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Science curiosity in learning environments: developing an attitudinal scale for research in schools, homes, museums, and the community

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ABSTRACT

Although curiosity is considered an integral aspect of science learning, researchers have debated how to define, measure, and support its development in individuals. Prior measures of curiosity include questionnaire type scales (primarily for adults) and behavioral measures. To address the need to measure scientific curiosity, the Science Curiosity in Learning Environments (SCILE) scale was created and validated as a 12-item scale to measure scientific curiosity in youth. The scale was developed through (a) adapting the language of the Curiosity and Exploration Inventory-II [Kashdan, T. B., Gallagher, M. W., Silvia, P. J., Winterstein, B. P., Breen, W. E., Terhar, D., & Steger, M. F. (2009). The curiosity and exploration inventory-II: Development, factor structure, and psychometrics. *Journal of Research in Personality*, *43*(6), 987–998] for youth and (b) crafting new items based on scientific practices drawn from U.S. science standards documents. We administered a preliminary set of 30 items to 663 youth ages 8–18 in the U.S.A. Exploratory and confirmatory factor analysis resulted in a three-factor model: stretching, embracing, and science practices. The findings indicate that the SCILE scale is a valid measure of youth's scientific curiosity for boys and girls as well as elementary, middle school, and high school learners.

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Attitudinal scale; curiosity; emotions in learning; exploratory factor analysis; scientific attitudes; science practices; youth

The discipline of science is often conceived of as a set of inquiry practices that are driven by human curiosity. Children, especially at young ages, are curious (Engel, 2009); children often engage in asking questions and making sense of the world around them, which are thought of as early scientific practices (Driver, 1985) and are examples of curious behaviors (Luce & Hsi, 2014). While curiosity is an important part of scientific inquiry, the psychological and educational literatures have debated about the nature of curiosity, how to measure it, and how to foster it in youth. As such, our research intention is to elucidate the nature of curiosity with young learners to develop (a) science learning theory that considers the role of emotion and (b) recommendations for educational practice to foster curious science learners. A first step toward these two goals for including

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emotion in the study of science learning is the creation of a measure for scientific curiosity that can be easily administered across informal and formal settings. Consequently, this article offers a 12-item scale to measure scientific curiosity, developed via an exploratory and confirmatory factor analysis that was conducted with 663 youth in 3rd–12th grade (ages 8–18) in two school districts in the U.S.A.

Curiosity in educational and psychological literatures

Curiosity to direct and regulate attention

Researchers have evolved the definition of curiosity over time. Berlyne (1954) first conceptualized curiosity as two types of behaviors: perceptual exploration and epistemic exploration. Curiosity research then focused on whether curiosity was a state (an emotional condition) or a trait (a personal disposition). Berlyne's (1966) initial studies focused on the nature of state curiosity; he focused on how curiosity related to complex stimuli and novelty that prompted information-seeking behaviors because of the learners' lack of information. Piaget (1969) described curiosity as an emotion simply: as a need to explain the unexpected. Loewenstein (1994) built upon Berlyne's ideas to propose that satisfying curiosity was an enjoyable process that was triggered by discovery of a specific gap in information. Extending this idea of satisfying gaps in information, Markey and Loewenstein (2014) defined curiosity as 'a desire for information in the absence of extrinsic reward' (p. 230). Silvia (2006), however, added complexity to the debate on the nature of curiosity by identifying observable behaviors such as devoting attention, processing deeply, recalling information, and greater persistence in a given situation that were dispositional in nature; these traits were found in persons recognized as being curious. Consequently, Silvia asserted that attention-based behaviors aligned with trait curiosity. Similarly, other researchers (Collins, Litman, & Spielberger, 2004; Kashdan, Rose, & Fincham, 2004) have taken the position that curiosity is a trait characteristic, corresponding with an individual's personality and disposition. Researchers with the trait characteristics perspective have developed scales to measure diverse constructs that correlate with individual's preferences, practices, and outcomes. This line of work defines a highly curious individual as someone who 'has the propensity more readily to recognize, pursue, and become absorbed in novel and challenging experiences' (Kashdan et al., 2004, p. 292).

Finally, Kashdan et al. (2009) argues that curiosity is a way people direct and regulate their attention. In our work, we adopt the definition of Kashdan et al.; curiosity, conceived as such, has two components: stretching and embracing. Stretching corresponds to actively exploring new information or experiences, maintaining concentration, and regulating attention toward an interest or goal. The other component of Kashdan et al.'s curiosity is embracing. Embracing is a willingness to be engaged in novel, uncertain, or unpredictable experiences, some of which could be considered unpleasant (Kashdan & Silvia, 2009; Kashdan et al., 2009).

Curiosity as its own construct separate from interest

In educational research and literature, curiosity and interest are often used interchangeably as the same or closely related constructs (Hidi & Renninger, 2006; Kashdan et al., 2004; Silvia, 2006). However, according to a literature review conducted by Grossnickle (2014), 'Theoretically, empirically, and practically, curiosity and interest are separate constructs, with certain conceptual overlaps' (p. 2). Grossnickle further defined curiosity in ways compatible with Kashdan et al. (2009) as, 'desire for knowledge or information in response to experiencing or seeking out collative variables, which is accompanied by positive emotions, increased arousal, or exploratory behavior' (p. 8). Although curiosity is often described as novelty, complexity, challenges, or exploration (Grossnickle), we define curiosity as the drive or desire to seek out those novelty, complexity, challenges, or exploration factors (Litman, 2008). Thus, although curiosity is often found or aligned with interest, it is considered a separate construct.

Scientific curiosity

Curiosity, based on the researchers' definitions above, could be assumed to be domain general – meaning it is not connected to a specific discipline. However, given our interest in curiosity as related to the engagement in science practices, we posited that a person might have science-specific curiosity and that aspects of curiosity may in fact be domain-specific. Curiosity in science is related 'to information seeking behaviors, such as those that are observed in learning environments' (Jirout & Klahr, 2012, p. 4) and can be defined as a desire for content-specific knowledge about natural phenomena (Spektor-Levy, Baruch, & Mevarech, 2013).

In fact, across various areas of science, these interest-based behaviors are evidenced, especially in children who have developed expertise in a specific science domain through intense, prolonged engagement in science over time (Crowley & Jacobs, 2002; Palmquist & Crowley, 2007; Zimmerman, 2012; Zimmerman & Bell, 2014). We posit that this intense engagement leading to expertise corresponds with a high level of curiosity in the children and adults. Individuals who are curious seek explanations for their interests and experiences and find pleasure in this, which satisfies their drive to learn (Kashdan et al., 2009). This discipline-specific view of curiosity aligns with the images of individuals with high interest in science who are likely to seek out difficult challenges in order to engage more fully in activities that they enjoy. In addition, science-interested learners tend to self-regulate and participate more regularly in astronomy, biology and other sub disciplines of science (Bell, Lewenstein, Shouse, & Feder, 2009). By creating opportunities for individuals to indulge in learning intensely about their disciplinary-specific topics, increased curiosity as well as development of long-term interests in science can result.

Curious individuals who engage in science practices are in fact constructing their scientific identity as they investigate, question, and manipulate, particularly when participating socially with others. Identifying with scientific enterprise focuses on a person's development of a scientific identity, as being someone who recognizes himself or herself (or not) as a scientist (Zimmerman, 2012; Zimmerman & Weible, in press). Often, identity is associated not only with recognition, but also with the sense of belonging to a community through participation in activities (Bransford, Brown, & Cocking, 2000). Many of these activities in science such as intense learning, asking questions, examining closely, and manipulating objects map onto the behaviors of highly curious people (Kashdan & Silvia, 2009).

