where it gets interesting

Competing Models of STEM Learning After School

by Bronwyn Bevan and Vera Michalchik

In an afterschool science program in a mid-sized city in the South, 12 sixth-grade students are about to make battery-operated motors using copper wires, paper clips, magnets, tape, and 9-volt batteries. Before starting the activity, one of the two classroom teachers leading this weekly program passes out ice cream cones to the children, who sit in two rows of desks facing the front of the class. Leaning back in her chair with her own ice cream, the other teacher makes small talk for several minutes before asking Investigation Club members what they know about motors.

The children and teacher casually converse about their experiences at home with their parents' cars, boats, or lawn mowers. The teacher shares what she learned from her own father, "a shade-tree mechanic," about fixing car engines. During the conversation the teacher calls out several components of car motors—air, oil, gasoline, batteries—when the children mention them.

After about 30 minutes, with all the ice cream consumed, the teachers pass out the activity worksheet and materials. They ask a student to read aloud the step-by-step instructions and then instruct the children to begin, working individually at their desks. The teachers roam through the room to assist them. The students hunch over their desks as they assiduously assemble the materials, carefully coil the copper wire around the battery, and affix the paper clips to the terminal nodes. As they work, they engage in casual side talk, giggles, and commentary. Concentration is in the air. Individuals ask for assistance: The copper wires keep springing off the battery; a connection can't be made. The teachers come over to hold the batteries or pinch the paper clips. Children continue good-naturedly to work at wrapping and

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rewrapping the wire, which just won't hold. Maybe the paper clips are too loose? There are some groans of frustration but no recrimination, and nobody gives up. As the hour nears 5 p.m., parents start to drift in to pick up their children. Nobody has gotten a motor to work. "Maybe it was the wrong gauge wire," says a teacher. She tells the children to write about what happened in their science notebooks. A single student picks up her notebook and starts to write. The others start packing up their bags and begin to leave one by one.

This description of an observation in May 2009 is representative of many science activities we have observed in afterschool settings serving middle school children. The setting is school-like, with desks in rows and teachers at the front of the room. The mood, featuring ice cream cones and casual conversation, is relaxed; the activity is materials-based; and the pedagogical context is spare, using untested activities and limited materials with minimal instruction and reflection. This particular project was one of 16 programs we studied as a part of a federally funded initiative on science learning in out-of-school time (OST).

> Use of this *additive model* of learning, we argue, may lead to missed learning opportunities for all children, and perhaps especially for children from high-poverty communities.

No operating motors were built during the two hours we observed the Investigation Club (a pseudonym), but many other things happened. Students identified and shared what they knew about motors and batteries from everyday life. They swapped stories and jokes with their teachers and with one another, solidifying their membership in a science-focused community. They undertook the science activities with alacrity and persisted despite frustrations. They gained familiarity with materials including copper wire, batteries, and clips as they assembled a multi-component apparatus. They directly experienced practices of science that involve building, tinkering, and refining toward the goal of constructing an operational instrument.

How Connections Happen—or Don't

Two days later, in the school-day science class, another teacher began the sixth-grade electricity unit. Four of her 24 students were part of Investigation Club. When she asked for examples of electricity in students' daily lives, one of the Investigation Club students gave the example of a car battery, whereas other students all referred to items that are typically plugged into a wall. The teacher called on the Investigation Club students to describe an electric circuit as she sketched it on the blackboard. They were also asked to distribute the materials for a fruit-battery activity and to demonstrate to their peers how to coil the copper wire to complete a circuit. This time, with the correct materials assembled, the Investigation Club students successfully completed the circuits—more quickly than did many of their peers. The teacher asked them to assist other students. Most but not all of the sixth-graders successfully completed a circuit before the end of the activity time. The teacher then led a discussion about the ways in which trials and failures are an intrinsic part of the scientific process. One of the Investigation Club children recounted how the club's earlier activity hadn't worked and described what he thought the problems might have been. The class discussed the variables that made it easier or harder to complete the circuits. The teacher led the students through a review of the key ideas, terms, and processes of the activity, moving into a six-week unit on electricity.

