How Science Learning Activation Enables Success for Youth in Science Learning

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Abstract

Expanding on recent advances in science education, cognitive and social psychology, and socio-cultural studies, the paper explores a construct called *science learning activation* and a theoretical framework that describes the characteristics, function, and impact of this construct. Authors define *science learning activation* as a set of dispositions, skills, and knowledge that commonly enable success in proximal science learning experiences and are in turn influenced by these successes. This study investigated the relationship between four dimensions of *science learning activation* (fascination, values, competency beliefs, and scientific sensemaking) and three indicators of success (choice, emotional and cognitive/behavioral engagement, and learning) in temporally proximal science learning experiences. Science learning activation, preferences to choose optional science experiences, engagement ratings, and learning outcomes were collected over multiple time points from diverse group of 681 fifth and sixth grade students from two different regions of the United States. Regression analyses, and hierarchical linear models controlling for demographic characteristics, revealed that: choice preferences were predicted by fascination, values, and sensemaking; engagement levels were predicted by competency believes, fascination, and values; and learning outcomes were predicted by scientific sensemaking. Further, successes themselves predicted further growth in activation: growth in fascination, values, and competency belief themselves were predicted by choice preferences and engagement levels; and growth in sensemaking was predicted by content learning. Thus, *science learning activation* provides a theory (and corresponding set of measurement tools) for proximal outcomes of early science learning interventions that can produce positive long-term outcomes through a reoccurring reinforcement process wherein the effects of an early intervention can lead toward additional positive effects from subsequent interventions. Conversely, poor experiences can lead to negative attitudes that hinder the next learning experience and eventually away from seeking future science learning opportunities. These findings have implications for theory, practice, and research.

Key words: science learning, engagement, choice preferences, motivation, activation

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Introduction

The label "science" is used to refer to a diverse collection of learning content and learning environments. At the same time, science knowledge, science skills, and dispositions towards science are developed in diverse contexts that span many learner years and involve many formats. Such formats include: textbooks, classroom lectures, various forms of classroom guided experimentation, but also fiction and non-fiction books, afterschool programs, summer camps, observation in the backyard, museum and science center visits, TV programs, friends and family, and the Internet (National Research Council, 2006 ,2007, 2009, 2011). Similarly, there is wide diversity in quantity and format of science instruction in schools within some countries due to lack of a national curriculum, placement of students into different academic tracks, or variation in pedagogical approaches at the teacher or school level (Banilower et al., 2013; Dorph, Shields, Tiffany-Morales, Hartry, & McCaffrey, 2011; Fortus & Vedder-Weiss, 2014; Hanushek, & Wöessman, 2006; Hartry, Dorph, Shields, Tiffany-Morales, & Romero, 2012). There is also wide diversity in access to and participation in out-of-school science learning, often as a result of parental income (National Research Council, 2009; Tucker-Drob, Cheung, & Briley, 2014). As a result, children entering a new science learning environment can differ greatly in prior experiences. Similarly, children exiting any given science learning environment can also differ greatly in what kinds of science learning experiences (especially out-of-school experiences) they will be offered next. This heterogeneity in incoming and outgoing experiences creates challenges in designing effective science learning opportunities.

The learning environment heterogeneity together with some long-term stability in effects of early science experiences is a major challenge to educational theory and practice. Can we develop theories that capture the interactive nature of learning experiences and yet also explain longer-term effects (i.e., cases in which an early exposure produced a life-long attachment to science) (Maltese & Tai, 2010)? Since pervasive forgetting and large environment heterogeneity across years generally undercuts long-term effects (Anderson, 1990; Engle, 2006), other factors must be strongly in play to produce long-term effects. From a practical perspective, can intermediate experiences be engineered such that positive longer-term outcomes are more likely despite the heterogeneous learning environments? Similarly, can particularly negative early experiences that begin a negative downward spiral be avoided or mitigated?

If learning were a simple accretion of knowledge, learner and environmental heterogeneity would not be especially problematic because it could be addressed by providing multiple opportunities to learn key content; each learner would eventually get all he or she needs to get. But learning science is about more than just accumulation of knowledge; it also involves the development of skills and attitudes (National Research Center, 2011; Osborne, Simon, & Collins, 2003). The development of skills and attitudes are not simple accretions—there are many ways in which individual dispositions and prior experiences shape this development. For example, prior experiences shape attitudes towards science, and these attitudes influence how learning unfolds (Efklides, 2011; Hidi & Ainley, 2008). Similarly, prior experiences build skills and knowledge, and these skills and knowledge shape what is noticed (Eberbach & Crowley, 2009), how it is evaluated and understood (Clement, 1993; Falk & Adelman, 2003; Smith, diSessa, & Roschelle, 1993), and what is later remembered (Bransford & Johnson, 1972). Further, participation in many science learning experiences are optional, especially in older learners (e.g., book reading, afterschool club participation, extra or advanced science classes), meaning that good early experiences can increase the number of later learning opportunities and poor early experiences can decrease the number of later learning opportunities.

To further complicate matters, although knowledge, practices, and attitudes can support each other, they do not necessarily grow together. For example, some interventions that build skills in science may reduce positive affect or motivations toward science learning, as suggested in the *Program for International Student Assessment* data within countries (Areepattamannil, Freeman, & Klinger, 2011) and in the *Trends in International Mathematics and Science Study* data between countries (Shen & Tam, 2008). Further, some interventions that build positive affect or motivations toward science might occupy time that otherwise would have been used to build science skills. Thus, there are complexities related to how earlier experiences shape choices to participate or not in optional learning experiences, and how they shape the engagement and learning during science learning experiences.

Interestingly, there are also individual differences in relationships toward science that show some stability over long periods of time. Positive early informal science learning experiences, as well as very positive (or very negative) school science learning experiences have been associated with long-term participation (or disengagement) with science (Fortus & Vedder-Weiss, 2014; Maltese & Tai, 2010; Vygotsky, 1978). Further, expectation to work in science or engineering careers by eighth grade does significantly predict whether students enroll in and complete STEM degrees in university (Tai, Liu, Maltese, & Fan, 2006). However it is important to note that many students who do not indicate such early interest complete such degrees as well (Cannady, Greenwald, & Harris, 2014).

This paper responds to the conundrum by building a theory that explains both short- and long- term effects in science learning. Expanding on recent advances in science education, cognitive and social psychology, and socio-cultural studies, we propose a construct called *science learning activation* and a theoretical framework (the *activation framework*) that describes the characteristics, function, and impact of this construct. We define *science learning activation* as a set of dispositions, skills, and knowledge that commonly enable success in proximal science learning experiences and are in turn influenced by these successes (i.e., they form short-term positive feedback loops to produce long-term outcomes). We refer to the elements of this set of dispositions, skills, and knowledge as *dimensions* of activation.

Through broad literature reviews, conceptual analyses of the diverse nature of science learning environments, and multiple rounds of prior pilot empirical work, we have identified four particular dimensions that likely meet this definition: (1) fascination with natural and physical phenomena, (2) valuing science for self and society, (3) competency beliefs in science, and (4) scientific sensemaking. Having high levels on these *science learning activation* dimensions should enable an individual to generally experience success in proximal science learning opportunities. Just as importantly, in order to lead to long-term outcomes, those successes, in turn, should support the individual to develop higher levels of these dimensions—this loop of activation to successes to activation change is the activation framework. In order to test the activation framework, we have developed measures of each dimension, and then empirically investigated whether the hypothesized dimensions of activation indeed both predict successes and further increase as the result of successes.

Background

How Does the Science Learning Activation Theory Explain Long-term Effects in Science Learning Outcomes?

One general way in which early experiences could possibly influence later experiences across widely heterogeneous possible paths is through a reoccurring reinforcement process based on transferable dispositions, skills, and knowledge. This basic insight leads to the following model that describes the mechanism by which activation leads to long-term outcomes. In particular, we posit that activation produces a reoccurring reinforcement process through four specific effects: higher levels on *activation* dimensions are thought to (1) enable choosing to participate in optional science learning opportunities; (2) produce positive and persistent cognitive, behavioral, and affective engagement in science learning settings; (3) collectively produce greater learning from these additional science learning opportunities and increased engagement effects; and (4) the increased engagement and learning produces increases in the *activation* dimensions. Thus, there is a reoccurring reinforcement process wherein the effects of an early intervention can lead toward additional positive effects from subsequent interventions. Conversely, poor experiences can lead to declines in dispositions or produce relatively weak skills that hinder the next learning experience and eventually away from seeking future science learning opportunities.

Our conceptualization of *science learning activation* builds on this model by focusing on what an individual consistently carries from one experience to the next (dispositions, skills, and knowledge) as opposed to what is less consistently carried from one experience to the next (e.g., particular physical resources, personal relationships). *Dispositions* refer to attitudes and beliefs about the self vis-à-vis various aspects of learning science content and engaging in science practices. *Skills* refer to strategies and abilities that an individual draws upon as resources to solve science-related problems and scenarios in productive ways. *Knowledge* refers to the (explicit, declarative) understanding of science phenomena, concepts, theories, processes, and social resources that are used together with scientific practices to engage in scientific sensemaking and solve science-related problems and scenarios in productive ways. Further, this conceptualization focuses on *proximal science learning experiences,* that is, the most temporally proximate learning experience an individual has (e.g., their next science class, next visit to a science center, next time they do a science activity at home, next time they participate in an afterschool science club) as opposed to current experience or long distance experiences, because the proximal experiences are the path from the current experience to the long-term outcome.

