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Review

Children's scientific curiosity: In search of an operational definition of an elusive concept[☆]

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ABSTRACT

Although curiosity is an undeniably important aspect of children's cognitive development, a universally accepted operational definition of children's curiosity does not exist. Almost all of the research on measuring curiosity has focused on adults, and has used predominately questionnaire-type measures that are not appropriate for young children. In this review we (a) synthesize the range of definitions and measures of children's curiosity and (b) propose a new operational definition and measurement procedure for assessing and advancing scientific curiosity in young children. In the first part of the paper, we summarize Loewenstein's (1994) review of theoretical perspectives on adult curiosity, and critically evaluate a wide range of efforts to create and implement operational measures of curiosity, focusing mainly on behavioral measures of curiosity in children. In the second part, we return to Loewenstein's theory and present an argument for adopting his "information-gap" theory of curiosity as a framework for reviewing various procedures that have been suggested for measuring children's exploratory curiosity. Finally, we describe a new paradigm for measuring exploratory curiosity in preschool children, defining curiosity as the threshold of desired uncertainty in the environment that leads to exploratory behavior. We present data demonstrating the reliability and validity of this measure, discuss initial results on developmental differences in young children's curiosity, and conclude with a general summary and suggestions for future research.

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Introduction

“Everyone knows what attention is”, William James (1950/1890) wrote famously over a century ago, and ever since, psychologists have struggled to reach a consensus on what attention really is. “Curiosity” has a similarly elusive definitional history. Here too, James offered an exasperatingly vague definition:

“‘Curiosity’ . . . is perhaps a rather poor term by which to designate the *impulse toward better cognition* in its full extent; but you will readily understand what I mean. . . . In its higher, more intellectual form, the impulse toward completer knowledge takes the character of scientific or philosophic curiosity. . . . Young children are possessed by curiosity about every new impression that assails them.” (James, 1899, pp 45–46)

In addition to its intellectual challenge, the elusiveness of a clear definition of curiosity has theoretical and practical implications. Absent a clear definition of what curiosity is, our understanding of developmental mechanisms that underlie it cannot be advanced, and the effectiveness of instructional processes aimed at stimulating and increasing it – especially in early science education (Engel, 2009) – cannot be assessed.

Curiosity is widely valued as a desirable attribute of a fully developed person, and is commonly depicted as an early appearing, albeit fragile, feature of young children’s orientation toward the world.

Children are born scientists. From the first ball they send flying to the ant they watch carry a crumb, children use science’s tools—enthusiasm, hypotheses, tests, conclusions—to uncover the world’s mysteries. But somehow students seem to lose what once came naturally. (Parvanno, 1990)

Parvanno’s lament expresses a common belief about an inevitable, albeit unintended, consequence of formal instruction – that children’s innate curiosity dissipates with age and schooling. However, there is little solid evidence about the developmental trajectory of curiosity, or what the impact of formal schooling might be on it. In fact, we present some preliminary data below suggesting that curiosity may be unaffected by age or schooling. These are important questions to pursue further, and in this paper we provide a basis for beginning to address them by focusing on a necessarily prior issue: the definition and measurement of curiosity. Following that, we discuss some novel empirical results with cross-sectional analyses of curiosity and the relationship with question asking in preschool through first grade children, and suggest instructional implications.

The lack of consensus about what “curiosity” really means, as well as how it can be measured, does not seem to have diminished the widespread enthusiasm for the term in establishing standards, and influencing legislation, particularly in the area of early childhood education. Many science curricula explicitly aim to foster curiosity, especially in young children (e.g., The University of Chicago Laboratory School science curriculum, University of Chicago, nd). The National Association for the Education of Young Children includes three separate “curiosity criteria” for assessing and accrediting preschool programs (National Association for the Education of Young Children, 2011),¹ and the first goal set by the National Education Goals Panel (NEGP) includes “openness and curiosity about new tasks and challenges” as an indicator of school readiness (Kagan, Moore, & Bredekamp, 1995, p. 23; National Education Goals Panel, 1995). The NEGP suggests that “children who start school with . . . a lack of curiosity are at greater risk of subsequent school failure than other children,” and reports that kindergarten teachers believe that curiosity is a more important predictor of school readiness, than the ability to count or recite the alphabet (NEGP, 1995, p. 24). The American Association for the Advancement of Science argues for the importance of curiosity in science education (American Association for the Advancement of Science (AAAS), 1993, 2008) and conducts annual workshops for elementary school teachers to train them in how to use developmentally appropriate procedures purported to foster children’s scientific curiosity.

¹ Specific NAEYC criteria: 2.B.04, “Children have varied opportunities to develop a sense of competence and positive attitudes toward learning, such as persistence, engagement, curiosity, and mastery”; 3.E.03, “Teachers use children’s interest in and curiosity about the world to engage them with new content and developmental skills”; 3.G.02, “Teachers use multiple sources (including results of informal and formal assessments as well as children’s initiations, questions, interests, and misunderstandings) to . . . foster children’s curiosity.”

In this paper, we attempt to advance the universal goal of such programs – fostering children's curiosity – by (a) focusing on unambiguous operational definitions of children's curiosity, (b) proposing some new procedures for measuring a potentially instructable form of early scientific curiosity in children, and (c) presenting some initial data on the development of curiosity in children and the relationship between curiosity and learning behaviors. We specifically focus on *scientific curiosity*, because it relates to information seeking behaviors, such as those that are observed in learning environments.² Within the set of papers on scientific curiosity, we limit our review to those that focus primarily on its developmental aspects. Because of the difficulty of using questionnaire-style measures of curiosity with the age group of interest here (discussed in more detail below), we focus specifically on behavioral measures of children's curiosity. Although more than 350 papers have been published in the last 50 years on the definition, measurement, training, and consequences of curiosity (“Curiosity”, 2010), few studies meet these criteria, and even fewer include operational definitions. Before describing these methods of assessing curiosity, we summarize the main theoretical positions on curiosity. We then turn to one highly plausible and reasonably well-defined construct, and describe several operationalizations and their use in assessing curiosity in preschool children.

Given that a central goal of just about every early science education program is to increase children's curiosity about the natural world, it would be of obvious importance if there were a widely agreed upon definition of curiosity. But there is no such definition, and – as we will show later in this paper – the operational measures for any particular definition vary widely from one study to another. Moreover, this definitional variability exists even within the subset of papers focusing on *scientific curiosity* – that is, studies limited to how people gather information and learn about some aspect of the natural world. Thus, one of our long-term goals is to describe a novel assessment tool to investigate the influence of curiosity on learning, and consequently, of curiosity on their learning, though this paper only describes the first step of designing and implementing a measure of scientific curiosity.

In sum, we believe that in order to understand the nature and development of children's scientific curiosity, as well as to study the extent to which any early childhood science program really does increase children's scientific curiosity, it is necessary to develop, and justify, an operational definition of curiosity in preschool children. That is a primary aim of this paper. In the following sections, we first summarize Loewenstein's (1994) review of theoretical perspectives on curiosity and then present an extensive review of operational measures of curiosity, focusing mainly on behavioral measures of curiosity in children. Then we return to Loewenstein's theory and present an argument for adopting his “information-gap” theory of curiosity as a framework for reviewing various procedures that have been suggested for measuring children's exploratory curiosity, and present work extending Loewenstein's theory to curiosity in children. Finally, we describe a new paradigm for measuring exploratory curiosity in preschool children, defining curiosity as the threshold of desired environmental uncertainty that leads to exploratory behavior, and describe some initial results of developmental trends in curiosity and the relationship between curiosity and question asking.

Theoretical background

The conceptual framework for our review of various procedures for measuring curiosity in children is based on Loewenstein's (1994) review and critical analysis of curiosity theories. After summarizing that broad review, we focus on his Information-Gap theory of curiosity and describe how we have used it to develop an operational measure of curiosity in young children.

Loewenstein's review is organized around four questions: (a) how to define and determine the dimensionality of curiosity? (b) what are the factors that determine the level of curiosity? (c) why do people voluntarily expose themselves to curiosity? and (d) what are the situational determinants of curiosity?

² Because of our interest in the relation between the development of curiosity and its educational implications, other types of curiosity were not included in our analysis, such as those relating to experimentation with sex or drugs or morbid curiosity, which are related to sensation seeking (Aluja & Garcia, 2005; Zuckerman & Litle, 1986).

Definitions and dimensions

Philosophers have struggled with the definition of curiosity for millennia, and have regarded it three different ways. Aristotle and Cicero viewed curiosity as an intrinsically motivated desire for information. St. Augustine and Hume viewed it as a passion, using terms such as “lust for knowledge”. Bentham and Kant referred to curiosity as being appetitive, similar to Ferubach’s idea that curiosity results from an unsatisfied knowledge drive. Later philosophers came to what Loewenstein referred to as the “pre-modern consensus” that curiosity is “an intense, intrinsically motivated appetite for information” (p. 77), including aspects of all three of the general definitions of curiosity from earlier philosophical theories. Many of these early theories regarded curiosity as similar to other drives such as hunger or thirst, and they did not address the question of whether curiosity was uni- or multi-dimensional. However, William James (1950) was one of the first to view curiosity as having at least two primary dimensions (a) common curiosity, including the excited or irritated feelings brought on by novelty, and (b) scientific curiosity, which is related to more specific items of information. Several subsequent theories continued or elaborated this multi-dimensional view of curiosity.

Behaviorist theories characterized curiosity in terms of a wide range of behaviors. Several of these characterizations describe curiosity in terms of attention to, or an orientation toward the object of one’s curiosity. These attention-laden descriptions were a departure from the earlier drive theories of curiosity. Other behaviors associated with curiosity included exploratory behavior, such as seeking variation in an environment. Berlyne’s many empirical studies of curiosity (1954, 1960, 1978), use a range of different behaviors to categorize distinct types of curiosity. According to Berlyne (1954), one type of curiosity was perceptual curiosity, which he saw as similar to a drive, thought to be aroused by novelty and reduced by exploration. Another was epistemic curiosity, which he defined as a desire for knowledge. A third distinction was between specific curiosity, which includes a desire for specific knowledge or information, and diversive curiosity, similar to boredom or stimulation seeking. An important contribution of Berlyne to the formulation of a definition of curiosity was his inclusion of both state and trait aspects, which remained a part of several subsequent investigations and measures of curiosity.

What causes curiosity?

The second aspect of Loewenstein’s treatment of curiosity addresses several different accounts of its cause. As mentioned above, many of the earliest theories viewed curiosity as a drive. Psychological drives produce arousal, which is unpleasant, and the arousal, in turn, motivates exploratory behavior in order to reduce the unpleasant arousal. In his theory of personality development, Freud suggests that curiosity develops as a product of the sex drive, resulting from the association of pleasure and sexual exploration. As children learn that overt sexual behavior is not socially acceptable, this exploration can sometimes evolve into general curiosity. Berlyne (1954) saw curiosity as having drive-like characteristics but suggested that context can activate cognitive processes that lead to arousal. He theorized that curiosity is aroused by environmental conflict or incongruity including, among other things, complexity, novelty, and surprise. Loewenstein, however, suggests that Berlyne’s question about whether or not curiosity is a drive is “probably neither answerable nor particularly important” (p. 82) beyond the general idea that curiosity is influenced by both internal and external factors.