This classroom teacher was aware that some of the students had recently attempted to complete circuits. She knew of their interest in science and their affiliations with the Investigation Club program. She called on them to spark group conversations, to demonstrate, and to assist other students. In this way, she leveraged their interests and growing capacities both to support their own learning and to advance the productive engagement of the whole class. She even knew that the afterschool activity had not unfolded as planned, so that the students' grasp of concepts might be tenuous; thus she took on the diagram sketching herself, with their verbal input leading the way.

Actually, this classroom episode didn't really happen, at least as far as we know. The afterschool program we observed was conducted in a school, with schoolteachers working as afterschool club leaders. However, because the design of the program was grounded in the assumption that interest sparked in one place—afterschool—would automatically generate interest in another setting—school—the afterschool program leaders did not make special efforts to connect to the classroom. The underlying model of learning was that interest is a steady construct. If it gets stoked in one place, it will catch fire in another. The research that documented the effects of the afterschool program, therefore, focused solely on what happened during afterschool hours and how it supported engagement. The study design did not test assumptions about how concepts and experiences in the afterschool setting would manifest in the school setting. We don't know if they did, if they didn't, or even if they had opportunities to do so.

This narrow focus is, we contend, a problem. It arises from a model of learning that views interest, engagement, and learning as context-free. Use of this *additive* model of learning, we argue, may lead to missed learning opportunities for all children, and perhaps especially for children from high-poverty communities. These children are more likely than children from higher-income communities to attend afterschool programs that are funded by government and private foundations. These funders often require programs to collect data that is informed by the additive model of learning—for example, pre- to post-program changes in interest or attitudes or in school-day grades or test scores. Use of these data in turn shapes afterschool program designs and possibilities.

That program relied on what we term the *additive model* of learning, which posits that providing children with rich science experiences in one setting is like filling a beaker. Students' levels of science interest, capacity, and commitment rise and should therefore remain equally high in other settings such as school, home, and other OST programs.

Competing Theories of Afterschool

Afterschool programs are currently conceptualized in two ways. One is represented by *expanded learning,* which includes a wide range of content-rich opportunities in the hours outside of school, including summer camps. The operating assumption is that, in structured OST programs, children can learn concepts or develop capacities or interests that will later enhance their engagement in everyday as well as academic settings. Some of these programs are science-specific. They might be based at science museums, like the XTech program at the Exploratorium, or in youth development programs devoted to science, like Project Exploration in Chicago. However, most expanded learning programs are not science-specific. For example, most 21st Century Learning Community Centers and equivalent district or county programs encompass a range of activities, including play, snack, homework time, and academic enrichment. Though most of the academic activities focus on reading and mathematics, increasingly afterschool leaders report that they are interested in incorporating science activities into their offerings.

The other model is *extended learning,* in which afterschool aligns more closely with the school curriculum. Interest in extended day models is growing as many communities seek more time to improve students' academic performance, generally measured by standardized achievement tests. Some argue that extended day programs can be organized so that learning activities are markedly different from school activities and yet directly reinforce key ideas or concepts from the school curriculum.

The *extended* school day, because it is clearly a part of the school curriculum and strategy, may be most logically assessed through school measurements such as test scores, attendance, and grades.

The *expanded* school day is more complicated. Its premise is that time after school might be fundamentally different from school time. Expanded afterschool programs might address subject matter, practices, terms, and instruments that are not included in the school curriculum or that are covered at more advanced grade levels. For example, expanded programs might include taking care of animals in a life sciences program based at a zoo, learning about complex systems through computer-based modeling at a local research agency, or participating in a youth research team associated with a local municipal agency's water quality studies.

The viability of expanded day programs in the eyes of policymakers and funders rests partially on the assumption that students who are engaged in high-quality OST science programs will build their interests, capacities, and commitments to science in ways that will carry over to enhance engagement in school science. Indeed, this premise informed the federal program that funded Investigation Club. That program relied on what we term the *additive* model of learning, which posits that providing children with rich science experiences in one setting is like filling a beaker. Students' levels of science interest, capacity, and commitment rise and should therefore remain equally high in other settings such as school, home, and other OST programs (Bevan & Michalchik, 2012).