How Does the Activation Framework Relate to Prior Literatures?

Three critical features of science activation are worthy of note in relation to prior literatures. The first of these features is the specification of dispositions, skills, and knowledge *in relation to science*. By specifying the character in relation to science generally, this work pushes past generalized psychological, sociological, and cognitive science theories related to motivation, dispositions, or cognition as those apply to learning in any content area towards a more specific understanding of the particularities as applied to science learning. This specification is critical to producing the malleable yet long-term predictive effect we hypothesize. Overall dispositions across all domains are likely fixed (e.g., Need For Cognition, (Cacioppo & Petty, 1982), Grit (Duckworth, Peterson, Matthews, & Kelly, 2007)), essentially a form of personality or temperament, and thus not a sensible target of intervention. Dispositions, skills, and knowledge in a particular class, afterschool club, or summer camp (as commonly conceptualized and measured in motivational research) are likely too malleable or effectively irrelevant to later learning contexts and contents in science. However, the relationship of the self to science and broader skills and knowledge of science is what is carried over time and learning contexts, and is also likely to be malleable.

The second of these features also plays a significant role. The theory and study described herein are based upon an atypical *joining of the cognitive and motivation/affect traditions* of research in psychology and educational research to identify and build for such uncommon critical experiences. The cognitive traditions have come to understand what is required to build difficult skills and knowledge (Anderson, 2009) but have largely ignored what builds identity or career interest (Bybee & McCrae, 2011). The motivational/affect traditions have come to understand what guides small-and large scale actions (Bandura, 1989; Gollwitzer & Bargh, 1996; Vallerand, Fortier, & Guay, 1997) and learning (e.g., Expectancy Value Theory (Eccles & Wigfield, 2002); Achievement Goal Theory (Harackiewicz, Durik, Barron, Linnenbrink-Garcia, & Tauer, 2008)), but have theories of content learning rooted in theorizing of the 1960s (studying makes perfect), 1970s (depth of learning), or 1990s (metacognition) that ignore disciplinary-specific elements of thinking and learning. More recent cognitive research has found that improving learning in science, in particular, has required more detailed understandings of what science thinking involves (i.e., a particular kind of sensemaking (Ford, 2008a, 2008b; Harackiewicz et al., 2008; Hutchison & Hammer, 2010; McNamara, 2004). While many of these theories have examined specific aspects of the *science learning activation* construct (and are briefly summarized in the sections below), no research has examined the full set of dispositions, skills, and knowledge that we investigate concurrently in the study described herein.

The third of these features is that these dispositions, skills, and knowledge *are malleable*. That is, unlike personality traits (which are understood to be stable), these constructs can be shaped by and changed through experience. Because they are malleable, they provide an explanation of how early experiences (e.g., before middle school) can initiate a process of ever-increasing participation in science, or ever-decreasing participation in science. In this case, the construct of malleable factors involves finding a balance between unproductive extremes. On the one hand, factors that predict important long-term outcomes must have some stability over time, or else there could be no long-term prediction. On the other hand, factors that are stable over time will tend, by definition, to resist most typically occurring interventions. For example, parental education level and personality are stable and predictive but not useful targets of intervention. By contrast, engagement in a task is a simple target of intervention, but will then also change (up or down) again easily in the next experience. To produce a functional resolution to this predictive-stability contradiction, we need a positive-reinforcing, semi-stable factor. By semi-stable, we mean that it should tend to remain at similar levels in the absence of experience, but extended focal experiences can change it. Because these characteristics can be carried across time and context, they can provide an explanation of individual differences in choices, engagement, and learning.

What are the Proposed Dimensions of Activation?

Specifically, which dispositions, skills, and knowledge will collectively have this bidirectional relationship to choice, engagement, and learning? Those under investigation in this study build on large prior literatures, which can only be briefly reviewed in this paper for space reasons. Each also involves novel conceptualizations of what is most important for science learning (rather than generically about academics) at the late elementary/early middle school critical time period (rather than generically about all ages). The four dimensions of science learning activation investigated within this study are:

1. *Fascination* in natural and physical phenomenon (emotional and cognitive attachment/obsession with science topics and tasks);
2. *Values* science (understands various interactions of self with science knowledge and skills and places value on those interactions within their social context);
3. C*ompetency beliefs* about self in science (perceives one's self as capable of successfully engaging in science activities and practices); and
4. S*cientific sensemaking* (engages with science-related content as a sensemaking activity using methods generally aligned with the practices of science).

Dimension 1: The activated science learner is *fascinated* by natural and physical phenomenon. A learner can have emotional and cognitive attachment/obsession with science topics and tasks that serve as an intrinsic motivator towards various forms of participation. This dimension includes aspects of what many researchers have referred to as curiosity (Gardner, 1987; Hartry & Beally, 1984; Litman & Spielberger, 2003; Loewenstein, 1994), interest or intrinsic value in science both in and out of school (Baram-Tsabari & Yarden, 2005; Dawson, 2001; Girod, 2001; Hidi & Renninger, 2006; Hulleman & Harackiewicz, 2009; Kind, Jones, & Barmby, 2007; Osborne et al., 2003; Reid, 2006), and mastery goals for science content (Ames, 1992). It also includes positive approach emotions related to science, scientific inquiry, and knowledge. Past research has found each of these constructs to be associated with choice towards, engagement during, and attainment in science learning (Hidi & Ainley, 2008; Hidi & Renninger, 2006). Conceptually, it is likely that these constructs strongly co-occur within individuals (e.g., those interested in science have mastery goals for science) and psychometrically we find these all cohere into a single factor. Therefore, as a whole, fascination should be an important driver towards these aspects of success.

Dimension 2: The activated science learner *values* science. "Values science" refers to the degree to which learners place importance on science including the knowledge learned in science, the ways of reasoning used in science, and the role that science plays in families and communities. In a young person, valuing science may express itself as both everyday value and career value. A learner can understand various interactions of self with science knowledge and skills and places value on those interactions within her or his social context (DeBacker & Nelson, 2000; Eccles & Wigfield, 2002; Osborne et al., 2003; Pintrich, 2003). This dimension draws upon expectancy value theory (Eccles & Wigfield, 2002; Wigfield & Eccles, 1992) and identity development theory (Tan & Barton, 2007) to consider the ways in which learners who value science will value: (1) the knowledge learned in science, (2) the ways of reasoning used in science, and (3) the role science plays in their own families and community contexts (Brickhouse, Lowery & Schultz, 2000; Costa, 1995; Dogan & Abd-El-Khalick, 2008; Hill & Tyson, 2009). Learners who value science are expected to be more likely to identify it as a possible career as they believe it is worthwhile and a valuable pursuit. Those who value science and the role it plays both in their own lives and in society are more likely to engage in learning science in and out of school whether or not they find it fascinating (Eccles, 2005; Lyons, 2006). Hence, like fascination, valuing science is also an important motivator towards success in science learning.

Dimension 3: The activated science learner has high *competency beliefs* about self in science. Competency beliefs in science refers to the extent to which a person believes that s/he is good at science functions and science tasks in science settings. Competency beliefs are a core construct in social cognitive theory, 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). In general, educational and psychological research has revealed that competency beliefs (or self-efficacy beliefs) are an important predictor of many types of achievement behavior (i.e., choice of task, engagement, effort, and persistence; (Pintrich, 1999, 2002; Schunk, Meece, & Pintrich, 2012). Educational and psychological research makes a clear distinction between people's actual competence and knowledge, and their subjective judgment and perceptions of them. Further, this body of research distinguishes between the role of actual and perceived competence in predicting their achievement tests and achievement behaviors. For example, research has found that college students' reasoning ability plays a more significant role than self-efficacy in predicting their achievement in science learning (Lau & Roeser, 2002; Lawson, Banks, & Logvin, 2007). By contrast, learners with high self-efficacy beliefs are more likely to be behaviorally and cognitively engaged in a learning process in the forms of choice, effort, persistence, and so on (Linnebrink & Pintrich, 2003). Durik, Vida, and Eccles (2006) found that individuals' subject-specific competency belief (e.g., reading) predicted their career aspiration (i.e., future choices). Thus, competency beliefs are relevant to both near-term and long-term choices.

Dimension 4: The activated science learner engages in *scientific sensemaking*. Scientific sensemaking refers to the degree to which the individual engages with science learning as a way to make science content clear to him or her, through an activity using methods generally aligned with the practices of science. The hypothesized behaviors associated with such practices around pre- and early-adolescent age levels include asking investigable questions, seeking mechanistic explanations for natural and physical phenomenon, engaging in evidence-based argumentation about scientific ideas, interpreting common data representations, designing relevant investigations, and understanding the changing nature of science (Apedoe & Ford, 2010; Lehrer, Schauble, & Petrosino, 2001). Although this list of behaviors is commonly labeled as scientific reasoning skills, we believe the label "sensemaking" is important and stands in contrast to simple rule following. The literature suggests that engagement in scientific sensemaking (both the ability to do so and the practice of doing so) will better position a child to engage in science learning (Lorch et al., 2010; Songer, Kelcey, & Gotwals, 2009; Zimmerman, 2007). More specifically, engaging with science-related content as a sensemaking activity propels engagement in science learning, the interest in choosing to spend time on further related activity, and the likelihood that learners will actually learn what is expected/desired of them in a deep way that is more likely to address scientific misconceptions (Chi, De Leeuw, Chiu, & LaVancher, 1994).

