

Gutiérrez, K. D., Baquedano-Lopez, P., & Tejada, C. (2000). Rethinking diversity: Hybridity and hybrid language practices in the third space. *Mind, Culture, and Activity, 6*(4), 286-303.

Gutiérrez, K. D., Morales, P. Z., & Martinez, D. C. (2009). Re-mediating literacy: Culture, difference, and learning for students from nondominant communities. *Review of Research in Education, 33*, 212-246.

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.

Hand, V., Penuel, W. R., & Gutiérrez, K. D. (2012). (Re)framing educational possibility: Attending to power and equity in shaping access to and within learning opportunities. *Human Development, 55*, 250-268.

Harackiewicz, J. M., & Hulleman, C. S. (2010). The importance of interest: The role of achievement goals and task values in promoting the development of interest. *Social and Personality Psychology Compass, 4*(1), 42-52.

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

Harré, R., Moghaddam, F., Cairnie, T. P., Rothbard, D., & Sabat, S. R. (2009). Recent advances in positioning theory. *Theory & Psychology, 19*(4), 5-31.

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.

Hellekson, K., & Busse, K. (Eds.). (2006). *Fan fiction and fan communities in the age of the Internet: New essays*. Jefferson, NC: McFarland.

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.

Herrenkohl, L. R., & Mertl, V. (2010). *How students come to be, know, and do: A case for a broad view of learning*. New York, NY: Cambridge University Press.

Hidi, S., & Renninger, K. A. (2006). The four-phase model of interest development. *Educational Psychologist, 41*(2), 111-127.

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

Hudicourt-Barnes, J. (2003). The use of argumentation in Haitian Creole science classrooms. *Harvard Educational Review, 73*(1), 73-93.

Ito, M., Gutiérrez, K. D., Livingstone, S., Penuel, W. R., Rhodes, J. E., Salen, K., . . . Watkins, S. C. (2013). Connected learning: An agenda for research and design. Irvine, CA: Humanities Research Institute, University of California.

Jenkins, H. (2006). *Convergence culture: Where old and new media collide*. New York: New York University Press.

Jenkins, H. (2007). Transmedia storytelling 101. Retrieved from http://henryjenkins.org/2007/03/transmedia_storytelling_101.html

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

Jocson, K. M. (2006). "There's a better word": Urban youth rewriting their social worlds through poetry. *Journal of Adolescent & Adult Literacy, 49*(8), 700-707.

Kafai, Y. B., & Peppler, K. A. (2011). Youth, technology, and DIY: Developng participatory competencies in creative media production. *Review of Research in Education, 35*(1), 89-119.

Kahn, L. H., & Civil, M. (2001). Unearthing the mathematics of a classroom garden. In E. McIntyre, A. Rosebery & N. Gonzales (Eds.), *Classroom diversity: Connecting curriculum to students' lives* (pp. 37-50). Portsmouth, NH: Heinemann.

Kahne, J., Lee, N.-J., & Feezell, J. T. (2013). The civic and political significance of online participatory cultures among youth transitioning to adulthood. *Journal of Information Technology and Politics, 10*(1), 1-20.

Kligler-Vilenchik, N., McVeigh-Schultz, J., Weitbrecht, C., & Tokuhama, C. (2012). Experiencing fan activism: Understanding the power of fan activist organizations through members' narratives. *Transformative Works and Cultures, 10*.

Maher, S., Epaloose, G., & Tharp, R. (2001). Connecting cultural traditions: Making comparisons. In E. McIntyre, A. Rosebery & N. E. Gonzalez (Eds.), *Classroom diversity: Connecting curriculum to students' lives* (pp. 14-27). Portsmouth, NH: Heinemann.

Moll, L. C., Amanti, C., Neff, D., & González, N. (1992). Funds of knowledge for teaching: Using a qualitative approach to connect homes and classrooms. *Theory into Practice, 31*, 132-141.

Nasir, N. i. S. (2002). Identity, goals, and learning: Mathematics in cultural practice. *Mathematical Thinking and Learning, 4*(2&3), 213-247.

Nasir, N. i. 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. i. S., & Cooks, J. (2009). Becoming a hurdler: How learning settings afford identities. *Anthropology and Education Quarterly, 40*(1), 41-61.

Nasir, N. i. S., & Hand, V. (2006). Exploring sociocultural perspectives on race, culture, and learning. *Review of Educational Research, 76*(4), 449-475.

National Research Council. (2009). *Learning science in informal environments: People, places, and pursuits*. Washington, DC: National Academies Press.

National Research Council. (2012). A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. Washington, DC: National Research Council.

New London Group. (1996). A pedagogy of multiliteracies: Designing social futures. *Harvard Educational Review, 66*, 60-92.

O'Connor, K., & Allen, A.-R. (2010). Learning as the organizing of social futures. In W. R. Penuel & K. O'Connor (Eds). *Learning research as a human science. National Society for Studies in Education, 109*(1), 160-175.

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

Pea, R. D., & Martin, L. M. (2010). Values that occasion and guide mathematics in the family. In W. R. Penuel & K. O'Connor (Eds). *Learning research as a human science. National Society for the Study of Education Yearbook, 109*(1), 34-52.