Many researchers value the ways in which high-quality expanded day programs productively engage children in science practices, communities, and learning. Research shows that, in these settings, children access resources—objects, instruments, expertise, settings—not otherwise available to them (Barron, Wise, & Martin, 2012). They expand their social networks through new relationships with one another, with science or mathematics professionals, and with other adults (Khisty & Willey, 2012). They expand their identities as achievers in the context of science (Barton & Tan, 2010; Fusco, 2001; Rahm, 2002). They take on new responsibility for and authorship of their science understanding (Vossoughi, 2012).

Although this research makes a compelling case that powerful science learning can occur in youth development contexts, as researchers we struggle with how to document and assess *at scale* the contributions such experiences represent for children. We emphasize *scale* because we know that STEM education funders, policymakers, and program leaders need documentation of program effectiveness and student learning. The evidence must be obtained in ways that are at once efficient, in that they do not require detailed and costly observations and interviews, while also being non-obtrusive, for example, not "ruining" the OST experience by requiring school-like paper-and-pencil tests.

Moving documentation and assessment to scale is, we argue, critical to ensuring that the expanded day continues to be an option in the face of the growing interest in extended day learning. We fear that, in the absence of demonstrated evidence of learning, extended day models, because they are easier to document through existing school measures, will be used with students from high-poverty communities, while harder-to-document expanded day opportunities will be reserved mostly for students from more wealthy communities, where science scores are of less concern. To date, efforts to develop effective expanded day assessment models that can scale up have been hindered by the assumptions of the additive model of learning.

Limitations of the Additive Model of Learning

The additive model of learning assumes that if children participate in afterschool STEM programs by *x* amount, their overall interest, capacity, and engagement in STEM—and particularly in school STEM—should rise by an amount equivalent to *x* (Bevan & Michalchik, 2012). We argue that the additive model limits attempts to understand learning across settings and timeframes in several ways.

First, even the most passionate science learner emerging from an OST setting can become bored or confused in a badly conducted school science class. It is equally true that even the most deeply committed school science student can be turned off during boring OST activities. However, in the additive model, if students attending OST STEM programs do not perform better in school science than children who do not attend, both the value of the OST program and the development of the learners are questioned. (See Kane, 2004, for a synthesis of four different program evaluations, though none are science-specific.)

A second problem stems from assumptions about how children categorize activities. The additive model presupposes that children who have a positive experience in a given science activity should later respond positively to other science activities. Children who like robots ought to like chemistry. This view suggests that children carry around a unified feeling about "science," regardless of whether their interests are in animals or planets, gadgets or gardens, illustrating plant life or watching things explode. In fact, researchers have documented the ways in which children's interests in science are domain-specific (Azevedo, 2011).

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Third, the additive model discounts the value of positive engagements with OST activities that may not directly link to school science but that may open the door for ongoing future engagement with science, including in the school setting. Such positive experiences might engage children in noticing specific phenomena, developing skills on which they can later draw, or establishing peer or adult relationships that make science more appealing. Generally, OST programs offer time, tolerance, safety, choice, and flexibility for intertwining emotional, aesthetic, and social elements into learning activities in ways not as easily accommodated by schools.

Fourth, the additive model underplays important contemporary paradigms in the learning sciences (Lave & Wenger, 1991; Rogoff & Lave, 1984; Sawyer, 2006). This research shows that, in order to make useful connections between their OST and school experiences, children benefit from clear points of articulation between the two. In this view, the construct of "interest" has little meaning apart from activities that directly relate to that interest. Practical experience is the basis on which children make connections among learning activities across settings. This reality has many pedagogical implications for the design and delivery of programs that seek to make these connections (Ito et al., 2012).

The additive model does not take into account the fact that a given context or activity system that provides for successful learning is not, at its core, the same as the next. A child engaged by the configuration of people, ideas, tools, tasks, processes, and possibilities in the afterschool setting will face a different configuration during the school day. Each evokes a different "fit" between the child and the activities at hand and therefore draws forth a different set of responses.