Another group of theories, which Loewenstein calls the incongruity theories, suggest three aspects of curiosity. First, curiosity is generated by a desire to make sense of the environment. Second, this desire for sense-making is aroused when one’s expectations are violated. Third, there is an inverted U-shaped relation between the degree of the violated expectations and the likelihood that curiosity will be aroused. Piaget’s theory of curiosity exemplifies this U-shaped effort to resolve incongruous situations: “the subject looks neither at what is too familiar, because he is in a way surfeited with it, nor at what is too new, because this does not correspond to anything in his [schemes]” (Piaget, 1952, p. 68). Piaget viewed curiosity as a part of the process of assimilation, resulting from cognitive disequilibrium. Piaget’s theory of development would suggest that children are curious from birth, with developing cognitive schemas leading to new opportunities for surprising experiences that are discrepant from what a child believes. Loewenstein observes that while the causal attribution

literature tends to support incongruity theories of curiosity, there is not much support for the existence of an optimal level of incongruity, and that the incongruity theories may only explain a fraction of situations in which curiosity can arise. Similar to the incongruity theories, Gestalt psychologists suggested that the sole cause of curiosity is the need for sense making, i.e., that organizing knowledge into “coherent wholes” is motivating.

The competence and intrinsic motivation theories of curiosity suggest that curiosity is a component of an overarching competence motive. [Deci \(1975\)](#) characterizes curiosity as an aspect of all intrinsically motivated behaviors. Other theories view curiosity as an effect of the need for cognition and/or an aversion to ambiguity. However, Loewenstein argues that each of these theories fails to address one or more important factors related to the cause of curiosity, such as the salience of the specific missing information.

Voluntary exposure to curiosity

In addition to critically reviewing the different theories of curiosity, Loewenstein examines the extent to which each theory can account for an apparent paradox: Humans tend to voluntarily expose themselves to curiosity evoking situations, yet drive theories suggest that curiosity produces unpleasant arousal. In Berlyne's later writings, he modifies his drive theory of curiosity, by distinguishing between arousal and stimulus intensity ([Berlyne, 1978](#)). He suggested an optimal-level idea, with extreme levels of stimulus intensity relating to increased arousal. He believed that when arousal was too low people would seek curiosity-inducing situations, and when it was too high, they would explore in order to reduce curiosity.

Situational determinants

Loewenstein organizes his response to the final question – about the situational determinants of curiosity – according to each theory's treatment of it. Drive theories predict that unsatisfied curiosity will intensify. Exposure to suitable stimuli can reduce or satisfy curiosity, but situational determinants are not included in these theories. Incongruity theories suggest that curiosity is directly caused by environmental stimuli, specifically when expectations are violated, and that the extremity of the violations is related to the intensity of curiosity that is experienced. Similarly, competence theories say that curiosity is a result of environmental stimuli or information related to a person's competence. In a series of studies on stimulus properties associated with curiosity, Berlyne presented people with trivia items intended to elicit cognitive conflict, measured by their ratings of how surprising they found each item, and asked them to rate how much curiosity was evoked by each item. He observed a positive correlation between people's ratings of cognitive conflict for the trivia items and the corresponding ratings of curiosity, and participants were most likely to learn the answers to those items they ranked as most curiosity-evoking. Unfortunately, Berlyne's subsequent work investigating this relationship focused more on aesthetics and visual preference, instead of continuing the use of curiosity ratings and physical exploration. Few other researchers have looked at specific situational determinants of curiosity empirically. Loewenstein does, however, present his own theory of curiosity – the information gap theory – that includes aspects of all of the theories he reviews, and he has run several studies investigating the situational determinants of curiosity, which we review later in this paper and use as a basis for our own measure of curiosity in young children. The information gap theory suggests that curiosity is a result of feelings of deprivation, which are unpleasant and motivate information-seeking to reduce these feelings. This theory does not consider information-seeking behaviors that are not aversive to be curiosity, for example when there are no feelings of deprivation of information such as in the case of external reward, or just general interest. Besides being inconsistent with the information gap theory, this type of information-seeking behavior is suggested to be qualitatively different from that which results from curiosity, such as less intensity and impulsivity ([Loewenstein, 1994](#)). Litman and colleagues have recently extended Loewenstein's information gap theory of curiosity to include both deprivation (D) and interest (I) dimensions ([Litman, 2005](#); [Litman & Jimerson, 2004](#)). Empirical support for these two dimensions of curiosity includes positive relationships between D-type and aversive feelings such as anxiety and anger, and negative or no relationship

between I-type and the same aversive constructs (Litman, 2010), as well as different knowledge states associated with I- and D-type curiosity (Litman, Hutchins, & Russon, 2005). We describe Litman's (2005) theory, including both D- and I-type curiosity, in more detail below, while focusing on D-type curiosity, using the information-gap theory, as the foundation for our operationalization of curiosity.

Loewenstein's review of the literature provides an informative critical review and integration of existing theories of curiosity and discusses the problem of measuring curiosity. However, it does not specifically focus on developmental aspects, especially the variety of operational definitions and assessment procedures used to measure curiosity in children. Because we use Loewenstein's theory to develop a measure of curiosity as uncertainty preference, measured as a stable, independent variable, we hypothesize that this type of curiosity does not change drastically over time without some cause or intervention. We begin by applying Loewenstein's theory to young children to determine the relationship between uncertainty and curiosity. We then extend this work to create a precise measure of children's uncertainty preference, and look at the extent to which this changes with development.

In the following sections, we organize our review according to the two primary methods used to study curiosity: Questionnaire or self-report measures (Table 1), and behavioral measures (Table 2). The behavioral measures are grouped in sections of how curiosity was defined, ordered from more general to more detailed definitions used. Studies are listed in the tables in the order in which they are discussed below. For each study cited, we provide a summary of its key features, and our assessment of its strengths and weaknesses. Following this review, we return to Loewenstein's theory as a foundation for developing a measure of curiosity in young children, and present our empirical work assessing the validity of our measure, concluding with a discussion of the measure's use in studying the development of curiosity and how educational programs facilitate (or hinder) that development.

Questionnaire measures of curiosity

Questionnaires and surveys are often used to assess curiosity. A wide variety of self-report questionnaires for measuring curiosity in adults have been developed, and there is at least one such self-report that has been developed to assess children's curiosity, although most of the children's curiosity questionnaires involve judgments by teachers. In this section, we will discuss several of these measures and explain their shortcomings and limitations.

In the adult literature, self-rating scales of curiosity include items that ask participants how they feel or act in different circumstances. Survey-style measures of curiosity have the same problems with face validity as do other survey and self-rating scales. To the extent that respondents view "curiosity" as a desirable personal attribute, the demand characteristics of self reports can easily distort the truth. Moreover, it is very difficult to be sure that participants' understanding of each questionnaire item is the same as that intended by the researchers. These challenges notwithstanding, many studies have used surveys and self-ratings to assess curiosity and some have been quite successful in validating the measures used and contributing to the curiosity literature. For example Boyle (1979) observed significant differences in learning after manipulating curiosity in a study using the Melbourne Curiosity Inventory (described below), and Kashdan and Roberts (2004) successfully predicted affect in social situations using the State-Trait Curiosity Inventory (described below). Although there have been several examples of questionnaire use to investigate the relationship between curiosity and many other variables in the curiosity literature, our focus in this paper is limited to the *measurement* of curiosity, so we review only the actual measures and not the results of studies using those measures.

The Ontario Test of Intrinsic Motivation (OTIM) – developed by Day (1971) – is a paper-and-pencil instrument designed to measure Berlyne's view of curiosity (discussed above) as a personality trait. It is based on a generalization of Day's (and Berlyne's) earlier work on preference for, and exploration of, visual complexity, assuming that the same preference would be present in non-visual domains. The scale, comprised of 110 self-report items, asked participants to answer true or false to trait-oriented areas of interest. It was designed to look specifically at the relationship between curiosity and other constructs such as anxiety, creativity, academic achievement and mental health (Day, 1971).

Beswick (1974) used items from several other measures to include in his own 16 item self-report measure of trait curiosity. His "cognitive process theory" perceives curiosity as "a process of creating,

Table 1
Questionnaire measures of curiosity.

General features of questionnaire measures:						
<i>Positive:</i> <ul style="list-style-type: none"> • Typically have high validity and reliability, • Require few resources (time, manpower) 				<i>Negative:</i> <ul style="list-style-type: none"> • Demand characteristics (“Good participant”, “socially desirable” responses) • Participants’ reading ability must match written items 		
Citation	Measure(s) of curiosity	Theoretical definition	Type of questionnaire	Age group	Strength of measure	Weakness of measure
Day (1971)	Ontario Test of Intrinsic Motivation (OTIM)	Curiosity is a personality trait related to preference for and exploration of visual complexity	110 item, self-report	Adults	Based on many studies of preference for and exploration of visual complexity	Lengthy measure, very narrow focus: limited to visual preference only
Beswick (1974)	Self-report measure based on his Cognitive-Process theory	Cognitive process theory: curiosity is a process of creating, maintaining and resolving conceptual conflicts	16 item, self-report	Adults	Adopted strong items from other measures, strong estimates of reliability and validity	Only measured “trait” aspect of curiosity
Leherissey (1971)	State Epistemic Curiosity Scale (SECS)	Curiosity is a state in which one (a) desires more knowledge about a learning task, (b) approaches a novel or unfamiliar learning task, (c) approaches a complex or ambiguous learning task, and/or (d) persists in information seeking behavior in a learning task	20 items, self-report	Adults	Moderate positive correlation with the OTIM, negative correlation with anxiety	Only measured “state” curiosity, measure items considered too “narrow” (Boyle, 1983)
Naylor and Gaudry (1976)	Melbourne Curiosity Inventory (MCI)	Curiosity as a trait develops with exposure to situations that stimulate state-curiosity responses; different situations can vary in the degree to which they arouse curiosity as a state	20 items each scale (40 total), self-report	Adults	Included scales for both “state” and “trait” curiosity. Items created using a reliable anxiety scale	Not clear how different or separate the two scales were; they had identical items, and only differentiated “state” and “trait” curiosity by a slight change in the instructions
Spielberger et al. (1980)	State-Trait Curiosity Inventory (STCI)	Curiosity is motivated by the environment and amount of uncertainty and discomfort resulting from complexity, novelty or incongruity, and there are individual differences in optimal levels of these environmental factors	15 items each scale (30 total), self-report	Adults	Included scales for both “state” and “trait” curiosity. Items created using a reliable anxiety scale	Not clear how different or separate the two scales were; they had identical items, and only differentiated “state” and “trait” curiosity by a slight change in the instructions