How is Success in Proximal Science Learning Defined?

In the *activation* framework, "success" refers to three elements: (1) choosing to participate in science learning opportunities; (2) experiencing positive engagement (affective, behavioral, and cognitive) during science learning experiences; and (3) meeting science content learning goals during these experiences.

We conceptualize *choice* to participate in science learning opportunities in a broad fashion to best reflect the heterogeneous experiences of young learners: choosing to participate in the next opportunity for science learning (e.g. a camp, a visit to a museum, or watching a science museum on TV). We take into account both extended instructional experiences (e.g., optional classes, organized summer camps or Saturday enrichment programs that follow an instructional curriculum) and the wide variety of smaller and less organized informal science learning opportunities (e.g., a museum visit, watching a documentary, reading a non-fiction book or a science fiction book with considerable embedded content, visiting a scientist's blog (Simpkins, Davis-Kean, & Eccles, 2006)). Although each informal science learning experience might be relatively brief, a learner that consistently participates in such experiences might collectively have more learning hours from these informal experiences than from a full year class (Bevan et al., 2010; National Research Council, 2009). Further, we conceptualize that the learner demonstrates choice preferences as a tendency to elect to participate in whichever optional science learning experiences are available in their environment (Sha, Schunn, & Bathgate, 2015). Such preferences, combined with availability and adult support, lead to actual choices (e.g., taking additional science classes, attending summer science camps, watching science-related TV shows, reading science fiction, attending science museums). In this study, we only measure choice preferences because we have found it easier to measure choice preferences consistently and reliably than to capture and interpret the wide variety of small scale "actual" choices a learner might make that are also highly variable in accessibility to different learners (Sha et al., 2015). Measuring what choices learners actually make (Fortus & Vedder-Weiss, 2014) could be heavily biased by the particular options made available to a learner (i.e., be a measures of their socio-economic status, rather than their choice tendencies).

Engagement as a construct is used in many very different ways in the literature, ranging from dispositional to situational. We conceptualize engagement as the situational to avoid circularity in theorizing (i.e., dispositions producing dispositions). We define engagement as one's focus, participation, and persistence within a task, and therefore related to adaptive or self-regulated learning (Carini, Kuh, & Klein, 2006; Finn, Pannozzo, & Voelkl, 1995; Fredericks, Blumenfeld, & Paris, 2004; Fredericks et al., 2011). In other words, activation dimensions are what learners bring into a particular task/setting and takes out of those specific task/setting experiences; engagement is what happens during the task, a result of the interaction between the learner's activation dimensions and the characteristics of both the task itself and the supporting environment.

In terms of the important contents of engagement, we include three dimensions of engagement: (1) behavioral engagement focuses on what a student involved in a learning activity would look like or be doing (e.g., actively participating in the science learning tasks or doing off-task behaviors); (2) cognitive engagement focuses on thought processes or attention directed at processing and understanding the science content in a learning task; and (3) affective engagement is conceptualized as those emotions that occur during and support or hinder a science learning activity. Research suggests that a combination of these three aspects of engagement supports students to learn (Fredericks et al., 2004). Thus, we focus on the aggregated engagement across the three engagement dimensions, although it is possible to focus on each dimension of engagement in isolation.

Science learning goals are highly contextual; the desired learning outcomes are particular to the curriculum, lesson, and teacher. Therefore, we define science *content learning* as the desired learning goals of the designed science learning environment. In this sense, activation dimensions work with the learning environment, like a catalyst in a chemical reaction, to enhance the relationship between the learner and the environment and thereby increase (or decrease in low activation cases) the content learning that results from the particular learning environment.

We hypothesize that the same factors that enable these three successes (choice, engagement, and content learning) will also themselves increase as a result of these successes, thus producing the desired positive-reinforcing situation. (Similarly, low levels on the activation dimensions would decrease success, which would further reduce levels on the activation dimensions.) We also hypothesize that a theory that includes only factors that enable a subset of these successes will not suffice (e.g., choice to participate with negative engagement will not produce good outcomes, and positive engagement without learning will also not produce the outcomes sought). Accordingly, this study tests the hypothesis that the proposed four dimensions of science learning activation will enable the three types of success in proximal science learning experiences, and that those three types of successes will, in turn, produce higher levels of these dimensions. To make the hierarchical linear models tractable, we treat the three success variables as independent outcomes, although they are likely mutually reinforcing (e.g., choice preferences and engagement contribute to learning). However, similar results are found using path analyses that take into account cross-success variable connections.

There are two different ways in which the activation theory could be falsified: 1) the three successes are not predicted by prior activation levels; or 2) changes in the dimensions of activation are not predicted by three successes (i.e., there is not a reciprocal relationship between activation and successes in proximal science learning experiences). Thus, in order to test the activation theory, we designed a study with two sub-studies, each set in a unique context to investigate the two main research questions listed below.

1. Are there relationships between input levels of each of the four dimensions of activation and choice to participate in science, engagement in science learning activities, and science content learning (i.e., are these four dimensions sufficient to predict large amounts of variance in each success variable)?
2. Do higher levels of choice, engagement, and content learning within specific science learning experiences coincide with increased levels of each of the dimensions of activation (i.e., do these four dimensions have reciprocal relationships with success)?

By looking at this new combination of constructs together in regression analyses, we can also provide new tests of the direct relationships between each construct and successful variable, as opposed to indirect/mediated relationships. For example, interest has been associated with learning outcomes in school (Chambers & Andre, 1997) and museum visits (Falk & Adelman, 2003), but it may be that this effect is mediated through differences in scientific sensemaking (i.e., interest *per se* might have no learning benefits). Teasing apart direct from indirect effects deepens understanding of the mechanisms of effects and better supports the design of more effective interventions.

The study involves two different science learning contexts (a science classroom and a science and technology center visit), and multiple instances of each (i.e., different classroom situations and different exhibits) to establish the productive nature of activation across heterogeneous learning environments, the very challenge that prompted this line of inquiry. It is rare for research to examine both contexts together, but children will likely need to be productive learners in both kinds of contexts. Hence, we looked for the same relationships among *science learning activation* dimensions and measures of success within both contexts. However, the nature of the context necessitates differences in the research design. A curriculum is extended over time and is expected to produce significant content learning, whereas a visit to an exhibit is quite brief and is not expected to produce large changes in content knowledge. Thus, we measure engagement across multiple time points in the curriculum, but only once per exhibit, and we only measure content learning for the curriculum case. Further note that we are not seeking to compare outcomes across contexts, but rather simply trying to establish the sufficiency of the activation account for predicting meaningful outcomes across contexts.

Materials and Methods

Participants

Sub-study 1: School. Participants were enrolled in one of thirty-eight sixth grade science classes from ten urban public schools in a mid-size city in the American Midwest. The sample represented a broad range of school types found in urban centers: mixed affluence schools and lower affluence schools, mixed-ethnicity schools and homogeneous minority schools, traditional middle-schools (only grades 6–8) and K-8 or 6-12 schools, general topic schools, and special focus schools. Students were primarily Caucasian (37%) and African American (35%), and 53% came from families in which at least one parent had a college education. A total of 592 consented students completed the measure of activation; of these, 461 (78%) completed each of the outcome measures (choice preferences, engagement, and learning). Incentives included the opportunity to win $200 (one winner per class), and a self-chosen small gift.

Sub-study 2: Science Center. Participants were enrolled in one of eleven fifth grade classrooms, or member of a boys and girls club, in one of several middle-class suburban cities in the greater San Francisco Bay area. The sample participants were primarily Caucasian (26%), Latino (40%) or African American (9%) and 46% came from families in which at least one parent had a college education. A total of 234 consented students completed the measure of activation; of these, 220 (94%) completed measures of choice preferences and engagement in a science-learning context. A self-chosen gift was provided as an incentive.

Procedures

Sub-study 1: School. During the first week of the school year, an assessment of content knowledge pertaining to the first unit of instruction was administered along with the measure of activation. On a separate day, demographic information was obtained including age, race, gender, and family background. On six separate occasions during the semester, students reported their level of engagement in the day’s science lesson. Particular activities in the curriculum were targeted, such that there was a range of activity type (to increase generality) and every student was sampled on the same set of activities (to remove confounds between student characteristics and activity characteristics as the source of engagement differences). At the end of the semester, content knowledge was assessed again to measure gains in student content knowledge from the beginning of the semester. At the same time, students' choice preferences to participate in science learning opportunities were also measured.