Studies have found that more curious students tend to have higher achievement or more academic success. Arnone, Grabowski, and Rynd (1994) found that more curious first- and second-grade students in a museum study scored higher on a content-oriented post-test than the less curious students. Conversely, Jirout and Klahr (2012) found that curiosity and achievement were independent, although curiosity was correlated with asking more questions; children who were more curious also recognize the questions that were more effective. Engagement of curious students with the course material and discussions of content appeared to stimulate learning in challenging situations (Kashdan & Silvia, 2009). In summary, through exposure to learning environments that stimulate curiosity and support for its expression, the students may further explore content areas as well as participate in discussions that increase interest and understanding in formal and informal settings.

Measuring curiosity and science-related curiosity

Because curiosity helps learners to direct and regulate their attention toward new information and to embrace in novel, uncertain experiences, it is an important aspect of learning (Markey & Loewenstein, 2014). Research methods that connect curiosity and learning include analyses of learners' actions and self- and teacher-reported assessments (e.g. Kashdan et al., 2004). Research on curiosity has examined learners in and out of the classroom using both behavioral measures and questionnaire-type measures (Jirout & Klahr, 2012). Most questionnaire-type scales created to measure curiosity have been validated and used only with adults. Day (1971) created the Ontario Test of Intrinsic Motivation, which consisted of 110 true or false items focused on relating curiosity to creativity, anxiety, and academic achievement. The Melbourne Curiosity Inventory (Naylor, 1981) used 20 Likert scale items (on two scales) to rate how participants felt at that moment to measure relationships between curiosity and anxiety. Goff and Ackerman (1992) used 59 Likert scale items in creating the Typical Intellectual Engagement scale that showed relationships between intelligence, academic performance, and curiosity. Other scales have investigated components of curiosity such as interest and deprivation (Curiosity as a Feeling-of-Deprivation scale; Litman & Jimerson, 2004) and exploration and absorption (Curiosity and Exploration Inventory, CEI; Kashdan et al., 2004).

Most studies of children's curiosity focus on behaviors, with a small number of scales developed for children. McReynolds, Acker, and Pietila (1961) first suggested that curiosity could be studied in children after rating 11-year-old children's curiosity about objects during structured and unstructured play. Their results indicated that children's curiosity and psychological adjustment were positively related. Similarly, Smock and Holt (1962) measured children's curiosity through observation of play with toys as well as learners' responses to visual stimuli. Smock and Holt indicated that a relationship exists between novelty and curiosity; a medium-sized degree of novelty increases the learners' curiosity, but too much unfamiliarity reduced the curiosity displayed by the children. In addition, their study suggested that gender and the mental rigidity (flexibility) of the student affected the level of curiosity; male students and those who were more mentally adaptable to new situations or stimuli demonstrated higher levels of curiosity. The Maw and Maw (1961) scale utilized curiosity ratings of youth by the teacher, peers, and self to identify high and low rankings of curious students. The Maw and Maw scale and ranking system were later modified to include behavioral measures after criticism that its scale measured intelligence rather than curiosity (Maw & Maw, 1970). Kreitler, Zigler, and Kreitler (1975) utilized questionnaire-type items, observed behaviors, and conversation between the researcher and first-grade students to examine five different 'types' of curiosity: (a) manipulatory curiosity, (b) perceptual curiosity, (c) conceptual curiosity, (d) curiosity about the complex, and (e) adjustive–reactive curiosity. Their findings indicated that not only were there different types of curiosity, but similar to Kashdan et al. (2009), it is necessary to clearly define the types of curiosity in order to measure curiosity accurately.

Several strands of research have developed scales or behavioral protocols to measure scientific curiosity in children. Measuring scientific curiosity is important because as *Learning Science in Informal Environments* (Bell et al., 2009) asserts, the 'development of practical, evidence-centered means of assessment' (p. 55) is a major challenge in assessing science outcomes in informal settings. One such desirable outcome is increasing curiosity in science. The Children's Science Curiosity Scale was developed in the 1980s (Harty & Beall, 1984; Harty, Samuel, & Beall, 1986) to measure students' scientific curiosity. Harty and Beall defined scientific curiosity as desire for information in science-specific domains. The Children's Science Curiosity Scale used Likert-type items centered on the novelty, complexity, and change aspects of curiosity with specific items based on common children's activities. As the scale's items were content- and context-specific, researchers (Gardner, 1987; Osborne, Simon, & Collins, 2003) heavily critiqued the statistical validity of the Hardy scale. Gardner argued that Harty and Beall's Children's Science Curiosity Scale measured students' interest in science topics, rather than actual curiosity about science and science practices. Harty and Beall (1987) rebutted Gardner's critique through the assertion that the Children's Science Curiosity Scale could be considered uni-dimensional, and they explained the derivation based on their definition of curiosity. Given the lack of curiosity measures for children, the Children's Science Curiosity Scale is in current use (e.g. Baxter, 1989; Gennaro & Lawrenz, 1992; Rubenstein, 2000; Sharp & Kuerbis, 2006; Ting & Siew, 2014), even though the critiques of what exactly the scale measures still have not been resolved.

More recently, researchers have created scales that incorporated items about content-specific science topics as a way to measure curiosity toward science as a construct within another measure. Bathgate, Schunn, and Correnti (2014) constructed a scale to examine motivation toward science experiences across a variety of contexts, interactions, and topics. They created a scale that utilizes the constructs of appreciation, identity, interest, persistence, responsibility, expected results, and curiosity to measure motivation toward science. Their scale's science curiosity statements were conceptualized to 'assess children's wondering, investigating, and excitement in learning' (Bathgate et al., 2014, p. 194) and used content-specific items. These science items were drawn from five domains ranging from environmental science (i.e. 'global warming') to engineering (i.e. 'make robots'). As such, this scale may not capture the motivation toward science for youth who do not align themselves with a science identity, dislike or have little interest toward the science domain within the question, or identify those topics as being related to what they consider science (Bathgate et al., 2014; Zimmerman, 2012)

Most recent curiosity studies (2011–2016) have utilized behavioral and open-ended interview measures of students to examine children's curiosity in science. Engel (2011) investigated student–teacher patterns of interaction during laboratory activities to examine how students' curiosity could be fostered through teacher support for asking questions and inquiry beyond the experimental constraints. Similarly, Jirout and Klahr (2012) utilized behavioral measures to measure scientific curiosity of children by observing their preferences and uncertainty during exploratory behavior. Jirout and Klahr adapted earlier procedures for children (Kreitler et al., 1975) and adults (Loewenstein, 1994) to create a protocol for 3- to 5-year old children in which a child chooses between pairs of items with varying levels of information provided about each. The child's choice was interpreted as the measure of curiosity. In alignment with literature on adult curiosity (Kashdan & Silvia, 2009; Kashdan et al., 2009), the children preferred a medium level of uncertainty, or curiosity, about the item. To further refine the measure of children's curiosity, Jirout and Klahr used a computer-based game, 'Underwater Exploration!' to record children's choices for amount of information provided (uncertainty) about fish outside an underwater window. Findings indicate that level of curiosity (expressed as uncertainty) is static across the age group examined. This measure of curiosity was aligned with study participants' question-asking about science topics for methodological triangulation; the researchers found that the children who were more curious through the game and interview were also more likely to ask questions in the actual science settings (Jirout, 2011). To investigate how teachers identified curiosity in young students within the classroom, Spektor-Levy et al. (2013) utilized open-ended questionnaires with 46 pre-school teachers to examine the teachers' perceptions of students with high levels of curiosity, behaviors that indicated curiosity, and scientific content that generated the most curiosity in the classroom. Findings indicated that the majority of the teachers felt that curious children expressed wonder, shared with others, and engaged with sensory exploration. Luce and Hsi (2014) investigated scientific curiosity and interest with 19 sixth-grade students using photo-journaling and interviews to better understand each student's expression of curiosity and how a student's curiosity related to his or her interest in science. Luce and Hsi found that a wide range of expressions of curiosity and interest existed in the students; curiosity expressions varied from focusing on specific topics to abstract topics about broad subjects. Luce and Hsi proposed longitudinal studies of the connections between curiosity, student interests, and science experiences to understand how curiosity relates to science preferences and practice.

