Crumpled Molecules and Edible Plastic:

Science Learning Activiation in Out-of-School Time

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"Informal environments beyond the school day promote flexibility that lets children engage in science in the same way they play sports or create art. Playing with bubbles, blocks, robots, and plants not only helps students when it comes time to learn physics, chemistry, and biology—but it also sparks an interest in science that translates to future classroom and career" (Coalition for Science After School, 2012).

The Coalition for Science After School highlights the dual nature of outcomes for science learning during out-of-school time (OST): Learning experiences should not only be positive in the moment, but also position youth for future success. Several frameworks speak to the first set of immediate outcomes—what youth learn, think, and feel as the result of informal learning experiences (Afterschool Alliance, 2013; Friedman, 2008; Hussar, Schwartz, Boiselle, & Noam, 2008; National Research Council [NRC], 2009, 2011).

Much less research has been conducted on longer-term outcomes—how OST experiences affect engagement over time, prepare youth for future learning, or even influence career trajectories. There are hints: By eighth grade, for example, career expectation is a better predictor of future success than math achievement (Cannady, Greenwald, & Harris, 2014; Tai, Lui, Maltese,

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& Fan, 2006), a finding that suggests OST programs might do well to focus on science interest and career awareness. In general, however, the field urgently needs research and practice frameworks that speak directly to the ways OST programming produces longer-term learning, engagement, and career outcomes (NRC, 2015).

Responding to this need, we have been developing a new framework and set of assessments built on the idea of *science learning activation*. This paper draws on in-depth interviews with and observations of adults and youth to explore this new concept. Researchers, evaluators, and program developers can use this description to judge whether the concept of science learning activation aligns with their goals and can help them understand, develop, and assess their work.

Science Learning Activation

The goal of the Activation Lab (www.activationlab.org) is to develop practical theories that explain both the immediate results of specific learning experiences and the longer-term effects of early engagement in science. Building on recent advances in science education, sociocultural studies, and cognitive and social psychology, we define *science learning activation* as the dispositions, practices, and knowledge that enable learners to be successful in science learning and that are, in turn, influenced by success. Science learning activation is a developmental feedback loop (Figure 1): Activated science learners have

the resources to be successful when they engage with science. This success makes them more activated, which makes them more likely to engage with science and be successful, which leads to more activation, and so on. This feedback loop is the heart of why activation is important. Learning experiences that increase science learning activation can encourage youth to follow pathways to science. Conversely, poor experiences can reduce activation, undermining future success and thus making young people less likely to pursue STEM literacy or STEM careers.

Our work suggests that activated science learners score higher than non-activated learners on the four dimensions in the Activation box in Figure 1: fascination, valuing science, competency beliefs, and scientific sensemaking. All four provide useful personal resources that individuals carry from one science learning experience to the next and that influence their chances of success in any given experience.

What is "success" in a science learning experience? Success certainly includes engagement during the experience and achievement of the intended science learning outcomes. However, successful learning experiences should also prepare youth for more learning, affecting their choices to participate in science activities in the future. Successful experiences encourage youth to perceive themselves as successful when they do science; this perception supports their confidence and agency.

The concept of science learning activation and our definition of success in science learning are based on five