All students in *Sub-study 1* experienced a common curriculum over this time period: a slightly adapted version of an earth sciences unit (on the topics of weather and climate) from the widely used Full Option Science System (FOSS) Science curriculum. For the purposes of this study, a critical adaption was a detailed script for teacher implementation (i.e., which activities to include or script) that produced greater uniformity across teachers than is typically observed for any given curriculum (see adaptation description at http://cogscied.org). Classroom observations and self-report surveys by the teachers suggest that the key elements of the curriculum were implemented across teachers as specified, with only some variation in the rate at which the materials were covered. Researchers coordinated with teachers to make sure engagement surveys were distributed on the exact days of the selected activities.

Sub-study 2: Science Center. During the fall semester of the school year, students visited a local science center on a field trip from their school or afterschool program. While on the field trip, students visited two exhibitions and completed a self-report engagement survey after each exhibition. Prior to coming to the science center, students completed the activation survey and reported their demographic information (e.g. age, gender, race and family background). After visiting the science center, students again completed the activation survey and reported their science choice preferences on a survey. The duration from the first to final survey was approximately one month; this short duration is unlikely to involve large changes in activation, but there may be significant shifts nonetheless during this transitional time in science learning because of a recent onset of relatively more time on science in classrooms and greater ability to independently explore science content.

Ethics statement. Data collection protocols and procedures for this study were approved by the Institutional Review Boards at both institutions involved in this research study. More specifically, The University of Pittsburgh's Institutional Review Board approved the research as #PRO11080012 and The University of California, Berkeley's Committee for the Protection of Human Subjects (CPHS) approved the research as #2011-06-3288. Only data from those individuals who submitted appropriate and IRB-approved assent, consent, and permission documentation were utilized in the study described herein. In particular, we obtained written informed consent from the next of kin, caretakers, or guardians on behalf of the minors/children enrolled in this study. None of the individuals working on the study had a related conflict of interest.

Measures

Science Learning Activation

Given that *science learning activation* is a new construct, there were no existing instruments that measured it as conceived. Accordingly, this study utilized a new assessment of *science learning activation*. While we did generally adapt strategies and item types found in prior assessments of related subconstructs, there were three reasons that existing assessments were inadequate. First, many instruments offer a superficial treatment of science, that is, they modify existing instruments developed in other fields and swap in the word science for the content domain (Simpkins et al., 2006). While this practice is appropriate for some purposes, we found that students often associate this type of use as pertaining to science class, rather than their experiences of doing science in or out of class. Instead, instruments making specific references to aspects or practices of science that exist both in or out of school intentionally draw the distinction between the domain of science and science class.

Second, few instruments are appropriate for 11-13 year olds. Several existing instruments include abstract words like "goal" or "endeavor" that are difficult for youth that age to put in context. Further, 11-13 year olds have different adult supports and activity structures than older students, who have greater autonomy in their decision-making. Thus the contexts of assessments need to be different. For example, middle schoolers do not select optional coursework, whereas they may have control over what to do after work is completed.

Third, we needed a different approach to assessing sensemaking relative to prior scientific reasoning measures. Assessments that make no use of scientific content at all do not measure the extent to which students use skills about actual content; students often rely heavily on prior beliefs, ignoring reasoning skills, when confronted with rich content. Yet, when embedding science reasoning tasks within science content there is a tension between selecting a particular science domain and sampling across a range of domains. Instruments that worked across content were too long to be feasibly administered, and those within a particular content area were often too specific to work across settings (i.e., depended upon students having been exposed to particular content knowledge).

We constructed a new instrument to measure the activation dimensions in a way that addresses each of these concerns. In this paper, we describe the measurement development process as a part of our overall evidentiary argument for valid uses of this instrument. This process included defining the constructs, vetting of cognitive processes used by subjects to respond to the items, analyzing the psychometric characteristics of the instrument, and examining the relationships among the *activation* dimensions and between each dimension and each measure of success. Taken together, the results of these efforts support our validity argument for the use of this instrument for the inferences made in this study. Ongoing work is aimed at continuously improving the assessment, as well as the larger theory that drives it. The measure reported here was sufficiently reliable to support the current study, but it is worth noting that improved assessments, based on this study, can be found at http://activationlab.org.

Construct definition. We first defined each dimension by delineating the ways in which individuals who are high, medium, or low within the dimension would differ from one another. We used findings from prior research as well as our own observation and interview data to support the development of these "construct maps." We then created items by borrowing and modifying items from a wide variety of prior survey instruments, but adapting them based on the concerns above and fit them to the construct maps.

Cognitive labs. Subsequently, items were pilot tested and iteratively improved using cognitive labs with children both generally connected and disconnected with science, asking them to explain each question and their choices in their own words to make sure the new items were generally interpreted and elicited ways of thinking as intended.

Psychometric characteristics. Looking into the psychometric characteristics of the instruments, Factor Analyses and Multidimensional Item Response Theory (MIRT) analyses were conducted on the larger study dataset to insure reliability, coherence, and separation of the measures of each dimension. Analyses reported below involve the resulting selected set of items that emerged from these psychometric analyses. Complete scales can be found in Appendix A. The fascination scale had 8 items involving general and context-specific cognitive and affective reactions to science content (α=0.89). The values science scale had 4 items reflecting a range of reasons students could value science content in their current and future lives (α= 0.70). The competency beliefs scale has 9 items that map onto each of the components of sensemaking (α=.90). The scientific sensemaking scale had 12 items (α=0.75). Constructed responses were scored and inter-rater reliabilities (Cohen's Kappa=.87) for each of these coding tasks indicate substantial rater agreement (Moore, Bathgate, Chung, & Cannady, (2013). Two parameter IRT models were used to calculate ability estimates (i.e., theta estimates) for each of these constructs.

Analyzing relationships. If the relationships predicted by the activation theory are found, then the study both supports the theory of activation and offers strong evidence that the instruments have predictive utility across contexts. In other words, the predictive utility of each instrument, described in the results section of this paper, offers strong validity evidence for the use of these instruments to measure these constructs.

The *Science Learning Activation Assessment* utilized for this study was administered individually to students and took less than 45 minutes to complete (via paper, computer, or iPad). The most time-intensive aspects are the sensemaking items because they require extended reading, student reasoning, and constructed responses.

Science Content Knowledge (Sub-study 1 Only)

Learning of content knowledge was assessed using a *science content knowledge test* administered as pre-test and post-test. Many students have some prior knowledge about weather and climate, and this prior knowledge is likely to be correlated with students' dispositions toward science in general. Therefore, if we want to assess the amount of "learning" that occurred during the study duration, it is critical to look at growth in knowledge, rather than just final knowledge levels (as is more typically done).

This test was built from released TIMSS, NAEP, and state science test items that matched the overall content of the FOSS Weather and Water unit. Only those items that matched the parts of the unit covered by all teachers were included in the final analysis (21 items; α=.78). Two example items include: (1) "What is the primary energy source that drives all weather events, including precipitation, hurricanes, and tornadoes? a) The Sun b) The Moon c) Earth's gravity d) Earth's rotation" and (2) "Locations in the Southern Hemisphere typically experience ____________. a) Longer days in June than January b) Equal amounts of daylight and darkness c) Longer days in January than June." Because post–pre change scores suffer from regression-to-the-mean phenomena that are especially problematic in regression analyses, instead we used post-test scores as the dependent variable with pre-test as a covariate in the regression.

Choice Preference

Student's general preference to chose to participate in diverse science learning opportunities when given options was measured using the *Choice Preference Survey* (Sha et al., 2015). We avoid measuring actual choices made because children vary greatly in their access to particular choices (e.g., distance to a particular museum, existence of a program at a local summer camp or afterschool setting, access to particular book types, free access to science websites), even though all children have access to at least some science learning opportunities. Five items were used to compute the choice preference variable (α=.82), with each item presenting choices between science and non-science options of a given type. The items included both immediate and future choices regarding experiences involving science and those involving other topics (e.g., math, history, art) both in and out of school. Two future-oriented items ask about making a choice of classes (i.e., next year) or being a scientist in the future. The remaining three items invite respondents to make a more immediate choice of an activity either in school (e.g., science experiment) or out of school (e.g., science museum visit, doing science at home).

Engagement in Science Learning Activity

The self-report *Engagement Survey* asks subjects about their level of affective, behavioral, and cognitive engagement in a particular science learning experience or lesson. The survey (see Appendix B) consists of 17 Likert items measuring students' affective-behavioral-cognitive engagement in a recently performed task (α=.87). A four-point Likert scale (YES!-yes-no-NO!) was used and all reversed coded items were recoded prior to analyses. Sample items include: During today's activity: "I felt happy or excited" (affective engagement), "I worked hard during the activity" (behavioral engagement), "I tried out my ideas to see what would happen" (cognitive engagement). It takes subjects about five minutes to complete, and it was completed immediately at the end of a lesson (Sub-study 1) or immediately after leaving an exhibit (Sub-study 2). Factor analyses were used to investigate the instrument structure and consistently found a best fit across data collections from a bi-factor model which produces an overall engagement score and separate affective engagement and behavioral-cognitive engagement sub-scores. For simplicity, here we use the overall engagement score in the analyses, although similar conclusions about the activation theory can be drawn when the sub-scores are used in analyses.