Penuel, W. R., Bates, L., Gallagher, L. P., Pasnik, S., Llorente, C., Townsend, E., . . . VanderBorght, M. (2012). Supplementing literacy instruction with a media-rich intervention: Results of a randomized controlled trial. *Early Childhood Research Quarterly, 27*(1), 115-127.

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., Coburn, C. E., & Gallagher, D. (2013). Negotiating problems of practice in research-practice partnerships focused on design. In B. J. Fishman, W. R. Penuel, A.-R. Allen & B. H. Cheng (Eds.), *Design-based implementation research: Theories, methods, and exemplars. National Society for the Study of Education Yearbook.* (pp. 237-255). New York, NY: Teachers College Record.

Penuel, W. R., & Fishman, B. J. (2012). Large-scale intervention research we can use. *Journal of Research in Science Teaching, 49*(3), 281-304.

Penuel, W. R., Fishman, B. J., Cheng, B., & Sabelli, N. (2011). Organizing research and development at the intersection of learning, implementation, and design. *Educational Researcher, 40*(7), 331-337.

Penuel, W. R., Roschelle, J., & Shechtman, N. (2007). The WHIRL co-design process: Participant experiences. *Research and Practice in Technology Enhanced Learning, 2*(1), 51-74.

Penuel, W. R., & Spillane, J. P. (in press). Learning sciences and policy design and implementation: Key concepts and tools for collaborative engagement. In R. K. Sawyer (Ed.), *Cambridge Handbook of the Learning Sciences* (2nd ed.). Cambridge, UK: Cambridge University Press.

Penuel, W. R., & Wertsch, J. V. (1995). Vygotsky and identity formation: A sociocultural approach. *Educational Psychologist, 30*(2), 83-92.

Polman, J. L., & Miller, D. (2010). Changing stories: Trajectories of identification among African American youth in a science outreach apprenticeship. *American Educational Research Journal, 47*(4), 879-918.

Polman, J. L., Saul, E. W., Newman, A., Farrar, C., Singer, N., Turley, E., . . . McCarty, G. (2010). A cognitive apprenticeship for science literacy based on journalism. In K. Gomez, L. Lyons & J. Radinsky (Eds.), *Learning in the disciplines: Proceedings of the 9th International Conference of the Learning Sciences* (Vol. 2, pp. 61-68). Chicago, IL: International Society of the Learning Sciences.

Quintana, C. (2012). Pervasive science: using mobile devices and the cloud to support science education. *interactions, 19*(4), 76-80.

Rahm, J. (2002). Emergent learning opportunities in an inner-city youth gardening program. *Journal of Research in Science Teaching, 39*(2), 164-184.

Riconscente, M. M., Kamareinen, A., & Honey, M. (2013). Badge-based STEM Assessment: Current terrain and the road ahead. New York, NY: New York Hall of Science.

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.

Rosebery, A., Ogonowski, M., DiSchino, M., & Warren, B. (2010). "The coat traps all your body heat": Heterogeneity as fundamental to learning. *The Journal of the Learning Sciences, 19*(3), 322-357.

Sadker, M., & Sadker, D. (1995). *Failing at fairness: How America's schools cheat girls*. New York: Simon & Schuster.

Schwartz, S. (2013, November 19). Spark: Integrating mentoring and connected learning. *The Chronicle of Evidence-Based Mentoring*.

Shepardson, D. P., & Britsch, S. J. (2006). Zones of interaction: Differential access to elementary science discourse. *Journal of Research in Science Teaching, 43*(5), 443-466.

Slack, A. (2010). Cultural acupuncture and a future for social change. Retrieved from http://www.huffingtonpost.com/andrew-slack/cultural-acupuncture-and_b_633824.html

Star, S. L., & Ruhleder, K. (1996). Steps toward an ecology of infrastructure: Design and access for large information spaces. *Information Systems Research, 7*(1), 111-134.

Stetsenko, A. (2010). Standing on the shoulders of giants: A balancing act of dialectically theorizing conceptual understanding on the grounds of Vygotsky's project. In W.-M. Roth (Ed.), *Re/Structuring Science Education* (pp. 69-88): Springer.

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.

Stringfield, S., & Datnow, A. (1998). Scaling up: School restructuring designs in urban schools. *Education and Urban Society, 30*(3), 269-276.

Taylor, E. V. (2013). The mathematics of tithing: A study of religious giving and mathematical development. *Mind, Culture, and Activity, 20*(2), 132-149.

Traphagen, K., & Traill, S. (2014). How cross-sector collaborations are advancing STEM learning. Los Altos, CA: Noyce Foundation.

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

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.

Wasserman, S. (2011). Beyond information: Ritual, relationship, and re-encounter through mobile connectivity. *Curator: The Museum Journal, 54*(1), 11-24.

Watkins, S. C. (2011). Digital divide: Navigating the digital edge. *International Journal of Learning and Media, 3*(2), 1-12.

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*.

Wyman, B., Smith, S., Meyers, D., & Godfrey, M. (2011). Digital storytelling in museums: Observations and best practices. *Curator: The Museum Journal, 54*(4), 461-469.

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.