Problem statement with research question

As we have argued through our literature review above, curiosity has important connections to students' persistence in science learning, interest in sciences, and deeper understandings of science; however, without an accepted scale with which to measure scientific curiosity, understanding the impact of such interventions is time-consuming, non-uniform, and difficult. Given this importance in learning and the lack of measures, researchers (Kashdan et al., 2009) have advocated for the development of scales to study curiosity across time and settings.

Because our review of the research found that behavioral measures that examine children's curiosity are often complex, time-consuming to administer, and difficult to analyze for curiosity alone (without conflating curiosity with intelligence, achievement, interest, and other variables), the goal of the present research is to construct a brief, reliable, valid measure of curiosity. We designed a measure that captures the aspects of stretching and embracing – specifically as they pertain to participation in the practices of science. As such, this study investigates the following research question:

- How can the components of curiosity (embracing, stretching, and science) be assessed? We also address the following sub-questions:
  - does our measure of science curiosity vary across boys and girls, and
  - does our measure of science curiosity change across age groups.

We answer these questions through an exploratory and confirmatory factor analysis that included a structural equation model. We investigated whether the model was a good fit for our data – with secondary analysis of the fit of the resulting model for boys and girls separately and for three specific age groups: upper elementary, middle school, and high school.

Construction of our scale

In this article, we outline the psychometric development of the scale (i.e. the development of items used as well as the psychometric validity of the scale). This is only the first step of developing the instrument: we acknowledge that the linkage of science and curiosity should be evidenced in both reported interests and observable behaviors (Kashdan et al., 2004). As such, a future phase of this work will consist of a confirmatory psychometric analysis and mapping individuals' scores to their behaviors. By testing an instrument that is connected to observable behaviors in classroom, museum, and community activities, the resulting curiosity scale can be used effectively to show the impact of educational interventions on curiosity and interest development in science. The psychometric research analysis presented here is the necessary first phase of this broader confirmatory work.

Assumptions undergirding the scale

In development of our scale, we found our research aligned with two unique strands of science learning from *Learning Science in Informal Environments* (Bell et al., 2009) with attitudinal characteristics that we attributed to curiosity: Strand 1: Developing interest in science and Strand 6: Identifying with the scientific enterprise. These two strands highlight the unique opportunities that informal environments are able to address – generating excitement and supporting individuals as they develop scientific identities. With this in mind, we sought to construct and validate an instrument with which to measure scientific curiosity for children in and out of schools.

Although many of the scales and protocols created to measure curiosity focus on one aspect of curiosity, the correlation between the different scales indicates that multiple aspects of curiosity exist and can be measured simultaneously. In psychology, a subfield called positive psychology has been exploring the traits of successful learners (as opposed to the study of mental disease and psychopathology). In positive psychology, the CEI-II (Kashdan et al., 2009) was developed using modern statistical analysis and testing techniques of exploratory factor analysis with 311 (247 female) undergraduate college students. A second sample of 150 (99 females) undergraduates taking a psychology course was used to further validate the CEI-II through confirmatory factor analysis. A third sample of students (119 undergraduates, 99 female) from a psychology course participated in various measures that were compared to their score from the CEI-II. Finally, Kashdan et al. (2009) used IRT to examine the psychometric properties. This inventory was found to be valid and to best capture 'the "fat middle" of curiosity best' (p. 995), which is considered the ideal function of a scale. Our goal is to adapt this CEI-II for younger learners.

Development of items

We adopt the perspective of curiosity as outlined by Kashdan et al. (2009) that conceives of two independently measurable (but correlated) aspects of curiosity: (1) stretching or exploring, seeking new information and experiences and (2) embracing, the acceptance of the novel, uncertain, and unpredictable nature of everyday life. Stretching and embracing can be aggregated to measure a single construct, curiosity.

The CEI-II was selected as a basis for our scale items as the CEI-II incorporated the primary components of most research on curiosity into the two traits of stretching and embracing. While the perspective on curiosity of Kashdan et al. (2009) was in alignment with the science education and educational literature we drew from, we could not use CEI-II items with young learners because, while the scale was statistically valid, it was (a) written with items appropriate for adult learners and (b) developed with psychology undergraduate (and primarily female) students. We modified the language of the CEI-II questions (see Table 1 for original items) to make the items more appropriate for learners from 3rd grade to 12th grade. Vocabulary too difficult for children that was used in the CEI-II was exchanged for more developmentally appropriate terms. In addition, items addressing adults in work situations were changed to items related to children in school settings.

We consider that the stretching and embracing characteristics of curiosity as stated in the CEI-II incorporate general curiosity, but also align with practices of science learning. Kashdan et al. (2009) advocates for the investigation of curiosity within and across different knowledge domains. Therefore, we added the additional component of items relating to scientific practices, so that our newly developed scale would measure not only domain-

Table 1. Original CEI-II scale (Kashdan et al., 2009).

CEI-II items
1. I actively seek as much information as I can in new situations.
2. I am the type of person who really enjoys the uncertainty of everyday life.
3. I am at my best when doing something that is complex or challenging.
4. Everywhere I go, I am out looking for new things or experiences.
5. I view challenging situations as an opportunity to grow and learn.
6. I like to do things that are a little frightening.
7. I am always looking for experiences that challenge how I think about myself and the world.
8. I prefer jobs that are excitingly unpredictable.
9. I frequently seek out opportunities to challenge myself and grow as a person.
10. I am the kind of person who embraces unfamiliar people, events, and places.

general curiosity, but also specifically curiosity in science – mirroring the perspectives based on the Children's Science Curiosity Scale (Harty & Beall, 1984; Harty et al., 1986). Given the earlier critiques of the Children's Science Curiosity Scale, we examined the items with great care. We found that items were too specific to subdomains of science as well as too dated (i.e. 'I would like to experiment with the gadgets inside the space shuttle'). Additionally, some items were too confusing to interpret; for example, does the answer 'no' to 'I wonder what causes colorful sunsets' mean that the students do not wonder about sunsets or that they know the answer already? The Children's Science Curiosity Scale items also included actions, 'I like to visit zoos … ' that may not be possible for all families based on geographic or economic challenges of attending a zoo. Consequently, we utilized the intent of the Children's Science Curiosity Scale (Harty & Beall, 1984) to measure curiosity in science in concert with two U.S. national science standards documents, the *Next Generation Science Standards* (NGSS, National Research Council [NRC], 2013) and the *K-12 Framework* (NRC, 2012), to develop science curiosity items. In addition, we addressed the concerns of Osborne et al. (2003) who advocated for measures of attitudes in science to focus on the distinction between 'attitudes towards science' and 'scientific attitudes.' We focus on measuring scientific attitudes that illustrate scientific characteristics, practices, and thinking based on Osborne et al.'s recommendation that such attitudes can promote a scientifically literate society that is capable of sustaining today's sociotechnological economy. The 20 new science curiosity items were designed to measure the scientific attitude of curiosity based on research on the role of emotions and dispositions in science learning in school (Duschl, Schweingruber, & Shouse, 2007) and out of school (Bell et al., 2009).