Data Analysis

To determine if there is a relationship between input levels of each of the four dimensions of activation and each of the success variables (choice to participate in science, engagement in science learning activities, and learning), we computed a series of multiple regressions. Using each success variable as a dependent variable, we used initial scores from each dimension of activation in a regression to determine which of the dimensions were statistically related to each outcome. To test the robustness of our models, we also conducted parallel analyses using hierarchical linear modeling (HLM; (Raudenbush & Bryk, 2002)), with students nested in their classrooms, with demographic covariates for gender, ethnicity, and parental education (whether any parent/guardian completed a 4-year college degree), and for prior achievement in mathematics and reading as measured by the Pennsylvania System of School Assessment (PSSA).

Next, analyses examined whether higher levels of the success variables (choice, engagement, and learning) within specific science learning experiences coincided with increased levels of each of the dimensions of activation. To do this, post-activation dimension scores were used as dependent variables, pre-activation dimension scores were entered as independent variables, and a regression was employed to determine if any of the success variables predicted the final scores in each dimension. This approach allows for investigating the relationship between the end of study activation dimension levels and the success variables while accounting for participants initial level of activation. Again, to test the robustness of our models, we conducted parallel analyses using HLM with covariates for gender, ethnicity, parental education, and prior achievement in mathematics and reading (using PSSA).

Results

Our presentation of the results begins with the presentation of means, standard deviations, and correlations for the variables in our multi-level regression in Table 1. For analyses, we centered the measures of the dimensions and success variables at their grand mean to reduce the covariance between the intercepts and the slopes, thereby reducing the potential for problems with mulitcollinearity in the model (Kreft, De Leeuw, & Aiken, 1995). We chose to center the variables at the student level using z-scores to also allow the regression coefficients to be standardized, allowing for interpretation of their relative strength. Each dimension of activation measured at pre-intervention is correlated with the measure of the same dimension at post-intervention; no correlations across constructs are so high as to cause collinearity problems for the multiple regression.

Table 1: Means, standard deviations, and zero-order correlations for variables in the study

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Mean	0	0	0	0	0	0	0	0	0	0	0	1450.	1334.	0.49	0.27	0.15	0.54
SD	1	1	1	1	1	1	1	1	1	1	1	221.4	196.5	0.5	0.44	0.35	0.5
N	932	935	935	937	838	881	643	932	935	935	937	512	501	829	800	800	625
1. CB Pre	–																
2. F Pre	.594**	–															
3. V Pre	.548**		–														
4. SSM Pre	.059	.049	.017	–													
5. Eng	.391**			.051	–												
6. Choice	.275**		.391*			–											
7. L	.137**		.079*		.111*		–										
8. CB Post	.687**							–									
9. F Post	.557**			.076*					–								
10. V Post	.529**			.023			.089*			–							
11. SSM Post	.068*	.061	.041		.064				.095*	.052	–						
12. Math	.053	.026	-.023		.094*	.113*		.103*	.034	-.021	.537**	–					
13. Reading	.049	.012	-.072		.085	.063		.118*	.005	-.071	.592**.		–				
14. Female	.005	-0.04	-.022		.030	-.092*	-.032	-.012	-.062*	-.026	.166**	-.016	.088	–			
15. AA.	.057	-.070*	.014	-	.004	-.093*	-	.051	-.032	.018	-	-	-	.059	–		
16. H/L	.038		.113*	-.115*	-.018	.094*	-.007	-.013	.115*		-	.014	-.037	-.02	-	–	
17. Coll	.074	.044	.005	.095*	.009	.010	.054	.042	.012	.011	. 100*	.084	.051	-.02	.073	-.065	–

CB=Competency Beliefs, F=Fascination, V=Values, SSM=Scientific Sensemaking, Eng=Engagement, Choice = Choice Preferences, L= Science Content Learning, Math=PSSA Math Gr 5, Reading = PSSA Reading Grade 5, AA=African American, H/L=Hispanic/Latino, Coll=Guardian College Graduate.
(* $p < 0.05$, *** $p < 0.001$)

Predicting Success (RQ 1)

We now describe the results related to the first research question: Are there relationships between input levels of each of the four dimensions of activation and choice to participate in science, engagement in science learning activities, and learning (i.e., are these four dimensions sufficient to predict large amounts of variance in each success variable)? Using each success variable as a dependent variable, analysis utilized initial scores from each dimension of activation in a stepwise regression to determine which of the dimensions were statistically related to each outcome. Table 2 presents the results from ten separate regression models, one for each measure of success, split across context for two different model specifications.

The variation in model specification is to show stability across analytic assumptions: ordinary least squares (OLS) regression (model I) vs. HLM (model II) that also includes covariates for gender, ethnicity, and parental education but not prior math and reading achievement as these data were not available for the science center context participants.

Table 2 reveals that *choice* is predicted by fascination and scientific sensemaking in both contexts (model I only for the school context) and by values in the school context. *Engagement* is predicted by 1) competency beliefs in the science center context (both model specifications) and school context (model I only); 2) *fascination* in both models in the school context, but not the science center context; and 3) by *values* for model I only in both contexts. Finally, learning is predicted by *scientific sensemaking* in both models (learning was not measured in the science center context).

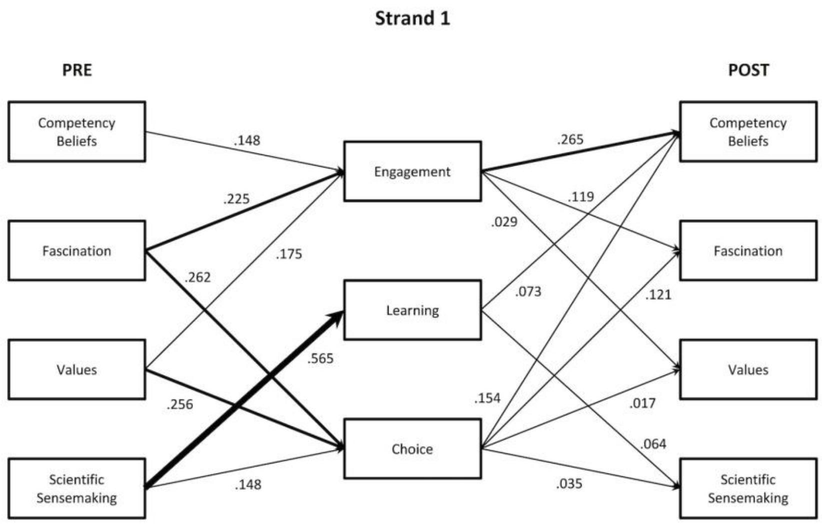
Table 2. Pre Activation Dimension Scores Predicting Choice, Engagement, and Learning in School and Science Center contexts, across simple and complex models

	Standardized Coefficients				
	Choice		Engagement		Learning
Context	School	Science Center	School	Science Center	School
Model	I II	I II	I II	I II	I II
Pre Competency Beliefs	0.013 0.007	0.115 -0.205	0.148* 0.056	0.289*** 0.388***	0.073 0.052
Pre Fascination	0.262*** 0.327***	0.410*** 0.447*	0.225*** 0.323***	-0.009 0.050	0.026 0.086
Pre Values	0.256*** 0.201*	0.222 0.031	0.175*** 0.083	0.260* 0.161	-0.011 -0.038
Pre Scientific Sensemaking	0.148*** 0.134	0.284*** 0.291*	0.054 -0.072	-0.083 -0.111	0.565*** 0.341***

(* $p < 0.05$, *** $p < 0.001$)

With a few exceptions, the findings are robust to model specification and the introduction of demographic covariates, and the model differences do not show large changes in coefficient strengths (including cases where coefficients are no longer statistically significant) across model specification. The largest differences across contexts appear to occur in the relationship between fascination and engagement and the relationship between values and choice, with the Science Center indicating no relationship, but the school context demonstrating a relationship. This may be, in part, due to the sample size difference between the two contexts. In summary, as presented on the left half of Figure 1, each element of success was predicted by different dimensions of activation.

Figure 1. Graphic depiction of relationships among science learning activation dimensions and success variables in Sub-Study 1—School



Further, all dimensions were independent predictors for at least one success indicator, providing evidence for the inclusion and non-redundancy among the included dimensions in activation.

Predicting Increases in Science Learning Activation (RQ2)

We now address our second research question: Do higher levels of choice, engagement, and learning within specific science learning experiences coincide with increased levels of each of the dimensions of activation (i.e., do these four dimensions have reciprocal relationships with success)? Analyses examined which success variables were associated with increases in levels of the dimensions of activation (see Table 3). Table 3 displays the results of sixteen separate regression analyses, one for each dimension of *science learning activation* for each context with two different model specifications. The two model specifications presented are: OLS regression (model I) and HLM (model II), which includes covariates for gender, ethnicity, and parental education.

Increases in competency beliefs were associated with students who reported higher levels of science choice preference in both contexts and with engagement and learning in the school context. Increases in fascination were associated with higher science choice preferences in both contexts and with engagement in the school context. Increases in value were only associated with greater reported engagement in the school context. Finally, increases in scientific sensemaking were associated with greater science choice (model I only) and higher end-of-unit exam scores (learning) in the school context.