Figure 1. The Science Learning Activation Framework
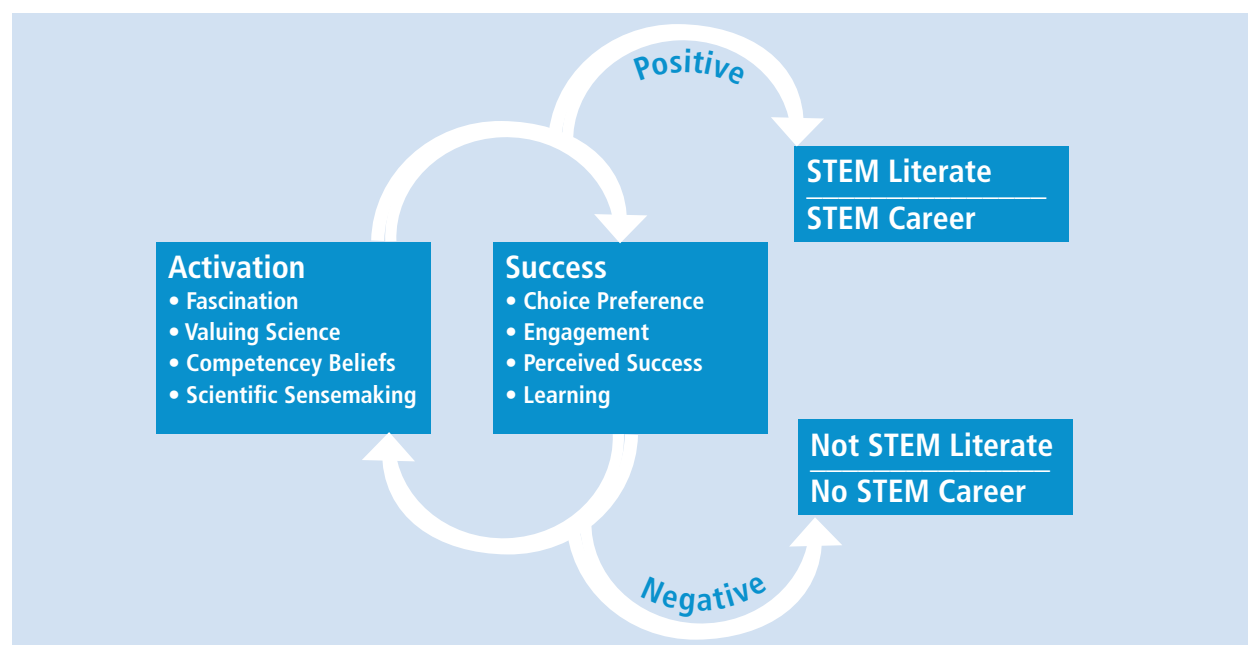
years (and counting) of literature review, research studies, and measurement development. The Activation Lab has:

1. Developed and extensively validated, across years of empirical work, survey measures of the four dimensions of science learning activation so they could be included in research and program evaluations. Technical reports are currently available at www.activationlab.org/tools; downloadable, customized measurement systems for field use will soon be available.
2. Analyzed longitudinal datasets to understand pathways toward diverse STEM careers (Cannady et al., 2014).
3. Engaged in a retrospective study of the life histories of approximately 70 scientists and engineers (Crowley, Barron, Knutson, & Martin, 2015; Knutson & Crowley, 2015).
4. Conducted two waves of in-depth case studies with 24 Bay Area youth whom we followed through selected science learning experiences in grades 5–8. Each case includes video observation, interview, artifact analysis, and survey data.
5. Conducted large-scale quantitative studies with thousands of youth exploring changes in activation and the relationship between activation and success (Bathgate, Crowell, Schunn, Cannady, & Dorph, 2015; Dorph, 2016; Dorph, Cannady, & Schunn, 2016; Dorph, Schunn, Crowley, & Shields, 2012, 2013).

Our work so far supports the positive feedback model: The four dimensions of activation all have positive effects on one or more of the aspects of success—choice, engagement, perceived success, and learning—which in turn predict increases in the dimensions of activation. Thus, science learning activation appears to provide developmental momentum that can support persistent success in science learning.

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The Dimensions of Science Learning Activation

To describe the four dimensions of science learning activation, we draw on two sources of qualitative data: in-depth case studies with 10–14-year-olds (number 4 above) and retrospective life-history interviews of adults who work in science (number 3). Descriptions of the four dimensions of activation below mix reviews of the literature, sample items from the survey scales that measure that dimension, and examples from our data to show how activation is grounded both in theory and in the lived experience of science learners.