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Table 1 (continued)

Citation	Measure(s) of curiosity	Theoretical definition	Type of questionnaire	Age group	Strength of measure	Weakness of measure
Maw and Maw (1970)	Teacher-classification, peer-ratings, “What would you do” task	Curiosity is demonstrated by an elementary school child when he: (1) reacts positively to new, strange, incongruous, or mysterious elements in his environment by moving toward them, by exploring, or by manipulating them, (2) exhibits a need or a desire to know more about himself and/or his environment, (3) scans his surroundings seeking new experiences, (4) persists in examining and exploring stimuli in order to know more about them	Teacher and peer ratings	Children, 5th-graders	Multiple sources of data are provided for each child. Peer-rating task was designed to be child-friendly	Correlated with intelligence suggests that may be measuring teacher and peers' perceptions of students as “good” or “bad” in school, not curiosity. Measure limited by only classifying children as “high” or “low”
Harty and Beall (1984)	Children's Scientific Curiosity	Curiosity considered to be frequency of and motivation to participate in science learning activities	Self-report scales of interest, attitudes, and curiosity	Children, 5th-graders	Effectively used by older, elementary-aged children	Items included in survey were about very specific behaviors, so children's individual interests could confound general measure of scientific curiosity
Loewenstein (1994)	Self-rating of feelings of curiosity	Curiosity is motivated by a lack of information; suggests an “optimal level” of information	Self-report	Adults	Scale was very simple to use and understand by participants	Measure was item-specific; participants rated curiosity about knowing specific information
Litman and Spielberger (2003)	Self-rating of feelings of curiosity and exploratory behavior	Curiosity is motivated by a lack of information; suggests an “optimal level” of information	Questionnaire and behavioral: Self-report and exploratory behavior	Adults	Both questionnaire scale and exploration task were very simple to use and understand by participants. No external reward or cost for exploratory behavior	Measures were item-specific; participants rated curiosity about knowing specific information, and only had opportunity to explore those specific items

Table 2
Behavioral measures of curiosity.

<div>General features of behavioral measures:</div> <div>Positive:<ul style="list-style-type: none">• Do not require reading and comprehension ability,• Tasks can be designed to be similar to participants' every-day experiences</div> <div>Negative:<ul style="list-style-type: none">• Resource consuming (man-power for both data collection and data coding),• Difficult to validate and standardize</div>						
Citation	Measure(s) of curiosity	Theoretical definition	Type of measure	Age group	Strength of measure	Weakness of measure
Kreitler et al. (1975)	Teacher-ratings, Object exploration, Novelty preference, Forced-choice exploration task	Curiosity is neither unitary nor homogeneous; Manipulatory and perceptual curiosity are the more dominant types, and curiosity about the complex, conceptual, and adjustive-reactive curiosity are less dominant types	Exploration and Preferences in structured situations	Children: 1st-graders	Used several measures to attempt to look at a range of "manifestations" of curiosity. Clearly described all measures	Study did not result in a single, "usable" measure, but rather suggested "types" of curiosity to be further studied. Very time consuming to administer all tasks
Byman (2005)	No new measure: Included five other measures from this table	Curiosity is a possibly multi-dimensional personality trait associated with sensation seeking	Self-report and teacher-report	Children: 5th-graders	Included a variety of questionnaire types in the factor analysis	Modified response scales and translated questionnaire; may have affected validity of measures included
McReynolds et al. (1961)	Object curiosity score	Curiosity is demonstrated by verbal and physical interactions with objects, with greater novelty stimulating greater curiosity	Spontaneous exploration	Children: 11 year olds	Task included a very large range of items for children to explore, helping to reduce possible confounds of different interests or familiarity levels	Did not code for or differentiate different behaviors or verbal questions, all were treated equally. Task (35 toys to be explored) and coding very time consuming
Minuchin (1971)	Object curiosity score, exploratory behavior frequency, teacher ratings	Curiosity is demonstrated with consistent responses to environmental stimuli, which can be measured by observation of behavior	Spontaneous exploration	Children: Pre-K (4s; Head Start)	Used observations of children with a specific object, as well as in natural settings	Did not control for different children's familiarity with the object used or with the observed activities (e.g., fieldtrip locations). Used rankings of children based on score, rather than score itself
Saxe and Stollak (1971)	Question asking and physical exploratory behaviors	Curiosity is demonstrated by instrumental actions which increase one's exposure to stimuli in the environment	Spontaneous exploration	Children: 1st-graders (Study included child–adult dyads; only children's curiosity measured)	Used observations of children exploring both novel and familiar objects in a natural play setting	Children's observed behaviors most likely affected by presence of mother during session. Did not control for different levels of familiarity with objects

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Table 2 (continued)

Citation	Measure(s) of curiosity	Theoretical definition	Type of measure	Age group	Strength of measure	Weakness of measure
Endsley et al. (1979)	Question asking and exploration of novel, over familiar, objects	Curiosity is the tendency to seek and collate new information	Spontaneous exploration	Children: 5-year olds (Study included child–adult dyads; only children's curiosity measured)	Used observations of children exploring both novel and familiar objects in a natural play setting	Children's observed behaviors most likely affected by presence of mother during session. Did not control for different levels of familiarity with objects
Smock and Holt (1962)	Preference for valued toy or unknown toy; Visual preference for stimuli differing in levels of novelty and familiarity, congruity and incongruity, ordered and un-ordered	Curiosity is motivated by exposure to new or different stimuli in one's environment	Preference for unknown, Visual preference for interesting stimuli	Children: 1st graders	Controlled for familiarity and preference for toys used in toy-preference task. Both preference tasks require little time and resources to administer	Only included one single trial of preference for unknown vs. valued toy. Majority of task was limited to visual preference, did not include actual exploratory behavior
Cantor and Cantor (1964)	Visual preference for novel vs. familiar stimuli	Curiosity is motivated by novel stimuli in one's environment	Visual preference for novel stimuli	Children: 5–7-year olds	Controlled for familiarity of visual stimuli using a familiarization/habituation procedure. Required little time/resources	Only observed children's visual preference for novelty, did not include actual exploratory behavior
Greene (1964)	Exploratory preference for exploring unknown over known success on a task	Curiosity is motivated by novelty as a problem-solving strategy	Preference for unknown	Children: Pre-K	Task controls for novelty and amount of success achieved before having an unknown exploratory choice. Required little time/resources	Exploratory preference for unknown confounded with individual differences in achievement motivation
Mendel (1965)	Exploratory preference for varying combinations of novel and familiar objects	Curiosity is approach behavior elicited by novelty	Preference for novelty/familiarity	Children: 3–5-year olds	Controlled for familiarity of objects using a familiarization/habituation procedure and offered range of groups of familiar/novel object proportions. Required little time/resources	Actual exploratory behavior beyond initial choice was not observed or coded. Children's curiosity was based on the single choice of toy group
Alberti and Witryol (1994)	Reward choice between known, valued toy and unknown, lesser-valued toy	Curiosity can be influenced by manipulations in uncertainty and information in a situation	Preference for unknown vs. valued object	Children, 1st- and 4th-graders	Included many trials of exploratory preference. Required little time/resources	Did not control for individual children's toy preferences; instead used previous toy shown to be highly valued by children as only "valued"

Henderson and Moore (1980)	Exploratory preference for known vs. unknown toy, preference for visual complexity, object exploration	Curiosity is the tendency to explore novelty in one's environment	Preference for unknown, Preference for complexity, exploratory behavior in structured task	Children: 3.5–5-year olds	Curiosity battery included range of tasks/variables measured, several trials included for each of the different tasks	reward option Did not control for individual children's familiarity with objects included, although one was not commercial object so novel to all children. Battery only resulted in single high/low curious categorization of children, despite range of variables measured
Arnane et al. (1994)	Visual interest in expected and unexpected stimuli, Exploratory behavior in a virtual environment	Curiosity is an intrinsic motivation to learn and explore, resulting from both an individual's tolerance of uncertainty and unfamiliarity levels and the presence of both of these in one's environment	Preference for unexpected visual stimuli, exploratory behavior	Children: 1st- and 2nd-graders	Measure included an aspect of exploratory behavior, although this was not used in study. Included multiple opportunities for both visual interest of stimuli and demonstration of exploratory behavior	Although exploratory behavior was part of the study, it was not coded and included in the actual curiosity measure. Children were ranked as either low- or high-curiosity based on their visual interest of unexpected stimuli
Vliestra (1978)	Exploratory behavior when presented with familiar toy objects and unknown, incongruent visual stimuli	Curiosity can be demonstrated by either specific exploration, motivated by novelty or discrepancy and mostly stimulus-related, or diversive exploration, motivated by interest and play behaviors and mostly response-oriented	Specific behaviors and time spent interacting with physical and visual stimuli	Children and Adults: Pre-k and College-aged students	Measure attempted to include two "types" of curiosity, coded both specific behaviors and time on different types of tasks (preference for different behaviors)	Did not control for different levels of familiarity and experience with objects. Different age groups most likely had different interpretations of task expectations and goals
Mittman and Terrell (1964)	Curiosity was manipulated, not measured, by stimuli. Study tested whether performance would be greater when curiosity was higher	Curiosity arises from the awareness of one's lack of knowledge or information in a situation	Curiosity manipulated by amount of information given	Children: 1st- and 2nd-graders	Curiosity was manipulated, not measured. Strengths of this approach is that it allows investigation of the influence of curiosity level on tasks	Curiosity was manipulated, but the study used a between-subjects design, so subjects were only tested while experiencing a single level of curiosity. A within-subjects design would have been a more valid approach
Charleworth (1964)	Amount of interest (reaction time, choice of repeating events) among different levels of surprise/violated	Curiosity is aroused when expectations or beliefs are violated	Reaction to surprising events	Children: 4–5-year olds (mostly low-income)	Task was simple and required little time and resources. Measure provided quantitative, objective data	While subjects could repeat events, there was no opportunity for exploratory behavior. The type/context of

(continued on next page)

Table 2 (continued)

Citation	Measure(s) of curiosity	Theoretical definition	Type of measure	Age group	Strength of measure	Weakness of measure
	expectations				without need for in-depth coding	surprise was always the same; not clear if results would generalize to other contexts
Schulz and Bonawitz (2007)	Exploratory preference among ambiguous, unambiguous, and novel options	Curiosity is greater for ambiguous situations than for novel or familiar ones	Exploratory preference	Children: Pre-K	Task was simple and required little time and resources. Measure provided quantitative, objective data without need for in-depth coding	Study only included opportunity to explore causal relationships. Not clear if results would generalize to non-causal contexts

maintaining and resolving conceptual conflicts". This theory is almost identical to Piaget's account of the process of equilibration: when incoming information does not fit into a person's current cognitive map, she/he will resolve this conflict by either altering how she/he perceives the stimuli to fit the current map or by altering that cognitive map to accommodate the information. A highly curious person, however, rather than execute either of these processes to reduce the conflict, will first seek additional information, and then use it to fill the gap in the cognitive map. Beswick's studies suggest that curious people seek not to avoid conflict, but rather to resolve uncertainty, while continuing to search for new experiences that produce cognitive conflict (Beswick, 1971, in Boyle (1983)). Apart from Beswick, however, most curiosity researchers felt that there might indeed be traits associated with curiosity. Moreover, they believed that the state aspects of curiosity were quite important and needed to be included in any curiosity measure.