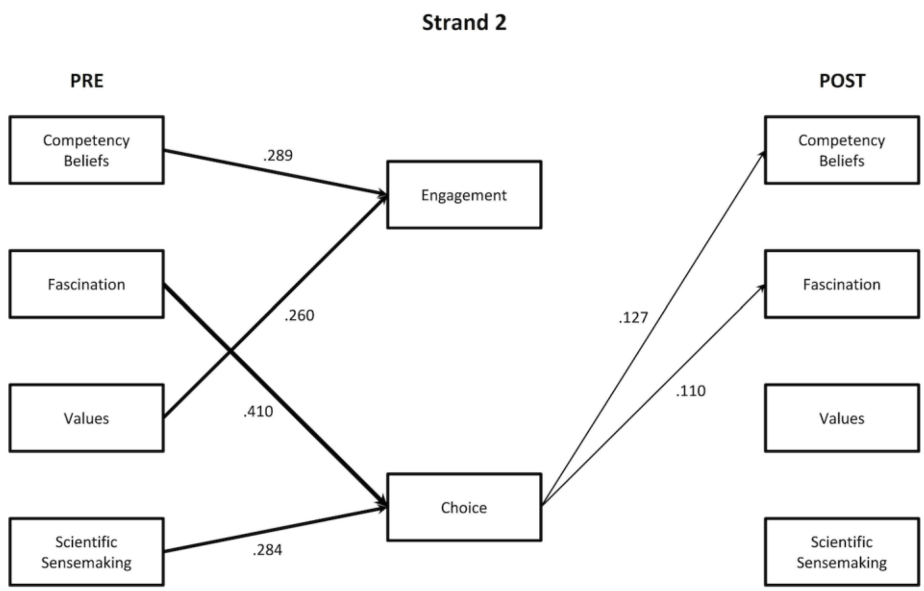
Table 3: Choice, Engagement, and Learning Predicting Post-Activation Dimension Scores, controlling for Pre-Activation Dimension scores in School and Science Center contexts, across simple and complex models

		Post Competency Beliefs		Post Fascination		Post Values		Post Scientific Sensemaking	
Context		School	Science Center	School	Science Center	School	Science Center	School	Science Center
Model		I	I	I	I	I	I	I	I
		II	II	II	II	II	II	II	II
Pre Competency Beliefs	I	0.523***	0.641***	-	-	-	-	-	-
	II	0.450***	0.517***	-	-	-	-	-	-
Pre Fascination	I	-	-	0.760***	0.823***	-	-	-	-
	II	-	-	0.721***	0.828***	-	-	-	-
Pre Values	I	-	-	-	-	0.964***	0.995***	-	-
	II	-	-	-	-	0.967***	0.942***	-	-
Pre Scientific Sensemaking	I	-	-	-	-	-		0.896***	0.956***
	II	-	-	-	-	-	-	0.845***	1.006***
Choice	I	0.149***	0.127*	0.114***	0.110*	0.014	0.006	0.031*	-0.007
	II	0.189***	0.170*	0.088*	0.124*	0.010	0.006	-0.005	0.018
Engagement	I	0.264***	0.092	0.122***	0.017	0.030***	-0.022	0.007	0.018
	II	0.339***	0.066	0.121***	0.024	0.034*	-0.026	0.013	0.027
Learning	I	0.073*	-	0.033	-	0.009	-	0.064***	-
	II	0.047	-	0.071	-	0.009	-	0.085*	-

(* $p < 0.05$, *** $p < 0.001$)

These relationships are depicted in a summary format in Figure 2. Again, the findings are largely robust to model specification and demographic controls with the only difference in significance coming in the relationship between choice preference and an increase in the sensemaking dimension within the school context.

Figure 2. Graphic depiction of relationships among science learning activation dimensions and success variables in Sub-Study 2—Science Center



Discussion

The theory of *science learning activation* makes predictions about how dimensions of activation and successes in science learning are reciprocally related to one another to enable long-term effects from early interventions. This study investigated the relationship between four specific dimensions of *science learning activation* and three indicators of success in science learning experiences, testing the hypotheses embedded within the theory of *activation*. The findings provide empirical evidence regarding the correlation between each of these dimensions and one or more of the measures of success. Our study extends past research on science learning and engagement to identify, measure, and correlate those dispositions, practices, and knowledge that enable success in proximal learning experiences.

First, we identified gaps in the current measurement of dispositions, skills, and knowledge related to science learning and constructed new instruments to fill these gaps. In the process of instrument construction, we gathered validity evidence to support appropriateness of inferences drawn from these instruments. Second, using these instruments, we sought to determine if there were relationships between input levels of each of the four dimensions of activation and choice to participate in science, engagement in science learning activities, and content learning. Analyses found each dimension was statistically related to at least one of the three success variables, and typically more than one success variable. Further, the four dimensions accounted for a large amount of variation in success, even when controlling for various critical participant characteristics (i.e., prior achievement, gender, ethnicity, and parental education). This lends support for the first half of the theory of activation, that individuals' initial level of activation can influence their experiences in science learning opportunities. Note that the activation theory is not about particular relationships from a specific dimension of activation to a specific success. Rather, the theory is that different environments may require different activation dimensions to enable success, and the overall theory is that every environment will draw on some activation dimension to enable higher levels of success.

Next, our statistical analyses found that each of the success variables was also associated with increases in levels of the one or more of the dimensions of activation. While there was variation in the number of relationships found between success variables and increases in activation across the two sub-studies, both sub-studies studies found that variation in the success variables predicted at least some variation in gain scores in activation dimensions. Given that the science center experience was quite brief large changes in activation were not expected from this single experience. The general existence of significant predictive relationships from success to changes in activations lends support for the second half of the theory of activation, namely that success in a learning experience leads to increased levels of activation. Future studies will further investigate the features of learning environments and experiences that support activation.

The existence of bidirectional relationships between successes in science learning and science activation provides support for the overall theory of activation, which in turn provides a resolution to the conceptual conundrum: how can early interventions produce long-term effects for science learning outcomes given the wide heterogeneity of possible intermediate learning experiences? The mechanistic explanation offered by the theory of activation suggests there can be iterative processes of changes in activation that influence later successes which then influence activation again. Of course, future research will need to examine activation and successes at more time points to document the iterative processes unfolding more directly.

Future research is also needed to directly examine the causality of the correlational relationships found in the current study. The analyses presented here controlled for likely confounds, but more rigorous studies are needed to test strongly the hypothesized causal relationships. At the same time, given the complexity of the interrelationships of variables and the likely difficulty of uniquely intervening on one variable at a time, we suspect much future research will continue to use regression techniques.

We also acknowledge that the data used to measure these constructs are entirely self-report data and we recognize the concern of stereotype threat and tendencies toward socially desired responses in self-report data. However, in the current context we do not see this as particularly problematic as we are not asking for sensitive information (e.g., negative behaviors), thereby reducing the risk of providing socially desired answers. Further, all demographic information is gathered after completion of the initial survey and several days passed before additional surveys were collected, even in the science center sub-study. Finally, in several instances (e.g., competency belief, value of science) we are interested in the perceptions of the respondents, and therefore self-report data are most direct way to capture those data.

The theory of activation describes a particular set of successes (choice, engagement, and content learning) and a particular set of activation dimensions that are thought to support those successes as well as be impacted by those successes. Future refinements to the theory may refine the set of successes (e.g., adding perceived success) or improve the set of dimensions of activation (e.g., add another dimension or improve the formulation of an existing one), but the overarching theoretical framework will remain the same and provides guidance of theory refinements. That is, activation should include dimensions and successes that participate in an iterative process that moves towards long-term outcomes.

It is also worth noting that the general theory of activation is structurally agnostic to content area (e.g., science vs. art) but must involve successes and dimensions that are deeply connected to content area. That is, there could be an analogous theory of art activation involving an iterative process between dimensions of activation and successes, but the constructs (and measures) of choice, engagement, learning, and activation dimensions would be specific to art. Similar dimensions of activation might be relevant (e.g., fascination in art, valuing art), but the details of those dimensions would have to be deeply connected to the nature of art and art learning situations.

Implications

General Theories of the Effects of Motivation on Learning

Many of the particular connections from activation dimensions to successes are replications of previous findings with closely related constructs. For example, we find that choice preferences are predicted by *fascination* and *values,* and that *engagement* is predicted by *fascination*, *values*, and *competency beliefs*. These findings replicate the general findings from the literature on the *Expectancy Value* theory. Similarly, that content learning is predicted by reasoning abilities has also been found before (Cavallo, 1996; Johnson & Lawson, 1998; Lawson et al., 2007). However, even for these replications, our study adds an important extension to the evidence in that we controlled more carefully for important covariates that could have been unmeasured confounds in prior studies (e.g., measuring reasoning ability in studies of the effects of motivational variables and vice versa).

The current study also reveals the extent to which skills and dispositions appear to have overlapping contributions to science learning. Much of the research literatures in learning have sharply divided into research on motivation (with little examination of reasoning skills) and the research on reasoning skills (with little examination of motivation). Although we also find that engagement is only driven by dispositions (not abilities) and learning is primarily driven by abilities (not dispositions), crossovers did occur. Specifically, scientific sensemaking abilities were independently predictive of choice preferences in a way that was not mediated by competency beliefs. This particular relationship should be the focus of future research to further unpack the basis of this connection (e.g., whether it is mediated success experiences).