We also aligned our scale items with the eight practices of science and engineering based on these and suggested examples of observable behaviors and actions within the K-12 Framework (NRC, 2012) and the NGSS (NRC, 2013). This is compatible with our intentions as the *Framework* states, 'The actual doing of science or engineering can also pique students' curiosity … ' (NRC, 2012, p. 42). The eight practices of science and engineering identified by the *Framework* are:

1. Asking questions (for science) and defining problems (for engineering);
2. Developing and using models;
3. Planning and carrying out investigations;
4. Analyzing and interpreting data;
5. Using mathematics and computational thinking;
6. Constructing explanations (for science) and designing solutions (for engineering);
7. Engaging in argument from evidence; and
8. Obtaining, evaluating, and communicating information.

The original items for science practices included topics of investigation, exploring, communicating, testing ideas, puzzling through solutions, and the like. Luce and Hsi (2014, p. 73) identified examples of curiosity within the context of scientific practices as 'engaging in scientific-like wonderment, question asking, experimentation, tinkering, pursuing an idea or following up on an inconsistency in knowledge, and ways of making meaning in scientific pursuits.' Other examples of curious behaviors were exploring, manipulating, interacting with the environment, observing, being attentive, asking questions, experimenting, and expressing interest in general information or facts (Jirout & Klahr, 2012; Luce & Hsi, 2014; Spektor-Levy et al., 2013; Zimmerman & Bell, 2014). As such, these practices that are central to science activity are often measured as observable behaviors when assessing student curiosity in the classroom. In a similar manner, the science items that we developed focused more on general practices in science, such as 'I would like to invent something new' and 'I mix things together to see what happens.' Although the science practices that we selected align with both the stretching (information seeking and exploration behaviors) and embracing (seeking novel and unpredictable behaviors) components of curiosity (Kashdan et al., 2009), these practices focus on specific behaviors, skills, and actions that are recognized as pertaining to science disciplines and domains, therefore encompassing a component of curiosity that is directed specifically at assessing curiosity in science (Spektor-Levy et al., 2013).

Thirty initial items in the SCILE scale

Based on the literature, the resulting initial Science Curiosity in Learning Environments (SCILE) contained 30 items (see Table 2) based on three main ideas, or factors, about curiosity:

Table 2. Initial 30 SCILE items prior to the exploratory factor analysis.

This sounds like me …	Always	Often	Sometimes	Not often	Never
If I saw something new, I would stop to check it out.	5	4	3	2	1
I like to find out how things work.	5	4	3	2	1
I like to solve riddles and mysteries.	5	4	3	2	1
I ask a lot of questions.	5	4	3	2	1
I like to look at the parts of a thing to understand how it works.	5	4	3	2	1
I would like to invent something new.	5	4	3	2	1
I mix things together to see what happens.	5	4	3	2	1
I like to learn about new discoveries.	5	4	3	2	1
I test out several ideas to see if any are right.	5	4	3	2	1
I compare things to see if there are any changes or differences.	5	4	3	2	1
I talk to people to find answers to my questions.	5	4	3	2	1
I like to work on problems or puzzles that have more than one answer.	5	4	3	2	1
I search for new information in books, on the Internet, at the library, or in a museum.	5	4	3	2	1
I explore new places, things, or ideas.	5	4	3	2	1
I experiment with stuff to see what will happen.	5	4	3	2	1
I look at objects to find patterns.	5	4	3	2	1
I like to make things that no one else has made.	5	4	3	2	1
I apply new information to an existing problem to see if that helps.	5	4	3	2	1
When I see a word I don't know, I look it up or ask someone what it means.	5	4	3	2	1
I like to know what causes things to happen.	5	4	3	2	1
I try to learn as much as I can in new situations.	5	4	3	2	1
I like days when I'm not sure what is going to happen.	5	4	3	2	1
I am at my best when something is very hard.	5	4	3	2	1
Everywhere I go, I like to find new things to look at or do.	5	4	3	2	1
I see a challenge as a way to grow and learn.	5	4	3	2	1
I like to do things that might scare me a little.	5	4	3	2	1
I look for new things to do, so I can learn more about the world and myself.	5	4	3	2	1
I like doing exciting and unpredictable things every day.	5	4	3	2	1
I like to try things that are hard for me.	5	4	3	2	1
I am happy to see new people, events, and places.	5	4	3	2	1

a. **Science practices** (20 questions developed from science learning and curiosity literatures);
b. **Stretching** to seek new information and experiences (5 items modified from CEI-II);
c. **Embracing** novel experiences of everyday life (5 items modified from CEI-II).

To confirm the appropriateness of the new curiosity assessment items with learners in third grade through high school, we checked the scale's reading level using a Flesch-Kincaid Grade level measure. The result was a 3.4 grade level for the SCILE scale.

Validating the SCILE scale

As stated above, we modified the original 10 CEI-II items to be more appropriate for a younger audience in terms of content of the items and language used as well as added 20 new items related to scientific curiosity based on the science practices literature, and therefore we validated the full 30-item survey through exploratory factor and confirmatory factor analyses as described below.

Setting and participants

The setting for this study was in the Mid-Atlantic USA in Pennsylvania; the three schools selected were classified by the U.S. Department of Education (2011) as rural, poverty-impacted schools. In 2010–2011, the US census listed the school districts' county with a slightly higher unemployment rate than the state and national average.

We administered the initial SCILE survey consisting of 30 items to 780 students in school grades from 3rd to 12th (see Table 3 for demographics). We received completed responses to 663 surveys (85%). The age of the students ranged from 9 to 18 years. The participants were drawn from the entire populations of four different school buildings within the two districts: one upper elementary building housing grades 4 and 5, one middle school with grades 6–8, one Jr/Sr High school housing 7–12, and one high school containing grades 9–12. In Table 3, the student ages are displayed as grade ranges.

Psychometric analysis

Determination of number of factors. We conducted an exploratory factor analysis (Fabrigar, Wegener, MacCallum, & Strahan, 1999) in SPSS using maximum-likelihood

Table 3. Demographics of participants ($n = 663$).

Category	Number of participants	Percentage
Gender		
Female	357	53.8
Male	306	46.2
Age range (as designated by school grade)		
Upper elementary (grades 4–5) – ages 9–11	159	24.0
Middle school (grades 6–8) – ages 11–14	231	34.8
High school (grades 9–12) – ages 14–18	273	41.2

Table 4. KMO and Bartlett's test.

Kaiser–Meyer–Olkin measure of sampling adequacy	.932
Bertlett's test of sphericity	
Approx. Chi-square	6598.249
df	435
Significance	.000*

*Significant at $p < .001$.

estimation with Promax rotation; this procedure has been used to validate other attitudinal scales in psychology and education (e.g. Kashdan et al., 2009). We selected the oblique rotation method for this analysis because we posit that the factors would be correlated components of scientific curiosity. An oblique rotation method was also chosen to construct a uni-dimensional scale (to combat the Gardner (1987) critique of the Children's Science Curiosity Scale (Harty & Beall, 1984)). The Kaiser–Meyer–Olkin measure of sampling adequacy was 0.932, which suggests that the internal reliability of our study was worthy of factor analysis; Bartlett's test of sphericity verified that factor analysis was appropriate – the approximate χ^2 was 6598.249 with 435 df, which was significant, $p = .000$ (see Table 4). Descriptive statistics were examined as well (See Table 5). After examining the eigenvalues and scree plot, which suggested that we retain six and four factors, respectively, we used a parallel analysis, which suggested that we retain three factors (Ledesma & Valero-Mora, 2007). This decision to retain three factors was made

Table 5. Descriptive statistics.