On the opposite side of the state-trait spectrum from Beswick, Leherissey focused on the state aspect of curiosity by creating the State Epistemic Curiosity Scale (SECS; Leherissey, 1971). The SECS consisted of 20 self-report items that attempted to measure when participants "(a) know more about a learning task; (b) approach a novel or unfamiliar learning task; (c) approach a complex or ambiguous learning task; and (d) persist in information-seeking behavior in a learning task." Leherissey's use of this measure was supported by the moderate, significant relationship with the measure and the OTIM, as well as by the commonly found negative relationship with anxiety measured by the State-Trait Anxiety Inventory (STAI; Spielberger, 1983).

Because studies consistently found a negative correlation between anxiety and curiosity, (Naylor, 1981; Naylor & Gaudry, 1976) used the STAI as a model for their Melbourne Curiosity Inventory, which included the C-State and C-Trait scale. Participants rated each of 20-items using a four-point, Likert scale (ex: "I feel like asking questions about what is happening"). While the items on both scales were the same, instructions on answering the items and the rating scale labels were different. Instructions for the C-Trait scale were to respond as to how he generally feels, while the C-State scale instructions were to respond as to how he feels at a particular moment in time. The ratings for the C-Trait scale were, "almost never, sometimes, often, almost always," while the C-State labels were, "not at all, somewhat, moderately so, very much." Around the same time, Spielberger, Peters, and Frain (1980) developed a similar, 15-item State-Trait Curiosity Inventory (STCI), also using the STAI as a model. Not surprisingly, the instructions, the response labels, and the actual items for both the MCI and STCI were very similar. However, the STCI was later developed into a general psychometric measure, the State-Trait Personality Inventory (STPI) which includes curiosity among several other factors.

Another measure recently used to study curiosity is the Typical Intellectual Engagement scale (TIE; Goff & Ackerman, 1992). This scale assesses "a personality trait hypothesized to relate to typical vs. maximal intellectual performance" (p. 539). The TIE is not intended to assess curiosity specifically, but rather to "differentiate among individuals in their typical expression of a desire to engage and understand their world, their interest in a wide variety of things, and their preference for a complete understanding of a complex topic or problem, a need to know" (Goff & Ackerman, 1992, p. 539). An example of one of the 59 items on the TIE is, "I prefer my life to be filled with puzzles I must solve," with participants responding on a six point Likert style scale. Von Stumm and colleagues suggest that the TIE can be used to assess curiosity, because "measures of intellectual investment and curiosity have matching conceptual roots, include semantically identical items, and share criteria validity for academic performance and intelligence; therefore, they appear to assess the same trait dimension, and corresponding scales might be interchangeably used." (von Stumm, Hell, & Chamorro-Premuzic, 2011, p. 577). In a meta-analysis of studies that assessed adults' TIE and several other personality, intelligence, and achievement traits, von Stumm and colleagues observed expected relationships between TIE (used as a measure of intellectual curiosity) and academic performance. Even after controlling for intelligence, TIE explained variance in academic performance, and the "additive predictive effect of the personality traits of intellectual curiosity and effort rival that of the influence of intelligence" (p. 574).

Several additional measures of various constructs have been used as indicators of curiosity or to validate curiosity scales. These include the Novelty Experiences Scale (NES; citation?), the Sensation Seeking Scale (SSS; citation), the Epistemic Curiosity Scale (ECS; Litman & Spielberger, 2003), the Curiosity as a Feeling-of-Deprivation scale (CFDS; Litman & Jimerson, 2004) and the Curiosity and

Exploration Inventory (CEI; Kashdan, Rose, & Fincham, 2004), which all were shorter versions targeting specific components of curiosity. For example, the CEI measures two specific components of curiosity: approach-orientated strivings for novelty and challenge (exploration) and the ability to direct and sustain attention toward inherently interesting activities (absorption). As discussed above, Litman and Jimerson's (2004) theory of curiosity includes two dimensions: interest (I) and deprivation (D) types. To assess these two dimensions, participants respond how often they encounter specific feelings, such as, "If I read something that puzzles me, I keep reading until I understand" (D-curiosity) and "I like to listen to new and unusual kinds of music" (I-curiosity; Litman & Jimerson, 2004). Measures of I- and D-curiosity were further refined to be a single scale including only 10 items, five for each dimension of curiosity, with support for the scale's validity and reliability (Litman, 2008). One benefit of the shorter length of these scales is that they take much less time to administer, which makes them ideal in areas such as education research where time is such a limited resource.

Although questionnaires have been useful in studying curiosity in adults, they can be difficult to use with children for two reasons. First, children have limited reading and comprehension abilities, and second they lack the skills and knowledge necessary to self-assess on abstract states or traits like curiosity. Some researchers have created very simple questionnaires for children, collected adults' curiosity ratings of the child, or even had children rate the curiosity level of their peers. One frequently used method of children's curiosity ratings is that of Maw and Maw (1964).

Maw and Maw developed the following definition and description for use by teachers and parents through a series of studies (Maw & Maw, 1961).

"Curiosity is demonstrated by an elementary school child when he: 1) reacts positively to new, strange, incongruous, or mysterious elements in his environment by moving toward them, by exploring, or by manipulating them, 2) exhibits a need or a desire to know more about himself and/or his environment, 3) scans his surroundings seeking new experiences, and 4) persists in examining and exploring stimuli in order to know more about them." (Maw & Maw, 1964, p. 31)

Maw and Maw (1961) had teachers classify children as high or low curious by having them rank their students from highest to lowest. Additionally, children rated their peers' and their own curiosity. They were presented with eight stories, four describing a very curious child and four describing a child that is not very curious, and they were then asked to give the name of a child (or themselves) that best fit the story. Although teacher and peer ratings were correlated, the teacher ratings also correlated with intelligence, and have been criticized as measuring IQ instead of curiosity (Silvia, 2006). To improve their measure of curiosity, Maw and Maw (1970) investigated the relationship between curiosity ranking (high or low) and a behavioral measure: children's exploration. Participants were 5th grade students, who were given the "what would you do?" task, which originally included 50 questions with subsequent revisions of 56 and 26 items. Children would choose the mostly likely of four given actions they would take in response to hypothetical situations. Maw and Maw concluded that boys classified as high curious by teachers and peers preferred more exploratory activities than girls classified as low curious. This study contributed to the investigation of curiosity in two ways. First, it provided some validation of the use of self-assessments of likely exploratory behaviors as an indicator of curiosity by demonstrating correlational results of multiple measures. Second, it offered child-friendly approaches to measuring curiosity by demonstrating that children were able to rate their peers' curiosity. However, because this method provides only a broad measure of whether children are "high" or "low" in curiosity, using a median split, it is not very useful in studying individual differences in children's curiosity or looking at relatively short term changes in curiosity – as judged by teachers or peers – caused by a specific curriculum or pedagogical strategy.

The children's curiosity measure that is most similar to the adult measures is Harty and Beall's questionnaire-style measure of children's scientific curiosity (Harty & Beall, 1984). Harty and Beall use a more specific view of "Scientific Curiosity" than previous researchers, who defined it as a desire for specific information in any domain, whereas Harty and Beall only include the desire for information in science domains. Fifth grade students completed the Children's Science Curiosity Scale, which included three subscales designed to measure their science interest, attitudes towards science, and scientific curiosity. All three scales used Likert rating scales and consisted of similar items, phrased differently depending on the specific measure. For example, the *interest* item might involve using a

telescope, the *attitude* item might ask about whether the student enjoys looking at stars, and the *curiosity* item might involve rating how often a student looks at the stars. Not surprisingly, the researchers report a significant positive relationship across the three measures. Also, they found that active items (such as using a telescope) were rated higher than passive items (like reading about a science topic). Although this study could have some implications for science education, such as including more active methods in instruction, the measure's external validity is suspect because the items referenced such few, specific behaviors as opposed to general exploration and information seeking behaviors. Additionally, younger children would be unlikely to understand the rating system of the items and might have trouble comprehending the described behaviors, as indicated in the literature on children's use of rating scales (Chambers & Johnston, 2002).

In summary, there is a tenuous match between most of the definitions of curiosity – which are related to actual behaviors – and the commonly used self-report measures, or reports by teachers and/or parents about children's curiosity. Additionally, even for measures of adult curiosity, it is difficult to determine exactly how the statements on these instruments are interpreted by participants, and whether or not these are the right items to use to measure curiosity. Consequently, some researchers have explored the item validity issue by including several measures in factor-analytic studies in order to discover the relationships between the different measures and their items.

Factor analytical studies

While some studies use multiple measures of curiosity to calculate a curiosity index, other studies look at items across several different measures for specific factors or types of curiosity using factor analysis. Several researchers have included several such measures in factor-analytic studies to determine the dimensionality of the curiosity construct. Both Ainley (1987) and Reio, Petrosko, Wiswell, and Thongsukmag (2006) had participants complete multiple measures and then a conducted factor analysis to identify types of curiosity. Ainley used five measures: the Test of Intrinsic Motivation (Beswick, 1971), Ontario Test of Intrinsic Motivation (Day, 1971), Melbourne Curiosity Inventory-Trait form (Naylor, 1981), Novelty Experiencing Scale (Pearson, 1970), and the Sensation Seeking Scale (Zuckerman, 1979). Data from 227 college students on all five measures were best fit by a two-factor model that included “depth”, associated with items that described investigation of objects, ideas, etc., in order to better understand them, and “breadth”, associated with items that included preferences toward variation or change seeking. The scales that loaded on the depth factor were: Test of Intrinsic Motivation, the Ontario Test of Intrinsic Motivation-Specific Curiosity, Melbourne Curiosity Inventory-Trait Form, Novelty Experiencing Scales-Internal Cognition and External Cognition. The scales that loaded onto the breadth factor were, Sensation Seeking Scales: Thrill and Adventure Seeking, Experience Seeking, Disinhibition, Boredom Susceptibility, and the Novelty Experiencing Scale-Internal Sensation. While the idea of breadth and depth factors of curiosity was not completely novel, the factor analysis did provide evidence of the two distinct factors across the different scales. Using the Melbourne Curiosity Inventory (Naylor, 1981), the State-Trait Personality Inventory (Spielberger et al., 1980), the Sensation Seeking Scale (Zuckerman, 1979), the Novelty Experiencing Scale (Pearson, 1970) and the Academic Curiosity Scale (Vidler & Rawan, 1974), Reio et al. identified three separate factors: (1) cognitive curiosity, including items related to information seeking such as “I like searching for answers” and “I like thinking a lot about a new idea”; (2) physical thrill seeking, including items that describe risky activities, such as cliff diving; and (3) social thrill seeking, which includes items that involve social risks, such as social drinking or participating in illegal activities just for the thrill of violating the law.