Dimension 1: Fascination

Fascination is emotional and cognitive attachment to science. It can serve as intrinsic motivation. This dimension includes aspects of:

- Curiosity (Litman & Spielberger, 2003)
- Interest or intrinsic value in science (Baram-Tsabari & Yarden, 2005; Hulleman & Harackiewicz, 2009; Osborne, Simon, & Collins, 2003)
- Mastery goals (Ames, 1992)
- Positive emotions related to science and scientific inquiry (Silvia, 2008)

All these constructs are associated with choosing to engage with science and with success in science learning (Hidi & Ainley, 2008; Hidi & Renninger, 2006). It makes sense that these aspects of fascination would occur together in the same individuals; for example, people who are interested in science are likely also to have mastery goals for science. In fact, our research has confirmed that all of these aspects of fascination cohere, psychometrically, into a single factor. Figure 2 provides sample items from our activation assessment that measure how fascinated youth are with science.

What does fascination sound like when you talk to a learner about science? Here is one example from a 12-year-old boy:

There's some things that's interesting about molecules, like, if you get different types of molecules and you put them together, you can actually make a new thing to use. In the past they found a type of molecule that … when you crumple it, it's able to uncrumple and then become smooth, and it's unburnable, so when it hits an object or hits fire, it's not able to burn.

Figure 2. Sample Survey Items in the Fascination Scale

	YES!	yes	no	NO!
a. After a really interesting science activity is over, I look for more information about it.	◯	◯	◯	◯
b. I need to know how objects work.	◯	◯	◯	◯
c. I want to read everything I can find about science.	◯	◯	◯	◯
d. I want to know everything about science.	◯	◯	◯	◯
e. I want to know how to do everything that scientists do.	◯	◯	◯	◯

Asked where he learned about these molecules, the boy described a "science show about, like, aliens. It showed … something that hit the earth…." He went on to describe the experiments scientists conducted on this material, trying to tear and crumple it. "And then they put it in … a fireplace, and then they lit it on fire, and then it wouldn't burn."

We have often found that young people who score high on the fascination scale, like this boy, convey their passion for science by giving detailed accounts of phenomena that have struck them. They sometimes tell stories of scientific discoveries, as this boy did. Sometimes they talk about their own experiences pursuing their scientific interests.

Our interviews with adults about their paths towards science careers also suggest that phenomena and facts can be a focus for early fascination. A 41-year-old female neuroscientist told the interviewer how fascination spurred her pursuit of science:

> I just know that it's fascinating, and I didn't know how everybody didn't want to be a biologist, because how do you not want to know how your heart pumps? How do you not want to know how your brain works? … The seeds of that, and how that's unfolded in all these different ways … have gotten me even closer to trying to understand my place in the world.

Dimension 2: Valuing Science

The second dimension of science learning activation is the degree to which learners *value* various aspects of science, including scientific knowledge, scientific

reasoning, and the role science plays in families and communities (Brickhouse, Lowery, & Schultz, 2000; Costa, 1995; Dogan & Abd-El-Khalick, 2008; Hill & Tyson, 2009). Young people may express both the everyday value and the career value of science. They can understand the interactions of self with science and value those interactions within their social context (DeBacker & Nelson, 2000; Eccles & Wigfield, 2002; Osborne et al., 2003; Pintrich, 2003). Learners who value science are more likely than those who do not to pursue science as a possible career. Whether or not they find science fascinating, those who value science and the role it plays in their lives and in society are more likely to engage in learning about science, both in and out of school (Eccles, 2005; Lyons, 2006). Sample items on the *valuing science* scale of our activation assessment are shown in Figure 3.

A 12-year-old girl we interviewed described the value of scientific invention: "In the past, science helped to make, like, the microwave and TV…. If you want to make a motor, you are able to know, like, science works." This girl also expressed the value of a scientific process that allows for mistakes:

> Some people make mistakes on science, which is good, because if you make a mistake, you can still think about it. Some people, when they make mistakes on science, they're able to— There are some kids in science who tried to make plastic, but they made a mistake, and they made edible plastic. That's why sometimes it's really good to … make mistakes, because you might create a new thing.

Figure 3. Sample Survey Items in the Valuing Science Scale

	YES!	yes	no	NO!
a. I think scientists are the most important people in the world.	O	O	O	O
b. I think science is more important than anything else.	O	O	O	O
c. Science makes the world a better place to live.	O	O	O	O
d. Knowing science is important for being a good citizen.	O	O	O	O
e. I think science ideas are valuable.	O	O	O	O

Another example of valuing science comes from a 25-year-old crop scientist. Before high school, she had thought she would go into politics. A pivotal moment occurred on a church mission trip during her senior year of high school, when she saw very poor people create cooperatives to grow corn.