Though people do carry with them continuously developing sets of interests, proclivities, and passions (see Gutiérrez & Rogoff, 2003; Holland, Lachicotte, Skinner, & Cain, 1998), how these interests and proclivities manifest themselves is not so simple. We posit that the additive model of learning is overly simplistic, to the point that it obscures what may be happening across settings. The persistence of this model may be one reason for the exceedingly mixed results in large-scale studies of afterschool learning (James-Burdumy, Dynarski, Moore, Deke, & Mansfield, 2005; Kane, 2004). Its use threatens the viability of expanded day programs, especially for children attending high-poverty schools.

Scholars argue for the need to conduct cross-setting studies both to understand how children develop interests and expertise over time and to discover the social arrangements and opportunities that exist—or do not exist—to support learning.

Contextual Model of Learning

In contrast to the additive model of learning, we posit a *contextual* model. In using this phrase, we follow a long line of scholars who have documented the ways in which learning, identity, interest, and participation are related to context (Esmonde et al., 2012; Gutiérrez & Rogoff, 2003; Holland et al., 1998; Lave & Wenger, 1991; McDermott & Varenne, 1998). Rather than counting on the direct transfer of knowledge, skills, or interests from one setting to another, researchers must identify the multiple and contingent ways in which children express their growing fluencies with diverse scientific practices. These fluencies will look different in different settings and may not appear at all when conditions do not support them.

In recent years, education researchers have begun to pay progressively more attention to learning across settings. Scholars argue for the need to conduct cross-setting studies both to understand how children develop interests and expertise over time and to discover the social arrangements and opportunities that exist—or do not exist—to support learning (Gutiérrez, 2012; Lee, 2008). Many thus undertake this research to advance educational equity (see Banks et al., 2007) because, as inequitable outcomes reveal, educational settings appear to vary in their ability to leverage learners' existing interests and resources (Bell, Bricker, Reeve, Zimmerman, & Tzou, 2012).

In-depth documentation of learning in a given setting is important (and especially informative for program leaders), but it may be limited when used to predict whether one approach or another is "more effective" unless it is contextualized across the settings of the learning ecologies in which it exists.

From an educational perspective, cross-setting research may reveal how and where children develop interests and capacities to productively engage in science, thus enabling program leaders to better leverage and coordinate learning resources. From a learning sciences perspective, research that follows children across settings, especially when it addresses nondominant communities that are frequently underrepresented in the literature, can strengthen our understanding of learning and human development and how these vary culturally by expanding the body of data to be more inclusive and therefore more complete (Bell et al., 2012).

Investigation Club Revisited

We return to the Investigation Club. Because it was part of a larger federally funded program called SCIstar (a pseudonym), the effects of participation in the Investigation Club were measured in part through pre- and post-program pencil-and-paper surveys to see if children's attitudes toward science changed. The assumption, following the additive model, was that, if attitudes changed during SCIstar participation, the changed attitudes would also play out in school, home, and other OST settings—and even possibly in career interests.

The surveys asked about children's prior experiences with STEM generally and with OST STEM; they also used an instrument designed to assess attitudes toward science (Weinburgh & Steele, 2000). Analysis of the data showed that children's positive attitudes in science, which started high on a five-point scale, held steady during the middle school years. This finding runs counter to the widely documented drop in positive attitudes and interest in science during middle school (George, 2000; Zacharia & Calabrese-Barton, 2004). Indeed, when we compared students participating in the 16 SCIstar projects with non-participating students matched for demographics and levels of interest in STEM, we found that attitudes toward science dropped in the comparison group but held steady for the youth in SCIstar (Bevan, Gallagher, Michalchik, Remold, & Bhanot, in review).

A contextual model of learning and a cross-setting model of research design would enable the field of informal science education to look for power where it actually exists and to locate breakages in the line that keep children from getting the full benefit of STEM experiences—in and out of school.