Factor analysis has also been used to examine specific types of curiosity. Litman (2008) investigated epistemic curiosity, similar to Reio's cognitive curiosity factor and including aspects of both Ainley's breadth and depth factors, using the Epistemic Curiosity Scale and the curiosity as a Feeling-of-Deprivation scale. He specifies that epistemic curiosity is a motivation driven by the desire for knowledge that leads to intellectual problem solving, learning new ideas, and resolving information-gaps. Within epistemic curiosity, he found the items of the two scales to load onto two distinct factors, interest (including items like, “I enjoy exploring new ideas”) and deprivation (including items like, “I can spend hours on a problem because I cannot rest without knowing the answer”). While each

of these studies provides a different perspective on the complexity of curiosity, none of them has produced a definitive definition of curiosity or a way to measure it that somehow addresses all of the other aspects of curiosity. One common finding that does support using the measures included in each, however, is that the paper-and-pencil type measures do all seem to correlate, suggesting that they are all investigating some aspect of curiosity.

Although there has been some success in using paper-and-pencil and factor-analysis methods of measuring curiosity, data from self-report questionnaires is limited in its use, and is quite difficult to establish construct validity, even in adults (Bertrand & Mullainathan, 2003; Piccinini, 2003). As a result, behavioral measures have become much more popular in the study of curiosity. This preference is especially true when studying children's curiosity, for several reasons. Depending on the target age group, children can have quite limited reading ability. Even if the survey items are administered orally, the risk of poor comprehension is much greater than with adults. Also, children get distracted and tire easily, and survey measures are not especially entertaining. In contrast, behavioral measures of curiosity do not require the same levels of comprehension skills and they measure actual exploration and information seeking, which is an essential manifestation of curiosity. Using observable behaviors as indicators of curiosity seems a much more valid method of measuring children's curiosity.

Behavioral measures of curiosity

Exploratory behavior is commonly observed in every day settings, especially those involving children. Given the widespread assumption that exploration is driven by curiosity, is not surprising that people presume to “see” curiosity-driven behavior in much of children's everyday activities. Behavioral measures of curiosity typically involve observing such behavior in a range of environments, from tightly controlled situations where researchers are interested in the effect of a specific aspect of the environment on curiosity, to broader approaches that observe spontaneous exploratory behavior under many different circumstances and environmental situations. Both ends of the spectrum have obvious benefits and costs with respect to construct and ecological validity, which has resulted in many different approaches to the measurement of curiosity. In the following sections, we describe these approaches and situate them along a spectrum ranging from broad to specific measures, beginning first with factor-analytic studies that include measures from both ends of the spectrum, as well as questionnaire-style measures similar to those discussed above. The subsequent sections include: Spontaneous Exploration Measures, Exploratory Preference Measures, Novelty Preference Measures, Measures of Preference for Complexity/Unknown, and Preference for Uncertainty/ Ambiguity. As with the previous section on questionnaire measures, our focus here is on the *measures* of curiosity, rather than on results that examine the relationship between curiosity and other variables.

Factor analytical studies: behavioral and questionnaire

Kreitler, Zigler, and Kreitler (1975) used a factor-analysis approach to measure curiosity in first-grade students. They collected both questionnaire-style teacher ratings as well as several direct behavioral measures of different manifestations of curiosity. Kreitler and colleagues' main goal was to analyze different manifestations to determine specific factors – or types – of curiosity. Their results indicate five separate “curiosity factors”: (1) Manipulatory Curiosity, (2) Perceptual Curiosity, (3) Conceptual Curiosity, (4) Curiosity about the complex or ambiguous, and (5) Adjustive-reactive curiosity.

Kreitler and colleagues included five behavioral measures of children's curiosity in order to assess: (1) observation of simple and complex stimuli, (2) preference of simple and complex stimuli, (3) structure of meaning, (4) object exploration, and (5) preference for the unknown. In this paper we describe only the latter three, because the first two were simply visual preference. The task addressing “structure of meaning” involved presenting children with toys (e.g., a car, an iron, a telephone, and a piano) and asking them to describe the objects. Children's responses were coded according to the number of things said and the number of types of comments, such as the object's function or place of existence. Kreitler et al. considered these behaviors to be conceptual exploration of the objects, even though children were only allowed visual exploration. Indeed, measures of this kind of behavior did load highly

onto the conceptual curiosity factor, along with measures of question asking and exploratory manipulation.

A second method of measuring conceptual learning used by Kreidler et al. included measures of manipulation and novelty/ambiguity preference in the object exploration task. In this task, children were presented with the same four toys, as well as four new, but equally familiar, toys (a truck, a red board with removable screws and flaps, a kaleidoscope, and a set of barrels that could be inserted into one another). The child could choose which set of toys to explore, and was then left alone in the room with the chosen toys while being observed through a one-way mirror. Finally, the experimenter returned and encouraged the child to ask any questions he or she had about the toys. The researchers coded the child's choice of toys to play with, the time it took the child to respond to the question of which toys to play with, the number of "inspective" manipulations of toys (when a child inspected a toy), the number of "customary" manipulations (child's use of toy in its customary manner), exploratory manipulations (behaviors to learn how an object operates or is structured, such as attempts to take something apart), the total time spent exploring the four objects, and a weighted index of questions asked about the toys. Variables from this task loaded into at least one of four of the curiosity factors identified in the study, with none in the "curiosity about the complex" factor.

In the "preference for the unknown" task, children were presented with pictures of houses, each with two "door" flaps, one of which had a picture showing what would appear under the flap, while the other flap was blank. Children were allowed to open one flap on each house. The researchers recorded which flap children opened on each house and how many times they switched between opening a blank flap to a picture flap or vice versa, variables that both loaded onto the "Adjustive-Reactive" factor of curiosity. (In the final sections of this paper, we describe the way in which we adapted and extended this procedure to develop a novel method for measuring children's exploratory preference under different levels of uncertainty.) In addition to the behavioral measures, the researchers collected curiosity ratings from teachers, which were analyzed as another variable in the factor analysis, where they loaded on the adjustive-reactive curiosity factor.

Variables collected using the five behavioral measures and teacher ratings were analyzed using factor analysis, resulting in five separate curiosity factors: (1) Manipulatory Curiosity, elicited by objects with some degree of novelty which can be explored manually; (2) Perceptual Curiosity, which mostly measures visual exploratory behaviors such as matching, comparing, and observing; (3) Conceptual Curiosity, which includes exploratory behaviors motivated by the desire to understand meaning or specific function of an object; (4) Curiosity about the complex or ambiguous, which measures exploratory preference for more complex objects or objects with more information to understand; and (5) Adjustive-reactive curiosity, which seems to measure exploration of objects that are most expected or common to the specific object, and basic identification and acknowledgment of all available objects.

This study is important in demonstrating that the many different types of curiosity may generate correspondingly many different behaviors. It is clear that the general term "curiosity" is substantially underconstrained with respect to definition, measurement, and implications. Only when the different "types" of curiosity are unambiguously and operationally defined, can cross-study comparisons be possible. Additionally, recognizing the different types of behaviors that can be considered to be curiosity can help researchers to determine what specific curiosity behaviors are relevant for specific research questions. For example, several of the variables collected in this study resulted from attention to complex pictures or patterns on paper vs. simple pictures or patterns. This type of perceptual data might not be appropriate to compare to exploration data when studying learning. On the other hand, the variables collected in the "preference for the unknown" are quite consistent with Loewenstein's Information-Gap theory that we discuss in more detail below, and this task was used to inform our initial attempts to measure development that are discussed in the final section of this paper.

Byman (2005) conducted a more typical factor-analytic study of curiosity with children, but included a measure designed to combine four of the five types of exploration identified by Kreidler and Kreidler (1994). The Broad C-trait scale, based on the scale created by Olson (1986), included manipulatory exploration, perceptual exploration, conceptual exploration, and exploration of the complex. In addition to this scale, Byman asked participants to complete a modified version of the OTIM (Beswick, 1974), the diversive explorations scale from the original OTIM (Day, 1971), a curiosity inventory created based on 4/5 exploration types identified by Kreidler and Kreidler (Olson, 1986), and

a modified version of the sensation seeking scale (Bjork-Akesson, 1990; Zuckerman, 1971). Additionally, Byman collected teacher ratings of children's curiosity using a modified version of Maw and Maw's method (Maw & Maw, 1961). Despite attempting eight different factor-analytic models of these data, Byman did not accept the fit of any model of curiosity that included multiple factors. A post hoc CFA, however, did suggest one acceptable model including three factors, two "almost-orthogonal" trait factors and one method factor. He presents the two trait factors as sensation seeking and curiosity, although does relate the sensation seeking to Ainley's factors of breadth of interest curiosity.

As will become evident when we describe the various methods of defining and measuring curiosity in the following paragraphs, there are many different ideas of what curiosity is. Factor analytic approaches provide a way to include multiple definitions and measures in the same study, and thus to clarify what is actually being measured. Byman's transformation of Kreidler et al.'s results into an easy-to-administer questionnaire measure, and analysis of that measure with other existing measures, is an interesting approach to validating the work as well as to creating a classroom-friendly application. While Byman's attempt was not successful in the study summarized here (perhaps because none of the other modified versions of measures were validated themselves), the approach could have implications for future curiosity research.

Spontaneous exploration

Several studies of children's curiosity simply observe their exploration of novel and/or familiar toys. Although McReynolds, Acker, and Pietila (1961) defined curiosity as a "tendency to obtain novel percepts", their measure of curiosity involved spontaneous exploratory behavior rather than novelty preference. They hypothesized that object curiosity in 11-year old children would be negatively related to psychological maladjustment. In addition to collecting teacher ratings of psychological adjustment, McReynolds et al. observed children playing with 35 small toys, 12 of which were in a structured play task while the other 23 were in a free play activity. The structured task involved children interacting with hidden objects and then attempting to guess the identity of each, followed by the chance to further explore each object after it was revealed. In the unstructured task, children were given all 23 remaining objects and told that they could play with them. Children were observed interacting with the toys and given a score of "object curiosity" calculated by tallying children's distinct exploratory behaviors while interacting with all 35 toys, such as removing a part of a toy (physical manipulation) or commenting on a specific aspect of a toy, for example, "This was made in China," (observation verbalized by child). McReynolds et al. also had teachers rate students' psychological adjustment on a 6-point scale for each of the following variables: nervous behavior, worry over achievement, classroom adjustment, adjustment to teacher, adjustment to peers, and over-all psychological health. The results suggest that there is a positive relationship between object curiosity and psychological adjustment, with children who show signs of anxiety demonstrating less curious behaviors. The authors also suggest that their results indicate that aspects of the classroom learning that depend on curiosity might be hindered by students' anxieties, and more generally, that curiosity can be successfully studied in children.