> I saw a real opportunity to solve problems on an individualistic level…. It was a very eye-opening experience in my life…. I was kind of like, "You know what? Politics can't solve a lot of these issues." I started looking at other things. It kind of made me open my eyes.

As a young person, this scientist had seen that science provided a way to solve a problem she cared about.

Dimension 3: Competency Beliefs

The dimension *competency beliefs* refers to the extent to which learners believe that they are good at science tasks. A core construct in social cognitive theory, competency beliefs are defined as "people's judgments of their capabilities to organize and execute courses of action required to attain designated types of performances" (Bandura, 1986, p. 391). Competency or self-efficacy beliefs are an important predictor of many types of achievement behavior, including choice of task, engagement, effort, and persistence (Pintrich, 1999, 2002; Schunk, Pintrich, & Meece, 2008). The sample items shown in Figure 4 illustrate how competency beliefs can manifest in individuals.

Prior research makes a clear distinction between people's actual competence and their subjective perceptions. For example, college students' reasoning ability has been shown to play a more significant role than self-efficacy in science achievement (Lau & Roeser, 2002; Lawson, Banks, & Logvin, 2007), but learners with high self-efficacy beliefs were more likely to be behaviorally and cognitively engaged in learning (Linnenbrink & Pintrich, 2003). Durik, Vida, and Eccles (2006) found that individuals' subject-specific competency beliefs predicted their career aspirations. Thus, competency beliefs affect both short-term and long-term choices.

Figure 4. Sample Survey Items in the Competency Beliefs Scale

I think I am very good at:	YES!	yes	no	NO!
a. Figuring out how to fix a science activity that didn't work.	O	O	O	O
b. Coming up with questions about science.	O	O	O	O
c. Doing experiments.	O	O	O	O

Observation of an 11-year-old boy in a science camp offers an example of a young person with high competency beliefs. First, he took charge of the activity, which involved timing the movements of mosquito fish. He confidently engaged in the task, demonstrating that he believed he knew what he was doing. When asked by the facilitator whether he needed help, the boy replied, "No, I can do it myself."

An interview with a physicist who works as a museum educator offers another straightforward example of how belief in one's own science competence provides momentum on a science learning and career pathway.

> I think at college … the fact that I started off in an Intro to Physics class with 70 people, and there were only two of us that graduated with a degree.… I feel like I made it all the way through to the end because I was good at it.

Dimension 4: Scientific Sensemaking

The final dimension, *scientific sensemaking,* refers to the degree to which individuals learn in ways generally aligned with the practices of science. The behaviors associated with sensemaking include asking investigable questions, seeking mechanistic explanations for natural and physical phenomena, engaging in evidence-based argumentation, interpreting common data representations, designing relevant investigations, and understanding the changing nature of science (Apedoe & Ford, 2010; Lehrer, Schauble, & Petrosino, 2001). Some of these behaviors are captured in the sample survey items in Figure 5. Research shows that these sensemaking practices are associated with choosing, engaging with, and learning from science activities (Chi, Leeuw, Chiu, & LaVancher, 1994; Lorch et al., 2010; Songer, Kelcey, & Gotwals, 2009; Zimmerman, 2007).

A 12-year-old provides an example of scientific sensemaking as he recognizes the importance of evidence, seeks coherent explanations for natural and physical phenomenon, and uses models to understand how things work.

> People in my school keep on saying there's aliens and stuff like that. There's no evidence about it.… You need to think more when you're doing science.… If you do science— if you make something with science and you know the answer but you don't

know really how it works … and you get confused, you can really think about it more. In a while, you'll be able to know how it works, and when you know how it works you can know how to be able to make a new model.

Similarly, a 42-year-old molecular biochemist describes her drive to engage in scientific sensemaking during her elementary school years, moving beyond mere enjoyment into a quest for making sense of how the natural world works.