	N	Mean	Std. Deviation	Skewness	Kurtosis
Check	663	3.67	0.859	−0.222	0.036
Work	663	3.75	0.984	−0.394	−0.45
Riddles	663	3.22	1.254	−0.042	−1.038
Questions	663	3.41	1.206	−0.14	−1.023
Parts	663	3.29	1.112	−0.075	−0.755
Invent	663	3.34	1.347	−0.197	−1.185
Mix	663	3.3	1.231	−0.132	−0.957
Discoveries	663	3.39	1.167	−0.18	−0.824
Test	663	2.95	1.124	0.094	−0.672
Compare	663	2.87	1.049	0.16	−0.561
Talk	663	3.5	1.094	−0.327	−0.59
Problems	663	2.97	1.257	0.094	−0.975
Information	663	3.11	1.239	0.018	−0.99
Places	663	3.62	1.085	−0.408	−0.538
Experiment	663	3.42	1.207	−0.294	−0.844
Patterns	663	2.89	1.131	0.24	−0.68
Things	663	3.2	1.307	−0.069	−1.093
Helps	663	2.78	1.143	0.183	−0.696
Word	663	3.64	1.159	−0.458	−0.7
Happen	663	3.71	1.103	−0.553	−0.402
Situations	663	3.64	1.027	−0.425	−0.276
Days	663	3.24	1.282	−0.172	−0.968
Hard Look	663	3.45	1.229	−0.329	−0.789
Challenge	663	3.79	1.078	−0.581	−0.461
Scare	663	3.4	1.164	−0.252	−0.742
World	663	3.64	1.234	−0.606	−0.623
Unpredictable	663	3.44	1.109	−0.177	−0.681
People	663	3.78	1.143	−0.608	−0.49
Try Valid	663	4.08	0.949	−0.815	0.045
N	663	3.48	1.134	−0.347	−0.521
(listwise)	663				

through comparison of the eigenvalues of our dataset and those of a randomly generated dataset – the eigenvalues for our first three factors were all higher than a random dataset's results for eigenvalues. Based on our theoretical framework and literature review, we identified the remaining three factors of the scientific curiosity scale as (a) stretching, (b) embracing, and (c) scientific practices.

Identification of items. We proceeded with the exploratory factor analysis to reduce the large number of items (i.e., 30) to a narrowed-down number of items. Our target was 10–15 items, given the age of the younger participants and the ease of administering the survey in a variety of settings (e.g., homes, schools, museums, outdoor, and community) as long as the items would best represent scientific curiosity. We identified three factors (stretching, embracing, and scientific practices) from this analysis. Looking at the Pattern Matrix, 12 of the 30 test items (see Table 6) loaded strongly onto one of the three factors at above 0.500 with 41.227% of the variance explained by the first three factors. These aligned items confirmed our hypothesized relationship to the three factors: embracing, stretching, and scientific practices. Therefore, from our analysis, we identified 12 items (see Figure 1) – 6 aligned with stretching (2 from the original CEI-II and 4 items we designed as science practices items), 2 from embracing, and 4 from science practices to form the final SCILE scale.

Table 6. Identification of the 12 SCILE items with factor loadings.

SCILE items initially targeted toward Science (Sc), Stretching (Str), and Embracing (E) curiosity		Components associated		
		Stretch	Science	Embrace
Sc1	If I saw something new, I would stop to check it out.			
Sc2	I like to find out how things work.			
Sc3	I like to solve riddles and mysteries.			
Sc4	I ask a lot of questions.			
Sc5	I like to look at the parts of a thing to understand how it works.			
Sc6	**I would like to invent something new.**		**0.500**	
Sc7	**I mix things together to see what happens.**		**0.727**	
Sc8	I like to learn about new discoveries.			
Sc9	I test out several ideas to see if any are right.			
Sc10	**I compare things to see if there are any changes or differences.**	**0.536**		
Sc11	I talk to people to find answers to my questions.			
Sc12	**I like to work on problems or puzzles that have more than one answer.**	**0.548**		
Sc13	I search for new information in books, on the Internet, at the library, or in a museum.			
Sc14	I explore new places, things, or ideas.			
Sc15	**I experiment with stuff to see what will happen.**		**0.815**	
Sc16	I look at objects to find patterns.			
Sc17	**I like to make things that no one else has made.**		**0.550**	
Sc18	**I apply new information to an existing problem to see if that helps.**	**0.566**		
Sc19	**When I see a word I don't know, I look it up or ask someone what it means.**	**0.575**		
Sc20	I like to know what causes things to happen.			
Str1	**I try to learn as much as I can in new situations.**	**0.741**		
E1	I like days when I'm not sure what is going to happen.			
Str2	I am at my best when something is very hard.			
E2	Everywhere I go, I like to find new things to look at or do.			
Str3	**I see a challenge as a way to grow and learn.**	**0.641**		
E3	**I like to do things that might scare me a little.**			**0.520**
Str4	I look for new things to do, so I can learn more about the world and myself.			
E4	**I like doing exciting and unpredictable things every day.**			**0.746**
Str5	I like to try things that are hard for me.			
E5	I am happy to see new people, events, and places.			

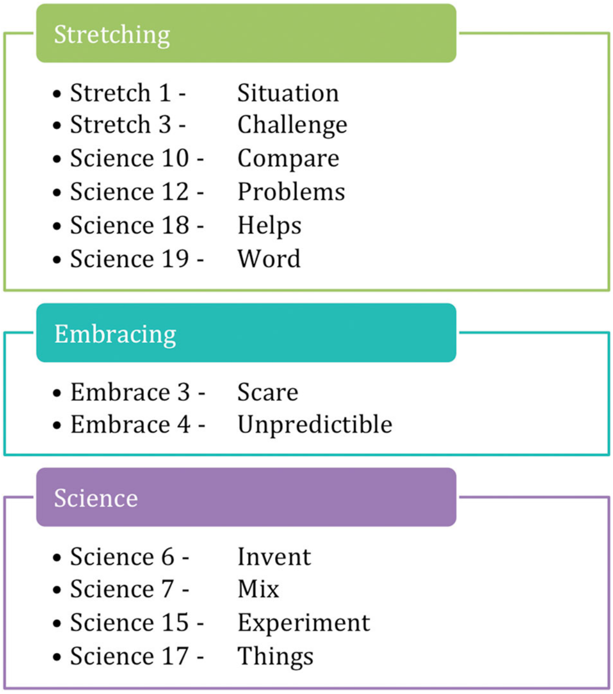

Figure 1. Alignment of SCILE items and factors identified using factor analysis. The three components explain 41.227% of the variance.

Confirmatory factor analysis

To further validate the SCILE scale and verify the factor structure between the variables, we performed a Confirmatory Factor Analysis on the data, utilizing AMOS software for this purpose. This analysis allowed us to verify that the relationship between the latent constructs of stretching, embracing, and science practices exists and is measured by the observed variables. Based on the number of factors determined in the initial exploratory factor analysis, the exploratory model, and theoretical framework, a model containing three latent variables, one with 6 indicators, one with 4 indicators, and one with 2 indicators was created (see Figure 2). The latent variables were connected via two-headed arrows in the model to indicate correlation. In addition, we correlated three error variances (e4<->e5, e12<->e8, e10<->e9) to generate better goodness-of-fit indices. The factor loadings (standardized regression weights) are shown in Figure 2. The goodness-of-fit indices were compared to statistical standards (Stevens, 2012) to determine the accuracy of the model. Although the χ^2 p-value for the model was significant ($p < .000$), which rejects the hypothesis that the model is a good fit, Stevens (2012) suggests that χ^2 statistic be considered a descriptive index instead of a statistical test rather than the p value. Therefore, we investigated the other indices, which ranged from acceptable to good (see Table 7). Based on multiple goodness-of-fit indices (GFI=.974, RMSEA=.043, CFI=.971, PCFI=.706) and statistical results, we determined that the goodness of fit for the three-factor model was acceptable (Table 7).