Minuchin (1971) also concludes that children's curiosity can be reliably assessed through observations and further suggests that there is consistency in a child's response to environmental stimuli. Like McReynolds et al., Minuchin includes an "object curiosity" measure, calculated from preschool children's observed interaction with a specific interesting toy for 2 min. Children were also ranked by their curiosity observed during several sessions in diverse activities, such as on fieldtrips and doing new activities in their school, and a checklist was used to record exploratory behaviors. Finally, teacher and observer ratings of children's curiosity were collected. Results indicate that the observations of children in different situations, the object-curiosity scores, and the observer ratings were all significantly correlated. Surprisingly, teacher rankings were correlated to the object-curiosity score and observer rankings at only one of the two preschools in the study. This may have been a result of a limited sample ($N = 18$ children) and the situations in which children were observed were limited in that they were all new, exciting and unusual activities for the children. However, these results do suggest that behavioral measures of curiosity, and measures based on observing children's behaviors in their natural environments, might provide reliable data on children's curiosity.

In addition to studying the effect of environmental aspects on children's curiosity, some researchers have suggested that interactions with caregivers may influence children's curiosity and spontaneous exploratory behaviors (Chak, 2007; Endsley, Hutcherson, Garner, & Martin, 1979; Saxe & Stollak, 1971). Both Endsley et al. (1979) and Saxe and Stollak (1971) observed child–parent interactions to investigate the relationship between maternal behaviors and children's curiosity. Saxe and colleagues observed parent–child dyads (with first-grade children) interacting in a room with several novel objects placed around a room. Specifically, to measure curiosity, they collected data on close attentive observations, manipulation of objects, seeking information, offering information, absolute frequency of the number of different kinds of objects manipulated, and whether a novel stimulus was observed during each 20 s interval. Similarly, Endsley et al., measured curiosity by observing 5-year old children interacting with a set of six novel toys and nine familiar toys, presented to children on two separate but close shelves, while their mothers were present. The researchers collected data on children's questions, excluding those asking for the parent's permission, and non-verbal exploratory behavior, defined as tactile contact with a toy, or visual regard combined with tactile contact of a toy by the mother. Several maternal behaviors were coded as well. Children's exploration of novel objects was found to be significantly related to their question asking, and there were no significant differences between male and female children's exploration of novel objects or their question asking. Unfortunately, data on children's exploration of the familiar objects were not reported. Additional analyses suggested that mothers' general positive interactions, question answering, exploratory behavior, and curiosity orienting behaviors were all positively related to children's exploratory behavior and question asking. The researchers had several conclusions on parent–child interactions, however they admit that further investigation of the affect of caregivers' behavior on children's curiosity would benefit from multiple methods of measuring children's curiosity development, such as more naturalistic approaches including alternative analytic strategies.

While these studies provide information about children's exploratory behavior, they tend to neglect a crucial factor: the characteristics of the objects explored. For example, when considering how many manipulations a child makes on an object, the total opportunities or possibilities for manipulation on objects should also be taken into account. Object familiarity may also be an important factor. The next sections discuss methods of measuring curiosity, with different types of manipulations of the objects being explored.

Exploratory preference measures

Measures of exploratory preference go beyond simply observing children's exploration of objects by looking at what specific object characteristics lead to different amounts of exploratory behavior. Smock and Holt (1962) used a paradigm similar to Berlyne's (1958) investigation of curiosity and preference for complexity, and they had a correspondingly similar hypothesis: that children would prefer to look at stimuli when they were more complex, incongruent, and conceptually conflicting. Stimuli varying in visual complexity, incongruity, and conceptual conflict were shown individually on a television screen, and children could choose to repeat a picture or change to a new picture. Preference for unknown was measured by children's responses to a prompt to choose between a known and unknown toy to play with. Children were more likely to choose stimuli higher in complexity, conflict, and incongruence, although there were wide individual differences in these choices. In addition, children preferred the unknown toy to the known toy. However, Smock and Holt conclude that these preferences were primarily driven by novelty, rather than by specific features of the stimuli because children may have less experience with the type of complex, incongruent, and conflicting stimuli used in their study, and they suggest that this novelty is a more likely motivator of curiosity. While this study provides interesting suggestions about the relation between children's curiosity and the level of complexity, incongruity, conflict, and familiarity of an object, the weakness of the stimuli presentation (visual) and unreported data suggest the need for further research in order to make a strong claim about the relationships of interest.

Novelty preference as measure of curiosity

Some researchers, such as Cantor and Cantor (1964), consider curiosity to be a function of stimulus novelty, consistent with Smock and Holt's hypothesis that their results may have been due to children's familiarity with types of stimuli (with more unusual or conflicting stimuli being more "novel"). In Cantor and Cantor's study, 66 five-year-old children were familiarized to figures on a screen, followed by a combination of those familiar figures with novel figures, and were able to control their looking time for each figure shown. The researchers found that despite different lengths of delay between familiarization and testing, children always preferred to spend the more time looking at novel visual stimuli. Greene (1964) also defined curiosity as a novelty preference; the greater a child's preference for novelty, the greater the child's curiosity. In his study, Greene investigated an alternative hypothesis with the question of whether children's curiosity is actually just problem solving efforts. Fifty-four preschool and kindergarten children were told that they were going to play a game where their task was to find where a dog was hiding. Each of ten trials included sets of two or three colored envelopes, one of which had a picture of a dog inside. Throughout the ten trials, the dog was always in the same color envelope ("correct" choice), and one of the other envelopes was always the same color as well ("incorrect" choice). Children were also given the option of a third envelope to choose beginning on the 4th, 6th, or 8th trial, depending on the condition. The "correct" choice did not change throughout the task. On the first trial, children chose one of the two options and would either be correct if they chose the color envelope with the dog in it, or incorrect if the dog was not in their chosen envelope. On the second trial, two-thirds of children selected to try the novel envelopes rather than those they had already opened, although this was observed less often if they had been correct on their previous selection. On the trial in which the third colored envelope was added, two-thirds of the children selected the new envelope over the one they had previously learned was correct, with no effect of what trial number the third envelope was added. The results of this study suggest that children's curiosity is influenced by, but separate from, problem solving efforts. Greene suggests that curiosity is demonstrated here as preference for novelty, because he considers the third envelope to be novel, however the results also fit into the following section of preference for the unknown, because while the additional envelope is new, its content (and correctness) are unknown.

Mendel (1965) attempted to look at the individual differences of curiosity measured as preference for novelty, looking specifically at gender and age differences as well as anxiety and investigating each of these at different degrees of novelty. Participants were 120 children in four age groups, ranging from 3.5- to 5.5-years old. After being familiarized with a set of toys, children were offered the choice of playing with one of five sets of toys including different combinations of the familiar and of novel toys, ranging from all familiar toys to all novel toys. Anxiety was measured using teacher ratings. Overall, the higher proportion of novelty of a set, the more often it was chosen to play with. Younger children and girls, however, did not show any significant difference in choice, so the effect was driven mostly by older children and males. An inverse relationship between anxiety and preference for degree of novelty was also observed. Children below the median anxiety score preferred the toy sets with most or all novel objects, but children above the median anxiety score preferred different sets at chance levels.

Novelty preference in children has been well documented in the literature, but perhaps leaves something important out when it comes to studying curiosity. As suggested by Mendel's method, familiarity and novelty can be thought of as being on a continuum, with objects able to be more or less novel and familiar, without being strictly one or the other. Other researchers have suggested that curiosity is more than just a reaction to novelty in a situation and have attempted to add other factors into their measures.

Preference for complexity/unknown as measure of curiosity

Although the studies mentioned, among others, have used novelty preference as a measure of curiosity, many researchers have suggested that curiosity is more complex than preference for novelty alone. In his studies, Witryol et al. measured children's choice of both novelty and complexity under different levels of familiarity (Alberti & Witryol, 1994; Cahill-Solis & Witryol, 1994; Wentworth &

Witryol, 1990). In a study investigating the relationship between curiosity and cognitive ability, Alberti and Witryol (1994) administered a behavioral measure of curiosity to 3rd and 5th grade children and collected data on their cognitive ability. Curiosity was measured using a binary choice preference test of stimuli between a novel option and a familiar option, with the added feature that there were four different levels of familiarity – from high familiarity to high novelty – induced by using four different familiarization sequences. The stimuli ranged in degrees of complexity as well. Additionally, teacher ratings of children's curiosity were collected. Cognitive ability was measured using the Stanford Achievement Test for 3rd grade participants and the Comprehensive Test of Basic Skills for the 5th grade participants. Children's choices of novelty over familiarity for all levels of complexity were used to classify them as curious. The results revealed a positive relationship among scores on the standardized tests and measures of curiosity and cognitive ability. Additionally, teacher ratings of curiosity were strongly correlated to children's cognitive ability; however, there was a lack of variance after removing the behavioral data, suggesting that teacher ratings of curiosity were not different enough from cognitive ability to offer additional predictive value of curiosity motivation. Further, these studies were limited by their inclusion of extrinsic rewards, because children were allowed to keep the object that they chose in the binary-choice task. It is not clear whether or not this would affect children's choice of exploration, but the demonstration of a relationship between curiosity and cognitive ability suggests the need for further study.

Henderson and Moore (1980) attempted to investigate a similar topic, the relationship between curiosity and intelligence in preschool-aged children. In this study, curiosity was measured using four separate tasks. Children's preference for complexity was measured by choice of geometric figures ranging in complexity using four pairs of two-dimensional designs. Preference for exploring the unknown involved children's choice between exploring a visible and a hidden toy. Object exploration was measured by observing how many drawers children opened and explored in a set of many options, as well as children's actions on the "Banta Box" curiosity task. Children's IQ was measured using the K-ABC, an intelligence test designed for children ages 2.5–12 years, which included global scores for simultaneous processing, sequential processing, mental processing composite, and achievement. No relationship between children's performance on the curiosity tasks and the children's IQ was observed. Henderson and Wilson (1991) measured curiosity as children's tendency to explore novelty, and the relationship between this measure and intelligence. Using both preference for the unknown and complexity, along with object exploration, the researchers calculated a measure of children's curiosity, but they found that it was not significantly related to intelligence in 4–5-year-old children.