> At least once a week or so, we had a day in nature where we'd collect bugs or things, and I loved that. I didn't love it in the way that you just enjoy the outdoors, but I loved it because I wanted to find out more and more and more things and how they worked. I remember I wasn't grossed out by the bugs, but I wanted to actually, like, open them up and see things.

What's New About Science Learning Activation for OST Programming

Not only is science learning activation well grounded in prior research, but many of its components are familiar drivers of science learning in OST. Three features of our framework make it novel and useful to OST science programs.

First, it defines activation *specifically in relation to science*. It pushes past both general theories, which apply to learning in any content area, and ratings of student outcomes from specific classes or OST programs, which may be too specific to guide later learning. Activation is a middle-level approach that applies what research says about general approaches to describe how youth build momentum specifically toward science; it could therefore be uniquely useful for OST programs that focus on science learning.

Second, the science learning activation framework *merges findings from research both on cognition and on motivation or affect*. Cognitive research has described what is required to build difficult skills and knowledge (Anderson, 2009) but has largely ignored what builds identity or career interest (Bybee & McCrea, 2011). Research on motivation and affect has described what

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Figure 5. Sample Survey Items in the Scientific Sensemaking Scale

The next set of questions are about dolphins. Some types of dolphins may become extinct in only a few years if something is not done to help them. Scientists are studying how different kinds of dolphins live, to learn what they need to survive.
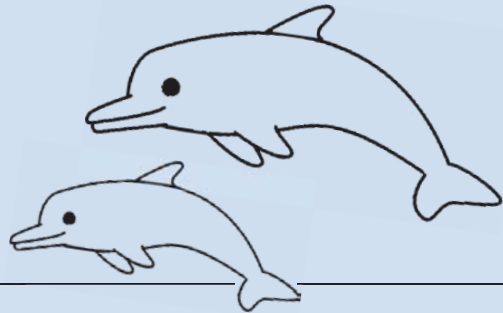
Elijah wonders if the temperature of the water makes a difference in how much dolphins play.

Which question is the best to ask to investigate this?

- ○ Do dolphins play in warm water?
- ○ Which other animals live in the same part of the ocean as dolphins?
- ○ Do dolphins live in warm or cold water?
- ○ Do dolphins play more when the water is warm or cold?

What would make one scientific explanation better than another for why dolphins play?

- ○ It is new and different.
- ○ It is in more books.
- ○ It is closer to what people think now.
- ○ It is based on more and better evidence.

A group of students are observing dolphins in a cove.

Maria and Celia both think:

- • Dolphins are affected most by the amount of noise.
- • Many dolphins left the bay when there was a lot of noise.

Maria says: Dolphins cannot hear each other when there is a lot of noise, so they leave.
Celia says: Dolphins leave because it is noisy, so when there is a lot of noise they leave.

Whose reasoning for why the dolphins leave the cove is more scientific?

- ○ Celia because she repeats the important idea.
- ○ Maria because she explains how the noise causes a problem.
- ○ Celia because she uses data collected from a study.
- ○ Maria because I would also leave if my environment was noisy.

guides learner choices (Bandura, 1989; Gollwitzer & Bargh, 1996; Vallerand, Fortier, & Guay, 1997) or learner persistence (e.g., Eccles & Wigfield, 2002; Harackiewicz, Durik, Barron, Linnenbrink-Garcia, & Taver, 2008). Though both disciplines have examined specific aspects of science learning activation, no research has outlined the full set of dispositions, practices, and knowledge that lead to positive long-term outcomes.

Third, the science learning activation framework recognizes that there is no single pathway to science, so that *the design of science learning interventions must be responsive to a broad range of learners.* The term "science" itself refers to diverse learning content and environments. Science dispositions, practices, and knowledge are developed in diverse contexts that span many learner years and involve many formats—not only textbooks, lectures, and classroom experiments, but also fiction and nonfiction books, afterschool and summer programs, museum and science center visits, television programs, and the internet (NRC, 2009, 2011). The quantity and format of school science instruction varies widely (Banilower et al., 2013), as does access to and participation in OST science learning (NRC, 2009). The youth in any given science learning environment—especially in OST—are likely to come from a great variety of prior science experiences; when they leave, they face a great variety of future experiences. This heterogeneity challenges the notion of a science learning pathway, in which successive learning experiences build on one another.