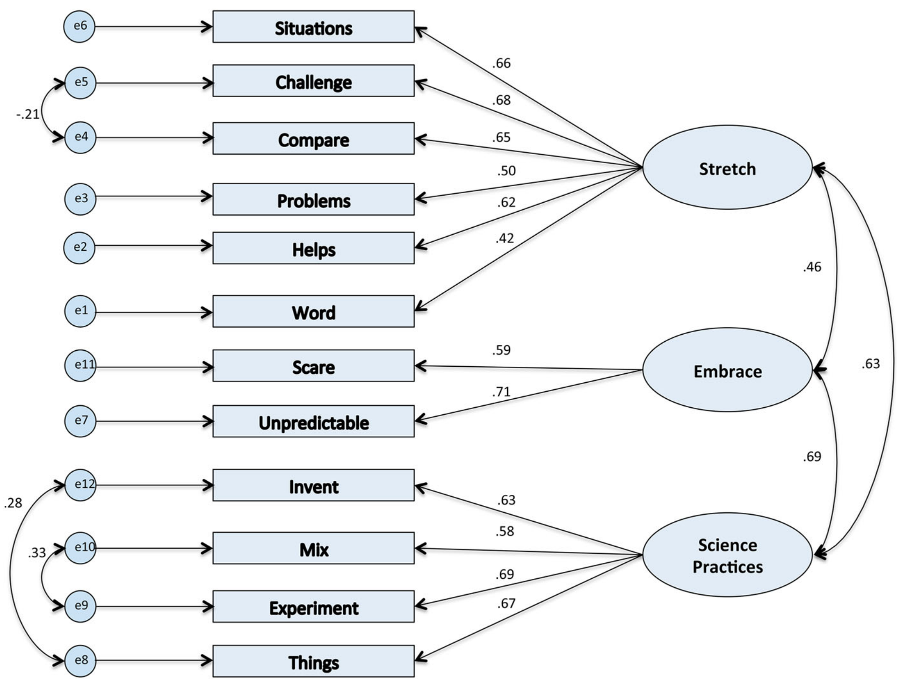

Figure 2. Model of SCILE scale. Developed from CFA showing three factors, variables, loadings and covariance.

After determining appropriateness of the initial three-factor model, we examined several other alternate models to determine goodness of fit. To rule out the possibility of other models that would also fit the data, we utilized a confirmatory factor analysis for two different alternative models. Models containing two and four latent variables

Table 7. Goodness-of-fit metrics for three-factor model. (Standards based on Hooper, Coughlan, & Mullen, 2008)

Overall goodness-of-fit index	Criteria standards	Model results	Evaluation results
Absolute fit indices			
Likelihood-ratio χ^2	$p > .05$	$p < .000$	Poor
df	–	48	–
CMIN		107.694	Acceptable
GFI	>.90	.974	Good
AGFI	>.90	.957	Good
RMR	<.08	.051	Good
RMSEA	<.08	.043	Good
Relative fit indices (compares model to Independence model)			
NFI	>.90	.949	Good
RFI	>.90	.930	Good
IFI	>.90	.971	Good
CFI	>.90	.971	Good
Parsimony fit indices (combats too many variables)			
PNFI	>.50	.690	Good
PCFI	>.50	.706	Good
Likelihood-ratio χ^2/df	<3	2.244	Good

Notes: GFI, goodness-of-fit index; AGFI, adjusted GFI; RMR, root mean residual; RMSEA, root mean square error of approximation; NFI, normed fit index; CFI, comparative fit index.

Table 8. Final SCILE scale.

This sounds like me	Always	Often	Sometimes	Not often	Never
I would like to invent something new.	5	4	3	2	1
I mix things together to see what happens.	5	4	3	2	1
I compare things to see if there are any changes or differences.	5	4	3	2	1
I like to work on problems or puzzles that have more than one answer.	5	4	3	2	1
I experiment with stuff to see what will happen.	5	4	3	2	1
I like to make things that no one else has made.	5	4	3	2	1
I apply new information to an existing problem to see if that helps.	5	4	3	2	1
When I see a word I don't know, I look it up or ask someone what it means.	5	4	3	2	1
I try to learn as much as I can in new situations.	5	4	3	2	1
I see a challenge as a way to grow and learn.	5	4	3	2	1
I like to do things that might scare me a little.	5	4	3	2	1
I like doing exciting and unpredictable things every day.	5	4	3	2	1

were analyzed and not found to have a better fit, which assumes that the initial three-factor model was appropriate.

In addition, multiple group comparisons were analyzed for boys and girls, as well as three age group bands in our sample. For the boys and girls, the model with all parameters constrained equally was found to be a better fit using a chi-square difference test ($\chi 2$ = 12.112, df = 9, p = 0.207). Across all age groups, the chi-square difference test also found that no significant differences existed across the groups for this model ($\chi 2$ = 23.944, df = 18, p = 0.157). A satisfactory fit of the model was found for each subgroup and for the multi-group analyses. As such, we conclude that the SCILE scale is suitable for boys and girls and for students in third through high school classrooms (or their out-of-school time activities). See the final SCILE scale items in Table 8.).

Discussion

In the past few years, many researchers have investigated the assessment of curiosity in science, primarily as (1) observable behavioral measures (Luce & Hsi, 2014; Spektor-Levy et al., 2013) or (2) as a component of scales measuring other constructs (Bathgate et al., 2014). Few studies, however, have focused on the psychometric development of a brief, validated measure of science curiosity. In this study, we sought to (1) delineate curiosity as it pertains to science through a brief self-report measure and (2) examine the performance of this scale across boys and girls and a range of school-aged youth. The SCILE scale provides initial evidence of science curiosity having a structure composed of three factors: stretching, embracing, and science practices. These dimensions of curiosity encompass the drive to seek out information and new experiences (stretching: six items), to test out experiences that are unfamiliar or uncertain (embracing: two items), and to participate in scientific practices in the pursuit of scientific knowledge (science practices: four items). The 12 SCILE items (see Table 8) show correlations between the subscales as expected, leading to our determination that these three components of stretching, embracing, and science practices are related aspects, allowing for the total, aggregated score to indicate an overall measure of science curiosity.

Alignment of items. The SCILE scale contains 12 items distributed across three factors: stretching, embracing, and science practices (see Table 8). The two items aligned with embracing curiosity focus on aspects of novelty and uncertainty. The six items loading onto the stretching factor include not only two items from the stretching component within the CEI-II scale (Kashdan et al., 2009), but also include four items originally crafted as questions oriented toward science practices. As the content of these items is centered on information-seeking behaviors, we posit that they align with Kashdan et al.'s definition of stretching curiosity, as well as aligning with fundamental practice within science. The four remaining SCILE scale items align with the science factor; these items target practices in science in ways that pertain to curious behaviors, primarily through exploring behaviors (Kashdan et al., 2004). Overall, we posit that these 12 SCILE items illustrate one concept, scientific curiosity, through three correlated constructs of stretching, embracing, and science practices (see Figure 1). Given the strong response and correlation from our large dataset with responses from over 650 young people, the 12 items of SCILE (see Table 8) provide a measure of a student's level of curiosity, with the reliability of the scale based on Cronbach's α of .91.