Arnove, Grabowski, and Rynd (1994) investigated 1st and 2nd grade children's curiosity by measuring their interest in either more or less familiar or expected stimuli. They classified children as low- or high-curious in order to investigate the effectiveness of different educational strategies on learning from exploration between children of different curiosity levels. The educational strategies were "guided" and "unguided" exploration of a virtual museum, and assignment to condition was done within level of curiosity (high/low groups), resulting in a two-by-two, between subjects experimental design (curiosity level by guidance condition). Their measure of curiosity was taken from a measure of trait curiosity developed by Maw and Maw (1964) and included 20 pairs of geometric symbols, one of which was more typical and one less typical of children's usual experiences. For example, one trial would include a picture of a triangle on its base and a picture of a triangle on its apex. Children were asked to indicate their preference for one of the symbols in the pair. The researchers scored the task out of 20 points, giving one point for each less-typical choice chosen. The children were split into low- and high-curious groups, and within each group they were assigned to different educational conditions. All children explored a virtual art museum, in which they could explore art to different degrees of depth, for example by looking closer at something, listening to additional narrated information on a piece of art or type of exhibit, or skipping sections all together. In one condition, children were allowed to explore the program in whatever ways they chose after a brief pre-training. In the other condition, children were given prompts to encourage exploration or provide guidance when poor decisions were made. For example:

In response to a child's action to move to a new lesson: "Are you sure you want to end the lesson? This next section is very interesting. You might really enjoy it."

In response to some information given by the program: “Do you wonder how you can tell this from looking at the painting? Stop and think about it! Then, touch the screen when you are ready to find out.”

Following the use of this exploration program, children were given a short break and then a post test. To measure achievement, children were shown eight of the aspects of the museum that children had encountered in the program and were asked to “tell me everything you know about what you see.” Responses suggesting recall of the program material, such as “it’s a painting,” or “it’s a still life,” were each given one point, while observations, such as “it’s in a frame,” were not given points. Arnone et al. observed a significant effect of curiosity level, with high-curious children scoring higher on the post-test in both conditions. While not significant, the achievement in the high curious group decreased slightly (about one point) when advisement was added to the exploration program, while achievement in the low-curious group increased slightly (about a point and a half) when advisement was added. An interaction between age and presence of advisement was also observed, with 2nd graders scoring higher with no advisements, and 1st graders scoring higher with advisement. This study provides empirical support that high-curious children benefit more than low-curious children in educational settings when they are given more freedom and control of their environment, however there was no control condition of an educational setting without freedom and control, so it is not known if the learning benefit seen here is due to the characteristics of the environmental setting.

Using a similar methodology, [Vlietstra \(1978\)](#) looked at preschool children’s and adults’ choice to explore houses with different incongruous animal pictures behind each of 12 doors, such as a caterpillar with a rabbit head and tail, over building blocks, a familiar yet enjoyable activity. The researchers considered any behavior to be exploration, but were interested in looking in the change of the type of behavior by participants. Typical “play” activity was considered to be “diversive exploration”, while investigatory responses to novel or discrepant stimuli were recorded as “specific exploration”. Vlietstra found that, over three sessions lasting 10 min, all participants spent a greater amount of time physically exploring the blocks than the houses. Adults differed from children in their consistency of exploration, especially across sessions, while children engaged in more activities and changed activity more than adults. Children were also more likely to decrease in both block and house play in the second half of the sessions, while adults continued to play with the blocks. Vlietstra’s conclusion suggests that people become more focused on specific activities, such as manipulatory patterns of constructive play as they age. They also suggest that children are more interested in looking, while adults are more interested in “doing”, which they suggest is a result of adults’ greater experience and resulting familiarization with the stimuli. The author’s construct of specific exploration is most similar to other researchers’ definition of curiosity, so the results of this study would suggest that children might exhibit more curiosity than adults, which is a common hypothesis but does not have any empirical support.

The studies described so far suggest that children prefer novelty, complexity, and the unknown when choosing what to explore. Another way to look at these factors is through the concept of uncertainty. Familiar and less-unknown objects provide minimal uncertainty, while novel and unknown objects provide maximum uncertainty. Complexity can also add to the amount of uncertainty, with less complexity leading to less uncertainty, and more complexity providing more uncertainty. Several researchers have used uncertainty in their measures of curiosity in children.

Preference for uncertainty/ambiguity

[Mittman and Terrell \(1964\)](#) investigated the relationship between curiosity and errors made on a geometric shape discrimination task. In their study, the researchers manipulated the level of curiosity that 1st and 2nd grade students experienced by presenting different levels of uncertainty about the identity of a picture made up of connected dots. Children were allowed to connect two dots for every correct answer on the discrimination task, making the unknown picture more visible, although the image was not identifiable until 30 dots had been connected. Children in the low curiosity group were shown what the image would be before the task began, children in the moderate curiosity group were shown the image after nine dots were connected, and children in the high curiosity group were shown

the image after 29 dots were connected. The researchers looked at the effect of the different levels of curiosity on children's error rate on the discrimination task. The results indicate that children in the high curiosity group made significantly fewer errors than both the moderate and low curiosity groups. Mittman and Terrel suggest that these results indicate that as children are faced with uncertainty over time, they experience an increasing level of conflict arousal. They further hypothesize that increased conflict arousal motivates children to be more efficient in their learning.

Several researchers have looked at children's reaction to surprise – rather than their exploration of novel or uncertain situations – as another window into children's levels of curiosity. [Charleworth \(1964\)](#) hypothesized that curiosity is greatest when well-formed expectations are violated, creating a large conflict or surprise, and that violated expectations would be more likely than novelty to lead to curiosity. He presented five- to eight-year old children with several instances of in which colored marbles were placed into a box from one side, and then came out of the box from a different door. The set of marbles put into the box and the set of marbles coming out of the box were manipulated to either be the same, which is what would be expected, or different, which would be a surprising and unexpected outcome. Children were given the option of seeing the event as many times as they would like, and the number of trials they chose to watch was collected as a measure of exploratory behavior. Children showed preference to explore the surprise condition most often in both studies reported, supporting Charlesworth's theory of curiosity as a result of incongruity between expected and unexpected outcomes in a situation. Similar findings about preschoolers' propensity to preferentially explore ambiguous rather than unambiguous situations have been reported by [Schulz and Bonawitz \(2007\)](#). Such claims are also consistent with earlier reports that the level of uncertainty in a situation affects amount of exploration ([Litman & Spielberger, 2003](#); [Loewenstein, 1994](#)). However they are limited by only investigating people's uncertainty about a causal relationship. It is not clear whether or not children will preferentially explore uncertainty about non-causal aspects of a situation.

Behavioral measures: summary

As demonstrated throughout this section, there are a wide variety of operational definitions and behavioral measures for curiosity, including: spontaneous exploration, exploratory preference, novelty preference, preference for complexity/unknown, and preference for uncertainty/ambiguity. Several studies define curiosity as spontaneous exploration, but they tend to ignore important factors, such as stimuli characteristics, and object familiarity. Exploratory preference is a promising approach to looking at children's curiosity, because it does take into account the characteristics of the stimuli for which children evidence the greatest exploratory preference, but the work reported in this area was quite vague and did not include important details, such as the child's familiarity with and/or prior preference for the objects. Moreover, because many of these investigations allowed only visual exploration, their results may not generalize to physical exploration. Novelty preference methods addressed issues of familiarity with objects by using novel stimuli, but this work just served as a replication of results already shown to be quite reliable in the field of novelty preference – which we consider to be independent from curiosity. The set of studies examining preference for complexity and the unknown demonstrates that it is not necessarily novelty that is preferred, but instead that curiosity can be activated by something familiar, but unknown. (That is, curiosity can be aroused by uncertainty about the existence of an item in a particular location, regardless of whether or not the object is familiar.) Additionally, curiosity is greater when stimuli are more complex, although this finding is typically demonstrated using visual, rather than physical, stimuli. The studies viewing curiosity as preference for uncertainty and ambiguity take the previous work to a slightly deeper level, suggesting that stimulus characteristics, *per se*, are less important than the relationship between the stimulus and the subject's knowledge, experience with, and understanding of the stimulus. These studies suggest that curiosity is a result of cognitive conflict or a gap in knowledge that is elicited by the stimuli or situation.

With regard to the methods for measuring curiosity described above, we view measures of curiosity using uncertainty and ambiguity to be the most specific because they subsume the other methods used within their framework. As previously mentioned, novelty, complexity, and the unknown can be interpreted as varying values on a continuum of uncertainty or ambiguity. The poles of this continuum – familiarity versus novelty, or known versus unknown – correspond to certain or unambiguous

knowledge at one end of the spectrum, and total uncertainty and ambiguity, at the other. After reviewing several theoretical perspectives on curiosity, Loewenstein arrived at the same conclusion and then developed his Information-Gap Theory of curiosity, which essentially defined curiosity in the same way as the uncertainty/ambiguity measures discussed above.

Information-gap theory of curiosity

Loewenstein's information-gap theory of curiosity combines ideas from Gestalt psychology, Social psychology, and behavioral decision theory. It views curiosity as "arising when attention becomes focused on a gap in one's knowledge." According to the theory, this gap produces a feeling of deprivation, which people are then motivated to eliminate by attempting to obtain the missing information. Loewenstein describes curiosity as a "reference-point phenomenon", with the reference point being the information that a person wants to know. Curiosity is caused when a person's reference point is above his current state of knowledge. Loewenstein provides strong arguments for how the theory explains curiosity more thoroughly than the other theoretical approaches, taking parts of each theory to provide a view of curiosity that explains not just what curiosity is, but also some of the paradoxes associated with it, such as people's voluntary exposure to curiosity and feelings of disappointment when it is satisfied. In the following paragraphs, we elaborate on this theory, and then describe some novel tasks – inspired by the theory – that we have designed to measure curiosity in preschool children.

Loewenstein's information-gap theory addresses each of his four criteria for evaluating theories of curiosity: they must (a) provide a definition of curiosity, (b) address its underlying cause, (c) explain the observed phenomenon of voluntary exposure to curiosity, and (d) discuss situational determinants of curiosity. Loewenstein defines curiosity as a feeling of deprivation resulting from awareness of a gap in knowledge. He addresses the cause of curiosity as being this feeling of deprivation, and the situational determinants of curiosity being those environmental stimuli that create the gap in knowledge, and the person's awareness of the gap. Additionally, he suggests that the intensity of curiosity is positively related to a person's ability to resolve the uncertainty and close the information gap, and that one is more curious about things that he or she knows about, because the more one knows about something, the more likely he or she is to focus on what is not known, increasing curiosity in that area. However, once a person knows a great deal about something, he or she sometimes is more likely to realize how much there still is to know about it, focusing again on what is not known, causing curiosity to decrease because the amount of what is unknown is so large.