The current studies also tested the contextual nature of the predictors of success in science. Rather than viewing these theories as monolithic factors that always should have similar effects across learning contexts, the activation theory frames the activation dimensions as resources that can do work for learning depending on the needs of the context. The study's results showed some similarities in effects across two very different contexts (e.g., fascination and sensemaking to choice). But there were also differences across contexts. For example, competency beliefs, but not fascination, predicted engagement at the science center whereas the reverse pattern held in the school context. Because this study was conducted with a particular curriculum, and other differences hold across the two samples, it is too soon to draw conclusions about whether this pattern generally holds for science and technology center visits vs. school science. However, the data suggested that there are contextual variations in which activation dimensions are important resources for achieving proximal successes. Following additional replications, this contextual variation, which might also be called features of the learning environment, should be included more generally in theories of science learning.

General Theories of the Development of Motivations and Abilities

The connections from experienced successes to changes in activation dimensions also contain conceptual replication. For example, research on engagement and the development of interest have found that positive experiences are important for growth in competency beliefs and the development of personal interest (Hidi & Renniger, 2006; Hidi & Ainley, 2008). The current results add to this literature by suggesting that choice preferences also contribute to their growth, even when engagement effects are controlled. These effects of choice preferences contribute to a broader sense of a self-regulated learner who controls not only how learning takes place but also what the focus of learning should be (at the broad topical level) during optional learning time. Note also that the effects of choice preferences appeared to be on more dispositional aspects of activation rather than on the more reasoning-based aspects of activation, contrary to the typical focus of self-regulated learning theories on content learning.

Design of Science Learning Experiences

Transformative outcomes from early science learning inventions will take place when we discover which early interventions have effects that maintain or grow rather than dissipating. In order to do that, we need to both know what immediate effects are predictive of growing long-term effects and be able to measure them rigorously. The theory suggests that those designing learning experiences could intentionally target *science learning activation* as an outcome while understanding it as an input as well. For example, designing science learning experiences during the middle school years could focus on strategic interventions designed to produce immediate effects on the dimensions of activation, with the idea that such immediate effects could launch the iterative process that produces long term outcomes. Future design efforts could then focus on understanding the specific features of learning experience interventions that support the development of activation.

This work may also have practical implications for program evaluation for several reasons. First, *science learning activation* is hypothesized to present convenient short-term evaluation targets with meaningful long-term predictiveness. Second, it offers a framework that is meaningful across learning environments and settings and thus affords the potential for engaging in comparative studies that are impossible with current measurement systems and technologies. Thus, after appropriate replications of the current study, an instrument that measures *science learning activation* is potentially transformative for the field of evaluation because it provides a simple common benchmark for programs to compare themselves against that has demonstrated importance in successful science learning.

Future Research

To address the limitations of correlation research, a series of future intervention studies could target each of the activation dimensions and track effects on the success variables to provide important validation of the theory of activation. Further, the studies here focused on a limited range of learning contexts and a particular set of ages. Replications in other contexts would also be useful to explore more fully the notion of activation dimensions as resources rather than always the same set of necessary elements. Replications at other ages would be useful to test the generality of the particular identified activation dimensions. As children grow older, science learning environments become more difficult and children have a stronger sense of career (Watson & McMahon, 2005); in younger children, adults play a stronger role in determining which experiences take place or are even offered (Vedder-Weiss & Fortus, 2012). These differences could influence the nature and importance of different activation dimensions.

The study of science learning activation as a multidimensional construct enabled us to give individuals scores on each dimension. One interesting finding not examined in this paper is that there were relatively few children who actually score high on all of the dimensions concurrently. More specifically, in our sample of almost many hundreds of ten to twelve year-olds, we found only five children were in the top third on all the dimensions. This finding provides important information and warrants future exploration of why such uniformly high activation levels are so rare. In a similar vein, future research should examine various patterns of scores on these dimensions using person-centered analyses (Jurik, Gröschner, & Seidel, 2013; Linnenbrink-Garcia, Pugh, Koskey, & Stewart, (2012).

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Appendix A: Science Learning Activation Assessment

Item Set 1: Fascination with Natural and Physical Phenomena

Text	Scaling/Scoring
In general, I find science:	4 = Very interesting 3 = Interesting 2 = Boring 1 = Very boring
I want to learn as much as possible about science.	4 = YES! 3 = yes 2 = no 1 = NO!
After a really interesting science activity is over: I can't stop thinking about it.	1 = Checked 0 = Un-checked
After a really interesting science activity is over: I look for information about it.	1 = Checked 0 = Un-checked
In general, when I work on science:	4 = Like 3 2 1 = Dislike
In general, when I work on science:	4 = Cool 3 2 1 = Dislike
In general, when I work on science:	4 = Enjoy 3 2 1 = Don't enjoy
In general, when I work on science:	4 = Love it 3 2 1 = Hate it

Item Set 2: Values Science

Text	Scaling/Scoring
How important is it for you to learn about science?	4 = Very important 3 = Important 2 = A little important 1 = Not at all important
Do you think you could become a scientist someday?	4 = YES! 3 = yes 2 = no 1 = NO!
In this activity you looked at some evidence about dolphins and you thought about what the evidence shows. How important is it to you to think like this?	4 = Very important 3 = Important 2 = A little important 1 = Not at all important
I talk about science or science ideas with people or someone in my family outside of school.	4 = YES 3 = yes 2 = no 1 = NO!

Item Set 3: Competency Beliefs in Science

Text	Scaling/Scoring
I think I am pretty good at: Science	4 = YES! 3 = yes 2 = no 1 = NO!
I think I am pretty good at: Coming up with questions about science	4 = YES! 3 = yes 2 = no 1 = NO!
I think I am pretty good at: Designing experiments	4 = YES! 3 = yes 2 = no 1 = NO!
I think I am pretty good at: Finding evidence for my ideas	4 = YES! 3 = yes 2 = no 1 = NO!
I think I am pretty good at: Figuring out why things happen	4 = YES! 3 = yes 2 = no 1 = NO!
I think I am pretty good at: Doing experiments	4 = YES! 3 = yes 2 = no 1 = NO!
I think I am pretty good at: Giving evidence when I tell my opinion	4 = YES! 3 = yes 2 = no 1 = NO!
I think I am pretty good at: Defending my opinion when others disagree with me	4 = YES! 3 = yes 2 = no 1 = NO!
I think I am pretty good at: Figuring out how to fix a science activity that didn't work	4 = YES! 3 = yes 2 = no 1 = NO!

Item Set 4: Scientific Sensemaking Post (Monkey Scenario)

<table>
<tr><th>Text</th><th>Scaling/Scoring</th></tr>
<tr><td>Elijah wonders if the temperature outside makes a difference in how much monkeys play. Which question is the best to ask to investigate this?</td><td>1 = Do monkeys play in hot weather?
0 = Which other animals live in the same part of the jungle as monkeys?
0 = Do monkeys like hot or warm weather?
2 = Do monkeys okay more when the weather is hot or warm?</td></tr>
<tr><td>Maria is wondering which monkey eats the most. What is the best evidence she could get to answer her question?</td><td>0 = She could guess which monkey eats the most.
0 = She could choose a monkey and count the number of pieces of fruit he eats and compare it to the number of leaves he eats.
0 = She could ask her friends which monkey looks like it eats the most.
1 = She could count the number of things all of the monkeys eat.</td></tr>
<tr><td>Seth says that monkeys are full after they eat 7 pounds of food.
<table>
<tr><th>Monkey</th><th>Amount of food given</th><th>Amount of food eaten</th></tr>
<tr><td>Monkey #1</td><td>3 pounds</td><td>3 pounds</td></tr>
<tr><td>Monkey #2</td><td>5 pounds</td><td>5 pounds</td></tr>
<tr><td>Monkey #3</td><td>7 pounds</td><td>7 pounds</td></tr>
<tr><td>Monkey #4</td><td>9 pounds</td><td>7 pounds</td></tr>
</table>
Which piece of evidence in the table above makes Seth think this is true?</td><td>0 = Monkey #4 got 9 pounds of food which is the most.
0 = Monkey #1 got the least amount of food and ate it all.
1 = Monkey #4 got 9 pounds and only ate 7 pounds of food.
0 = Monkey #3 got 7 pounds and ate 7 pounds of food.</td></tr>
<tr><td>Yasmine wonders if monkeys like to sit in tall or short trees. What should she do to answer her question?</td><td>0 = Put all of the monkeys in tall trees then move them to short trees and see where they sit the most.
0 = Put one group of monkeys in tall trees and another group of monkeys in short trees and see who sits the most.
0 = Put all of the monkeys in short trees and see if they seem happy.
1 = Put the monkeys in a place with tall and short trees and allow them to sit wherever they want.</td></tr>
</table>