While in this first phase of research, we did not do a curiosity behavior comparison to scores; however, the psychometric results of the final selected items align with other ethnographic studies of science practices across settings – reinforcing the relevance of the items on SCILE scale to youth's everyday science activities. For example, a large research project (Bell, Bricker, Reeve, Zimmerman, & Tzou, 2013) based on an ethnographic study of a multicultural community of an elementary school found that children and their families self-reported an interest in mixing (Bricker & Bell, 2014) and in experimenting with things (Zimmerman & Bell, 2014), reinforcing the inclusion of two items: 'I mix things together to see what happens' and 'I experiment with stuff to see what will happen.' Given youth's interest in building, making, and tinkering (Bevan, Gutwill, Petrich, & Wilkinson, 2015; Wardrip & Brahms, 2015; Zimmerman & Bell, 2014), the two items 'I would like to invent something new' and 'I like to make things that no one else has made' fit well into the scale.

Some items that we conceived of as science practice items in SCILE aligned to the 'stretching' factor of curiosity. The inclusion of these items, 'I apply new information to an existing problem to see if that helps' and 'I compare things to see if there are any changes or differences,' is also warranted by the research on youth's activities. For instance, in a study of children in an afterschool club, Birmingham and Calabrese Barton (2014) found that high levels of affect and engagement were found when children developed questions and experiments to compare incandescent light bulbs to compact fluorescent lamp bulbs (commonly referred to as CFLs).

Gender and curiosity. While early work of Smock and Holt (1962) suggested that gender of the student affected the level of curiosity, our confirmatory factor analysis indicates that the SCILE scale had no appreciable difference between male and female students. This is important given work on gender and science that shows a gender gap in the achievement of science careers (Archer et al., 2012) – our early indications from this dataset show scientific curiosity to be similar for boys and girls.

Child's age and curiosity. The initial analysis of our scale indicates that three age ranges were adequately incorporated by scale. While more data collection and analysis is needed to understand how, when and in what circumstances scientific curiosity may vary by age, the initial fit of our model was not significantly different across age ranges. This finding is encouraging in light of the research that shows aspirations toward science do vary by age (DeWitt et al., 2013).

Next steps: ecological validity

Our next step is to administer the 12-item SCILE scale to approximately 300 learners in grades 3–12 in order to perform an additional confirmatory factor analysis. To investigate the ecological validity of the scale, we will administer the SCILE scale in conjunction with behavioral observations. This will allow us to examine the relationship between the students' SCILE curiosity measure, observable behaviors, and activities that the youth see as science related, as well as their self-reported level of interest in these activities.

Conclusion

Within this project, we aimed to advance an understanding of how curiosity in science can be measured when researchers work with children within or across formal and informal settings. Increased curiosity has been shown to be a benefit for youth in development of scientific literacy and understandings of technology and environmental issues (Bathgate et al., 2014); therefore, finding interventions that support students' curiosity in science is important. As such, we constructed the SCILE scale that is suitably written for youth, is short (12 items), and easy to administer and score. We created the SCILE scale as a tool to quickly measure self-reported levels of curiosity with youth that is applicable for research in schools, homes, museums, and the community settings. The SCILE encompasses a definition of curiosity as containing aspects of stretching, embracing, and science practices. The findings indicate that the SCILE scale is a valid measure of youth's scientific curiosity for boys and girls as well as elementary, middle school, and high school learners. This SCILE measure can support future research on scientific curiosity as it pertains to students in school, field trip, museum, and inquiry settings to better assess outcomes of educational programs that address ways of involving students more deeply in science and cultivating their interests in STEM.

Disclosure statement

No potential conflict of interest was reported by the authors.

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References

Archer, L., DeWitt, J., Osborne, J., Dillon, J., Willis, B., & Wong, B. (2012). "Balancing acts': Elementary school girls' negotiations of femininity, achievement, and science. *Science Education*, *96*(6), 967–989.

Arnone, M. P., Grabowski, B. L., & Rynd, C. P. (1994). Curiosity as a personality variable influencing learning in a learner controlled lesson with and without advisement. *Educational Technology Research and Development*, *42*(1), 5–20.

Bathgate, M. E., Schunn, C. D., & Correnti, R. (2014). Children's motivation toward science across contexts, manner of interaction, and topic. *Science Education*, *98*(2), 189–215.

Baxter, J. (1989). Children's understanding of familiar astronomical events. *International Journal of Science Education*, *11*(5), 502–513.

Bell, P., Bricker, L., Reeve, S., Zimmerman, H. T., & Tzou, C. (2013). Discovering and supporting successful learning pathways of youth in and out of school: Accounting for the development of everyday expertise across settings. In B. Bevan, P. Bell, R. Stevens, & A. Razfar (Eds.), *LOST opportunities* (pp. 119–140). Dordrecht: Springer.

Bell, P., Lewenstein, B., Shouse, A. W., & Feder, M. A. (Eds.). (2009). *Learning science in informal environments: People, places, and pursuits*. Washington, DC: National Academies Press.

Berlyne, D. E. (1954). A theory of human curiosity. *British Journal of Psychology. General Section*, *45*(3), 180–191.

Berlyne, D. E. (1966). Curiosity and exploration. *Science*, *153*(3731), 25–33.

Bevan, B., Gutwill, J. P., Petrich, M., & Wilkinson, K. (2015). Learning through STEM rich tinkering: Findings from a jointly negotiated research project taken up in practice. *Science Education*, *99*(1), 98–120.

Birmingham, D., & Calabrese Barton, A. (2014). Putting on a green carnival: Youth taking educated action on socioscientific issues. *Journal of Research in Science Teaching*, *51*(3), 286–314.

Bransford, J., Brown, A. L., & Cocking, R. R., National Research Council (US) Committee on Developments in the Science of Learning, and National Research Council (US) Committee on Learning Research and Educational Practice. (2000). *How people learn: Brain, mind, experience, and school.*

Bricker, L. A., & Bell, P. (2014). "What comes to mind when you think of science? The perfumery!": Documenting science-related cultural learning pathways across contexts and timescales. *Journal of Research in Science Teaching*, *51*(3), 260–285.

Collins, R. P., Litman, J. A., & Spielberger, C. D. (2004). The measurement of perceptual curiosity. *Personality and Individual Differences*, *35*, 1127–1141.

Crowley, K., & Jacobs, M. (2002). Building islands of expertise in everyday family activity. In G. Leinhardt, K. Crowley, & K. Knutson (Eds.), *Learning Conversations in Museums* (pp. 333–356). Mahwah: Lawrence Erlbaum Associates.

Day, H. I. (1971). The measurement of specific curiosity. In H. I. Day, D. E. Berlyne, & D. E. Hunt (Eds.), *Intrinsic motivation: A new direction in education* (pp. 99–112). New York, NY: Holt, Rinehart, & Winston.

DeWitt, J., Osborne, J., Archer, L., Dillon, J., Willis, B., & Wong, B. (2013). Young children's aspirations in science: The unequivocal, the uncertain and the unthinkable. *International Journal of Science Education*, *35*(6), 1037–1063.

Driver, R. (1985). *Children's ideas in science*. Philadelphia: Open University Press.

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (2007). *Taking science to school*. Washington, DC: National Academies Press.

Engel, S. (2009). Is curiosity vanishing? *Journal of the American Academy of Child & Adolescent Psychiatry*, *48*(8), 777–779.

Engel, S. (2011). Children's need to know: Curiosity in schools. *Harvard Educational Review*, *81*(4), 625–645.