The evaluation of SCIstar involved other elements in addition to the surveys, notably extensive on-site observations and interviews. However, in none of the 16 projects did local project leaders or evaluators take a cross-setting approach to understand if and how SCIstar experiences might be showing up in other settings, such as home, school, or other OST programs. As the external evaluators of the program, we did not have institutional review board clearance to conduct this research ourselves.

If the program had been based on a contextual model of learning, the situation would have been different. Cross-setting approaches would have been used to design, develop, and document the Investigation Club project. From the beginning, school and OST leaders would have developed a shared set of goals for the students. Program design and evaluation would have included determining how to follow children in home and other settings. Program leaders would have identified ways to document growing STEM interest or capacities during the school day. Documentation would not have been limited to grades and standardized test scores; it might have included the nature of student participation, questions, leadership, and engagement in STEM activities in and out of school. Depending on the focus of the activity—in the case of Investigation Club, energy and earth systems—a study could have determined whether key concepts as well as scientific practices were carried into the school day.

This method of research is not simple. It requires coordination across multiple systems and stakeholders (see Penuel, Fishman, Sabelli, & Cheng, 2011). However, simpler forms of research are not providing the field with useful information. We are looking for a broken power line on our property because that is where we live, but the power line could be broken anywhere in the entire network. Also, there could be power at the house next door or in the community across the river, but we have not had the inclination or wherewithal to look. A contextual model of learning and a cross-setting model of research design would enable the field of informal science education to look for power where it actually exists and to locate breakages in the line that keep children from getting the full benefit of STEM experiences—in and out of school. Such approaches would inform the work of educators, researchers, and policymakers.

Fostering an Ecology of STEM Learning

The additive model of learning not only runs counter to the contemporary understanding of learning but also undermines the potential of OST programs to support youth engagement in STEM learning. It leads to use of false measurement strategies, such as holding OST STEM programs accountable for school outcomes. These documentation strategies in turn shape—and potentially narrow—program design and implementation. Moreover, the additive model diverts attention from the central issue of making rich learning opportunities more equitably available across local learning settings. A single powerful science learning opportunity—whether at home, in afterschool, or at school—can be exciting and memorable. However, unless it is embedded in an ecology of further opportunities that include higher-level mathematics, feature role models of all kinds, and offer increasingly advanced and complex learning, the single science learning opportunity is likely to remain singular.

In contrast to the additive model of learning, we posit a contextual model that conceptualizes learning as a process that takes place over time and across settings, in response to specific people, ideas, tools, and opportunities. This process can also be shut down or diverted when opportunities and connections are not made available or comprehensible (Barton & Yang, 2000; Bell et al., 2012).

The distinction between *additive* and *contextual* models is not a minor or semantic issue. The additive model represents a fundamental misconceptualization (see Stetsenko, 2009) that can undermine the developmental power of the OST setting. For example, the assumption that interest carries across settings independent of the types of opportunities available can lead policymakers to devalue or even defund powerful OST programs whose effects don't register on school measures. The school itself—not the OST program, which has no control over the school day—should be accountable for how young people perform on school measures.

To better understand and capture the complex processes of learning, research in OST STEM needs to take a longer view of how OST fits into a larger learning ecology. It needs to attend to the specific contexts of STEM learning and clearly tie the measures of learning to the models of learning. Taking such an approach implies that:

- School measures should be considered as relevant to OST programs only when robust connections between school and OST have been designed and implemented.
- Better (and embedded and naturalistic) measurements of learning must be developed for OST STEM programs, especially when they have different, and perhaps richer, goals for learning than do many school science programs (see Michalchik & Gallagher, 2010).
- Research frameworks that better account for learning as it develops across settings and time must be developed and incorporated into studies of OST learning.
- More STEM OST programs should be supported and made more equitably available. We suggest that this need for more, and more equitable, high-quality STEM learning opportunities applies equally in school settings.

Only when the entire STEM learning ecology is taken into account, and when young people have access to high-quality STEM learning opportunities, can the results of studies of children's STEM interest be fully interpreted and appropriately applied.

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