To understand how these features play out concretely in program design, consider two 11-year-old children, Laura and Greg. Laura told us she had little interest in science. However, as we observed, she got engaged in building an airplane and radio control tower out of thin wooden blocks and in creating a wind turbine. Later, she explained that these activities interested her because she drew on experiences of learning with her father, who was a pilot. The blades on the turbine were exactly like propellers on an airplane. The activities were compelling to her because of her prior experience, so her low level of fascination with science did not keep her from engaging— and learning STEM practices along the way.

By contrast, Greg indicated that he did not find these same activities relevant to his life. But that did not matter;

he was highly engaged and learned a lot because, he explained, he likes science when he gets to use his hands, though he doesn't like reading about science in books. Greg was attracted by the chance to design and build a functional wind turbine. Fully engaged in the activity, he learned how wind can be converted into energy.

OST programs serve youth who, like Laura and Greg, start with varied activation points; understanding what motivates them will enable programs to support their learning. Program designers should consider who their learners are and what learning experiences will serve them. One size doesn't fit all. Young people who are high in fascination may be likely to learn about a particular area of science if that area already interests them. Youth who are high in valuing science may be motivated to engage in an activity if they see its direct applicability to helping people or solving a societal problem. Young people who are high in competency belief are likely to be drawn to areas in which they already feel adept; they may require encouragement or scaffolding to work with others whom they do not perceive to be as competent. Youth who are high in scientific sense-making may be turned off when asked to memorize facts or to do a hands-on activity that does not offer opportunities for scientific thinking.

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Expanding Use of the Framework and Its Tools

Empirical work designed to show when and how learning experiences support the development of science learning activation must ask several important questions. How and when do science learning experiences support an individual child to develop activation? For whom and under what conditions do different combinations of activation dimensions enable which aspects of success? Further study of these questions will enable exploration of:

- Design principles that produce interventions targeted toward developing specific dimensions of science learning activation
- Diagnostic information about where an individual young person begins at the outset of an OST science program
- Measures of the effects of interventions on the four dimensions of science learning activation and the four factors of success

Another potentially transformative role for the science learning activation framework is in program eval-

uation and improvement. The first steps toward widespread use are underway. Activation Lab staff use the activation survey to conduct evaluations of several OST programs that have found the activation framework to be aligned with outcomes they care about. These programs are interested in measuring outcomes in the individual activation and success dimensions, driven by the desire to position their participants for success in future science learning.

Further, Activation Lab researchers have designed and piloted ActApp, a system that facilitates use of the instruments to measure activation and success dimensions. These instruments include both the survey scales described above and the qualitative interview and observation protocols. ActApp offers easy access to these tools to enable program designers and educators, in all kinds of STEM learning settings at all levels, to make continuous program improvements, help young participants succeed, and conduct summative evaluations of program impact. Administered on- or offline, ActApp is well suited for OST providers and evaluators because it can be scored without specialized skills or knowledge and interpreted without statistical expertise. During the pilot process, several organizations used ActApp to survey hundreds of youth in OST STEM programs. The pilot suggests that ActApp can work for researchers and evaluators who seek well-established measurement tools and for program providers who seek psychometrically sound assessments and high-quality evaluation resources (Dorph, Cannady, & Hartry, 2015).

Our goal in developing the science learning activation framework and measures has been to identify a meaningful outcome that can be measured reliably and that might be expected to increase over time in response to strong science learning experiences in and out of school. Our work so far has connected activation with the literature on learning, motivation, interest, and engagement in science; produced empirically grounded, psychometrically tested, and field-ready assessments; and studied the relationship between activation and success. Further studies, both underway and planned, explore how activation changes as the result of short-, middle-, and long-term exposure to science learning experiences.

OST programs are an important venue for developing science learning activation; they offer flexibility and opportunities youth may not encounter elsewhere. Because activation positions youth for success and persistent engagement in science learning, researchers and program providers may want to consider science learning activation as a fitting program outcome.

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