Fabrigar, L. R., Wegener, D. T., MacCallum, R. C., & Strahan, E. J. (1999). Evaluating the use of exploratory factor analysis in psychological research. *Psychological Methods, 4*(3), 272–299.

Gardner, P. L. (1987). Comments on "toward the development of a children's science curiosity scale." *Journal of Research in Science Teaching*, *24*(2), 175. Retrieved from http://dx.doi.org/10.1002/tea.3660240209

Gennaro, E., & Lawrenz, F. (1992). The effectiveness of take-home science kits at the elementary level. *Journal of Research in Science Teaching*, *29*(9), 985–994.

Goff, M., & Ackerman, P. (1992). Personality-intelligence relations: Assessment of typical intellectual engagement. *Journal of Educational Psychology*, *54*(4), 537–552.

Grossnickle, E. M. (2014). Disentangling curiosity: Dimensionality, definitions, and distinctions from interest in educational contexts. *Educational Psychology Review*, *28*(1), 23–60.

Harty, H., & Beall, D. (1984). Toward the development of a children's science curiosity measure. *Journal of Research in Science Teaching*, *21*(4), 425–436. Retrieved from http://dx.doi.org/10.1002/tea.3660210410

Harty, H., & Beall, D. (1987). Authors' response to comments on "Toward the development of the children's science curiosity scale". *Journal of Research in Science Teaching*, *24*(2), 177–178.

Harty, H., Samuel, K. V., & Beall, D. (1986). Exploring relationships among four science teaching-learning affective attributes of sixth grade students. *Journal of Research in Science Teaching*, *23*(1), 51–60.

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

Hooper, D., Coughlan, J., & Mullen, M. (2008). Structural equation modelling: Guidelines for determining model fit. *Electronic Journal of Business Research Methods*, *6*(1), 53–60.

Jirout, J. J. (2011, March). Curiosity and the development of question generation skills. In *AAAI fall symposium: Question generation*. Pittsburgh, PA. Retrieved from http://www.aaai.org/ocs/index.php/FSS/FSS11/paper/view/4194

Jirout, J., & Klahr, D. (2012). Children's scientific curiosity: In search of an operational definition of an elusive concept. *Developmental Review*, *32*(2), 125–160.

Kashdan, T. B., Gallagher, M. W., Silvia, P. J., Winterstein, B. P., Breen, W. E., Terhar, D., & Steger, M. F. (2009). The curiosity and exploration inventory-II: Development, factor structure, and psychometrics. *Journal of Research in Personality*, *43*(6), 987–998.

Kashdan, T. B., Rose, P., & Fincham, F. D. (2004). Curiosity and exploration: Facilitating positive subjective experiences and personal growth opportunities. *Journal of Personality Assessment*, *82*, 291–305.

Kashdan, T. B., & Silvia, P. J. (2009). Curiosity and interest: The benefits of thriving on novelty and challenge. In C. R. Snyder & S. J. Lopez (Eds.), *Handbook of positive psychology* (2nd ed., pp. 367–374). New York, NY: Oxford University Press.

Kreitler, S., Zigler, E., & Kreitler, H. (1975). The nature of curiosity in children. *Journal of School Psychology*, *13*(3), 185–200.

Ledesma, R. D., & Valero-Mora, P. (2007). Determining the number of factors to retain in EFA: An easy-to-use computer program for carrying out parallel analysis. *Practical Assessment, Research, and Evaluation*, *12*, 1–11.

Litman, J. A. (2008). Interest and deprivation factors of epistemic curiosity. *Personality and Individual Differences*, *44*(7), 1585–1595.

Litman, J. A., & Jimerson, T. L. (2004). The measurement of curiosity as a feeling of deprivation. *Journal of Personality Assessment*, *82*, 147–15.

Loewenstein, G. (1994). The psychology of curiosity: A review and reinterpretation. *Psychological Bulletin*, *116*(1), 75–98.

Luce, M., & Hsi, S. (2014). Science-relevant curiosity expression and interest in science: An exploratory study. *Science Education*, *99*(1), 70–97.

Markey, A., & Loewenstein, G. (2014). Curiosity. In R. Pekrun & L. Linnenbrink-Garcia (Eds.), *International handbook of emotions in education* (pp. 228–245). New York, NY: Routledge.

Maw, W. H., & Maw, E. W. (1961). Information recognition by children with high and low curiosity. *Educational Research Bulletin*, *40*, 197–224.

Maw, W. H., & Maw, E. W. (1970). Self-concepts of high-and low-curiosity boys. *Child Development*, *41*(1), 123–129.

McReynolds, P., Acker, M., & Pietila, C. (1961). Relation of object curiosity to psychological adjustment in children. *Child Development*, *32*, 393–400.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas (Common Core)*. Committee on Conceptual Framework for the New K-12 Science Education Standards. Washington, DC: National Academy Press. Retrieved from http://www.nap.edu/catalog.php?record_id=13165.

National Research Council. (2013). *Next generation science standards (NGSS)*. Washington, DC: National Academy Press. Retrieved from http://www.nextgenscience.org/.

Naylor, F. D. (1981). A state-trait curiosity inventory. *Australian Psychologist*, *16*, 172–183.

Osborne, J., Simon, S., & Collins, S. (2003). Attitudes towards science: A review of the literature and its implications. *International Journal of Science Education*, *25*(9), 1049–1079. Routledge. doi:10.1080/0950069032000032199

Palmquist, S. D., & Crowley, K. (2007). Studying dinosaur learning on an island of expertise. In R. Goldman, R. Pea, B. Barron, & S. Derry (Eds.), *Video Research in the Learning Sciences*, (pp. 271–286). New York, NY: Routledge.

Piaget, J. (1969). *The psychology of intelligence*. New York, NY: Littlefield, Adams.

Rubenstein, D. J. (2000). Stimulating children's creativity and curiosity: Does content and medium matter? *The Journal of Creative Behavior*, *34*(1), 1–17.

Sharp, J. G., & Kuerbis, P. (2006). Children's ideas about the solar system and the chaos in learning science. *Science Education*, *90*(1), 124–147.

Silvia, P. J. (2006). What is interesting? Exploring the appraisal structure of interest. *Emotion*, *5*(1), 89–102. doi:10.1037/1528-3542.5.1.89

Smock, C. D., & Holt, B. G. (1962). Children's reactions to novelty: An experimental study of "curiosity motivation". *Child Development*, *33*, 631–642.

Spektor-Levy, O., Baruch, Y. K., & Mevarech, Z. (2013). Science and scientific curiosity in pre-school—The teacher's point of view. *International Journal of Science Education*, *35*(13), 2226–2253. doi:10.1080/09500693.2011.631608

Stevens, J. P. (2012). *Applied multivariate statistics for the social sciences*. New York, NY: Routledge.

Ting, K. L., & Siew, N. M. (2014). Effects of outdoor school ground lessons on students' science process skills and scientific curiosity. *Journal of Education and Learning*, *3*(4), 96–107.

Wardrip, P. S., & Brahms, L. (2015). Learning practices of making: Developing a framework for design. In *Proceedings of the 14th international conference on interaction design and children* (pp. 375–378). ACM.

Zimmerman, H. T. (2012). Participating in science at home: Recognition work and learning in biology. *Journal of Research in Science Teaching*. *49*(5), 597–630.

Zimmerman, H. T., & Bell, P. (2014). Where young people see science: Everyday activities connected to science. *International Journal of Science Education*. *4*(1), 25–53.

Zimmerman, H. T., & Weible, J. L. (in press). Learning in and about rural places: Connecting students' everyday experiences to science practices in the environmental sciences. *Cultural Studies of Science Education*. doi:10.1007/s11422-016-9757-1