<table>
<tr><th>Text</th><th>Scaling/Scoring</th></tr>
<tr><td>A group of students have decided to observe two forests that are exactly alike. Usually there are the same number of Grey Shanked Douc Monkeys in each of these forests. The number of monkeys in a forest could be influenced by the amount of construction, trash, and the different types of trees. The students observed the monkeys in these two forests and counted the number of monkeys in each forest. Their results are shown below.
Test A:
<table>
<tr><td>Forest</td><td>Amount of construction</td><td>Amount of trash</td><td>Different types of trees</td><td># Monkeys in the forest</td></tr>
<tr><td>Forest #1</td><td>Lots</td><td>A little</td><td>A few</td><td>8</td></tr>
<tr><td>Forest #2</td><td>A little</td><td>A little</td><td>A few</td><td>20</td></tr>
</table>
Test B:
<table>
<tr><td>Forest</td><td>Amount of construction</td><td>Amount of trash</td><td>Different types of trees</td><td># Monkeys in the forest</td></tr>
<tr><td>Forest #1</td><td>A little</td><td>Lots</td><td>A few</td><td>14</td></tr>
<tr><td>Forest #2</td><td>A little</td><td>A little</td><td>A few</td><td>14</td></tr>
</table>
Test C:
<table>
<tr><td>Forest</td><td>Amount of construction</td><td>Amount of trash</td><td>Different types of trees</td><td># Monkeys in the forest</td></tr>
<tr><td>Forest #1</td><td>A little</td><td>A little</td><td>A few</td><td>8</td></tr>
<tr><td>Forest #2</td><td>A little</td><td>A little</td><td>Lots</td><td>14</td></tr>
</table>
</td><td>1 = Construction
0 = Trash
0 = Different types of trees</td></tr>
<tr><td>What would make one scientific explanation better than another?</td><td>0 = It is new and different.
0 = It is closer to what people think now.
0 = It is in more books.
1 = It is based on more and better evidence.</td></tr>
<tr><td>Scientists sometimes change their explanations. Why?</td><td>0 = Scientists change their explanations as they get older.
0 = So other scientists will agree with them.
0 = Scientists don’t need to change their explanations once they have evidence.
1 = New evidence causes scientists to change their explanations.</td></tr>
<tr><td>How might a scientist get evidence that there will be an earthquake near her home soon?</td><td>0 = She saw a report on the news that there might be an earthquake.
0 = She read lots of facts about earthquakes and thought about them.
0 = She heard stories about other earthquakes near her home.
1 = She used tools and instruments to gather evidence for the prediction.</td></tr>
<tr><td>Dr. Powers is investigating how dolphins communicate with each other. Which of these would be an important part of her work as a scientist?</td><td>0 = Ask people if they have a favorite type of dolphin.
1 = Talk to other scientists about dolphins.
0 = Decide if dolphins are more popular then sharks.
0 = Write imaginative stories about dolphins.</td></tr>
</table>

Text	Scaling/Scoring	
[Based on choice from M2010] <u>Choice 1</u>: You said that the amount of construction makes monkeys leave that part of the forest. How could construction make monkeys leave the forest? Please explain how construction can affect monkeys. <u>Choice 2</u>: You said that the amount of trash makes monkeys leave that part of the forest. How could trash make monkeys leave the forest? Please explain how trash affects monkeys. <u>Choice 3</u>: You said that the number of different types of trees make monkeys leave that part of the forest. How could the number of different types of trees make monkeys leave the forest? Please explain how the number of different types of trees can affect monkeys.	High (4): Mechanistic and Scientifically Accurate cause and effect relationship	- Student describes mechanisms or specific descriptions of monkeys, AND - Describes the relationship between the multiple factors that can affect monkeys. Explaining the how process of these different components. OR - Student may discuss one of the factors in depth. - Explaining the cause and effect relationship
	Mid High (3): Scientifically accurate cause and effect relationship	- Student makes a scientifically accurate cause and effect relationship, which includes the HOW.
	Mid Low (2): Cause and effect relationship NOT scientifically accurate	- Uses evidence from the table in the survey. OR - Student is trying to make a cause and effect relationship that is NOT scientifically accurate. - Student's explanation is not specific, mentions what could happen (effect), but lacks the HOW (cause), how something happens.
	Low (1): No Cause and Effect Relationship	- There is no link between cause and effect. OR - General statement, just a feeling. - Related to scenario.
	Null (0):	- Student writes statements that are unable to be interpreted or are otherwise unrelated to the question. OR - Student restates the question.
<u>Choice 1</u>: President Obama is going to a meeting about the Grey Shanked Douc Monkeys next month. At the end of the meeting they will decide what to do for the monkeys. You have been asked to make a recommendation about what should be done to help the monkeys. We know you aren't a monkey expert, so you probably have lots of questions! You can ask questions that would help you make your argument that the best way to help the monkeys is to move them into a wildlife reserve. If you could ask a scientist who studies monkeys some questions, what would you ask? <u>Choice 2</u>: President Obama is going to a meeting about the Grey Shanked Douc Monkeys next month. At the end of the meeting they will decide what to do for the monkeys. You have been asked to make a recommendation about what should be done to help the monkeys. We know you aren't a monkey expert, so you probably have lots of questions! You can ask questions that would help you make your argument that the best way to help the monkeys is to improve their natural habitat. If you could ask a scientist who studies monkeys some questions, what would you ask?	High: (3) Asks informative and investigable questions	If answered, the questions would give you more information to use to support your choice about the scenario. - Uses specificity and detail in language. - Question(s) is directly related to scenario. - Questions use good question words like how or why
	Mid: (2) Basic questions	Writes questions that are relevant to the scenario, but are general and do not provide any additional information to help inform the decision between the two options.
	Low: (1) Repeated or confused questions	Confuses parts from multiple questions, including those previously mentioned. OR Explanations or statements that are not phrased as questions but have relevant information. OR Irrelevant questions
	Null: (0) No question or off topic	Student restates their position that they have chosen. OR Student makes statements about the control of variables.

Text	Scaling/Scoring
Choice 1: Now, write a letter to President Obama explaining why you think that moving the monkeys to a wildlife reserve is the best way to help them. Here is some evidence that you can use in your essay to President Obama: 1. Monkeys that are caught and moved may have a hard time adjusting to their new environment, but resume normal behavior after some time. 2. Scientists have studied natural habitats and have found that when you take one animal it can affect all the others. They have also found that it can take a while for natural habitats to get better once you try to improve them. 3. Construction could be eliminated in the forest by not allowing companies to build in the reserve. Construction could be reduced in the natural habitat by reducing the number of construction companies allowed. Choice 2: Now, write a letter to President Obama explaining why you think that trying to improve the monkeys' natural habitat is the best way to help them. Here is some evidence that you can use in your essay to President Obama: 1. Monkeys that are caught and moved may have a hard time adjusting to their new environment, but resume normal behavior after some time. 2. Scientists have studied natural habitats and have found that when you take one animal it can affect all the others. They have also found that it can take a while for natural habitats to get better once you try to improve them. 3. Construction could be eliminated in the forest by not allowing companies to build in the reserve. Construction could be reduced in the natural habitat by reducing the number of construction companies allowed.	High (3): Claim connected to reasoning and evidence Mid High (4): Both reasoning and evidence Mid (3): Unsubstantiated reasoning OR Unwarranted evidence Mid Low (2): Solutions only OR Statement of mechanism Low (1): Personal OR Severity only Null (0): Claim only

Appendix B: Engagement in Science Learning Activity

Text	Scaling/Scoring
During today's activity: I felt happy or excited.	4 = YES! 3 = yes 2 = no 1 = NO!
During today's activity: I felt relaxed or calm.	4 = YES! 3 = yes 2 = no 1 = NO!
During today's activity: I felt frustrated or annoyed.	4 = YES! 3 = yes 2 = no 1 = NO!
During today's activity: I felt tired or sad.	4 = YES! 3 = yes 2 = no 1 = NO!
During today's activity: I felt bored.	4 = YES! 3 = yes 2 = no 1 = NO!
During today's activity: I was thinking during the activity.	4 = YES! 3 = yes 2 = no 1 = NO!
During today's activity: I explained things to others.	4 = YES! 3 = yes 2 = no 1 = NO!
During today's activity: I tried out my ideas to see what would happen.	4 = YES! 3 = yes 2 = no 1 = NO!
During today's activity: I thought about how ideas in the activity related to other things.	4 = YES! 3 = yes 2 = no 1 = NO!
During today's activity: I was paying attention during the activity.	4 = YES! 3 = yes 2 = no 1 = NO!
During today's activity: I was doing what I was supposed to be doing.	4 = YES! 3 = yes 2 = no 1 = NO!

Text	Scaling/Scoring
During today's activity: I did more than was required of me.	4 = YES! 3 = yes 2 = no 1 = NO!
During today's activity: I worked hard on the activity.	4 = YES! 3 = yes 2 = no 1 = NO!
During today's activity: I asked questions or talked with an adult.	4 = YES! 3 = yes 2 = no 1 = NO!
During today's activity: I asked questions or talked with another student.	4 = YES! 3 = yes 2 = no 1 = NO!
Did you do any of these things during today's activity? I figured out something about science.	4 = YES! 3 = yes 2 = no 1 = NO!
Did you do any of these things during today's activity? I checked to make sure I understood what we were doing.	4 = YES! 3 = yes 2 = no 1 = NO!