The assumption that curiosity is related to feelings of deprivation – which are unpleasant – raises the question of why people voluntarily seek curiosity-inducing situations. Loewenstein does not view the arousal of curiosity, *per se*, as voluntary, but rather as an unavoidable consequence of the choice to expose one's self to curiosity-evoking situations. He argues that people derive pleasure from satisfying their curiosity by acquiring missing information, and they expect the gains from that pleasure to be greater than the feelings of loss produced by the ultimate satisfaction of the curiosity itself. He compares curiosity to a type of gamble, where people estimate the likely benefits of satisfaction (the acquisition of the missing information), weighted by its probability of occurring—and the costs (the negative feelings associated with missing information) weighted by the duration of those feelings. Individuals have different, subjective levels at which they are willing to expose themselves to curiosity-evoking situations. He also suggests that there are several situations in which exposure to curiosity is involuntary, such as when an expectation is violated, when a person is presented with a question or puzzle (what Berlyne called "thematic probes"), when a person is exposed to an event with an anticipated but unknown outcome (such as finding out which team won an athletic event, especially if the person has a specific prediction of the outcome), when another person knows something that one does not know, but wants to find out, or when a person realizes that they do not remember something that was previously learned.

Loewenstein's information-gap theory addresses several other aspects of curiosity: intensity, transience, impulsivity, and feelings of disappointment. Intensity of curiosity is determined by the situational aspects discussed above, including a person's ability to resolve an information gap and their current state of knowledge about the information. A more general perspective of this theory on what

causes the intensity often observed with curiosity is that curious behaviors are motivated by a type of loss, the feeling of deprivation associated with not having some desired information. Studies in decision sciences have demonstrated that people are more motivated to act by a loss than from an anticipated gain. One intriguing aspect of curiosity that has been noted by many curiosity theorists is its transience, that is, the fact that curiosity can be intense one second, and then seem to disappear the next. The information-gap theory suggests that this characteristic of curiosity is related to the cognitive resource required for curiosity, attention. When attention is distracted from the information gap that causes curiosity, the curiosity dissipates. Impulsivity of curiosity is commonly observed when attention is focused on an information gap. Because the feeling of deprivation is such a strong motivator, people are likely to opt for the quickest solution to avoid cognitively induced deprivation. When people do satisfy curiosity, there is often a slight feeling of disappointment. The information gap theory attributes this to the change from the feeling of deprivation to a, “natural hedonic state”, which is quickly replaced by a neutral state, similar to what is observed in the satisfaction of other drives like hunger. The fleeting feeling of pleasure, and fast transition from the feeling of deprivation to the neutral state, is why Loewenstein believes there is often a slight feeling of disappointment from satisfying curiosity. Loewenstein and his colleagues have conducted several studies – all with adult participants – to evaluate some of the predictions derived from his information-gap theory (Loewenstein, Adler, Behrens, & Gillis, 1992). In several studies, he found that participants are more curious when there is an information gap than when there is no information gap, and most curious when they have some knowledge about the information. Another study showed that people are more curious about insight problems, which created an information gap, than incremental problems, which did not produce an information gap.

There are several reasons why Loewenstein's information-gap theory is the most promising perspective from which to investigate children's curiosity, especially in education research. First, and most importantly, it is specific enough to provide an operational definition. Second, it is consistent with the important aspects of earlier theories, including the drive theories, incongruity theories, and competence theories. Third, while the theory does not conflict with the drive theories by viewing curiosity as aversive, it also deals with specific state curiosity. Thus, it considers internal and external determinants of curiosity, both of which must be understood in order to study curiosity in the context of instruction. It is important to understand individuals' subjective reference points and their current knowledge state, as well as how to influence these in a way that can motivate learning behaviors, such as exploration. Given that studies with adults have demonstrated that curiosity leads to exploratory behavior and greater learning (Berlyne, 1954; Litman, 2005; Loewenstein, 1994; Lowry & Johnson, 1981), it is important to develop procedures that increase curiosity in children. As Loewenstein notes, more is known about educating motivated students than about how to actually motivate them, which is knowledge that research in curiosity can provide. Fourth, and finally, the information-gap theory of curiosity is well-supported empirically.

As mentioned earlier in this paper, recent theoretical work in defining curiosity has extended Loewenstein's information gap theory of curiosity to include both deprivation and interest dimensions (Litman, 2005; Litman & Jimerson, 2004). Litman (2005) describes several important differences between two “types” of curiosity: interest (I)-type and deprivation (D)-type. Similar to the information gap theory, D-type curiosity is motivated by reducing the feeling of uncertainty or deprivation, while I-type curiosity is motivated by the desire to stimulate interest. D-type curiosity is associated with the feelings of “missing” information from one's existing knowledge of something (consistent with Loewenstein's conceptualization of curiosity), while I-type is associated with positive feelings of engagement from learning new information. Finally, D-type curiosity has been described as “need to know”, and I-type as “take it or leave it” (Litman, 2009). These constructs have been found to be psychometrically different, and while they are correlated (r values = .69; Litman & Jimerson, 2004), empirical work has found that items associated with D-type curiosity led to much higher levels of exploration than those associated with I-type (Litman, Hutchins & Russon, 2004), and Litman (2005) hypothesizes that D-type curiosity motivates more information seeking behavior than I-type. Just as we believe that it is important to assess curiosity as both a state and individual difference variable, we believe it will be important to extend the study of both I- and D-types of curiosity to developmental and education research. For the current paper, however, we focus on the latter in both cases, with the goal of devel-

oping a measure to specifically address D-type curiosity, using the information-gap theory as a foundation for our operationalization. While we stress our opinion that both I- and D-types of curiosity are important in this area of research, we chose to begin with the study of curiosity as a feeling of deprivation because it has been found to lead to a higher intensity and magnitude of curiosity (Litman, 2005; Litman & Jimerson, 2004), and the implications of understanding children's curiosity related to resolving uncertainty has direct educational applications. Specifically, it is likely much easier to create uncertainty in a learning environment that could lead to D-type curiosity than to predict what content or stimuli will engage an entire classroom of children's interest and lead to I-type curiosity.

A theory of curiosity for research on early educational interventions

In the introduction to this review, we noted the oft-mentioned importance of curiosity in educational standards, curricula, and legislation. Curiosity is often described as something that teachers can foster, enhance, and use to motivate children to learn. However, without an operational definition of curiosity, it is impossible to determine the success of such efforts. In this section, we describe a novel procedure that we have designed to assess young children's scientific curiosity as an individual difference variable, using Loewenstein's theory as an over-arching framework. Although we acknowledge that curiosity can be influenced by inherent aspects of the stimulus, the measure to be described below conceptualizes curiosity as a relatively stable cognitive variable. However, we believe that our measure is sensitive enough to detect changes over time, for example from the beginning to the end of a school year. Our operational definition of curiosity is: *the threshold of desired uncertainty in the environment which leads to exploratory behavior*. Our technique for measuring it is to create an environment that enables us to observe children's preferences for exploring and resolving varying levels of objective uncertainty. Thus, we look at curiosity specifically as children's level of preferred uncertainty, and for the remainder of the paper, the term curiosity is meant to refer specifically to curiosity as uncertainty preference.

Adapting Loewenstein's theory so as to create a measure of children's curiosity presents several challenges. First, empirical support for the theory is limited to experimental procedures primarily suitable for use with adults. Thus, we had to modify those measurement procedures for use with children, while still maintaining a defensible connection between the procedures and theoretical constructs. Another challenge was to create theoretically grounded assessments that would be useful in educational settings, especially those aiming to increase children's curiosity as an index of the success of an instructional intervention (Klahr, Zimmerman, & Jirout, 2011). In the following sections we first describe studies in which we attempted to replicate the previous findings of the relationship between information gaps and exploratory behavior in children. Then we describe our approach to designing a valid measure of curiosity levels in individual children.

Support for Information-Gap Theory and Extension of Adult Findings to Young Children

We adapted the protocol used in the adult research (Litman et al., 2005; Loewenstein, 1994) for use with three- to five-year-old children. Whereas adults were asked to rate their feeling-of-knowing (FOK), the literature suggests that children are unable to accurately rate their own FOK (Lockl & Schneider, 2002). Therefore, we designed a task in which we experimentally manipulated the level of information children had. Instead of being asked to indicate their FOK to an item, children were given the option to explore items for which they had different amounts of information about what they would find. For example, the equivalent of an adult's FOK response of "I know" would be an item in which the child was presented with information about which there was no uncertainty about what they would find from exploring. The equivalent of an adult's FOK response of "I don't know" would be an item in which the child was given no information (and therefore total uncertainty) about what they would find from exploring. The equivalent of an adult's FOK response of "tip-of-tongue" would be an item in which the child was given some information, but not enough to know for sure what they would find; there would be a medium-level of uncertainty, with only a few possibilities of what the child would find from exploring. Instead of asking children to rate their curiosity about the items,

we determined which items children were more or less curious about by presenting pairs of items differing in uncertainty level, and asking children to choose the one they wanted to explore, using their exploratory preference as the measure of curiosity.

Our general procedure, adapted from an exploration measure used by Kreitler et al. (1975), is as follows. Children are presented with a series of items, each requiring them to choose one of two options to explore. The two options differ in the size of the information gap (i.e., the amount of uncertainty presented). In our first study, children were exposed to three levels of information gaps: a minimum gap, in which they knew what they would find when they explored; a medium gap, in which they knew that if they explored they would find one of a small set of possibilities; and a maximum gap, in which there was no information about what they might find. For example, when exploring a “neighborhood” of houses, children choose one of two doors to open on each house, with each door covering a picture of one of the two pets that live in the house. A minimum level of uncertainty would be presented by a door with a window, showing a small view of the pet through the window. A medium level would be presented by a door with a clue, indicating that the pet behind the door is one of a small set of possibilities indicated on a “clue chart”. The maximum level is presented by a door with no window or clue about what type of pet is hidden behind it. Results from several studies indicate that children understood the task and that exploratory preference was consistent with the information gap theory, with children choosing to explore more when there was an information gap than when there was not. No differences in exploratory patterns were observed between younger (four year old) and older (six year old) children. Children preferred the medium level of uncertainty, where there was some information given, over both the maximum and minimum levels. These results are consistent with the literature on adults’ curiosity, although they do not inform the question of individual differences, because most children appear to have the same preferred uncertainty level: medium. This general finding can be thought of as state curiosity, because some uncertainty in the environment, specifically a “medium” amount, will promote curiosity. The literature supports the study of curiosity as both a state and a trait (Boyle, 1979; Naylor, 1981, 2004), though, and individual preference for a specific level of uncertainty (with different levels preferred by different children) is a method of looking at individual differences in children’s curiosity as uncertainty preference, and developing a measure of this individual difference was our goal in this work.

Curiosity as an individual difference variable

We suggest that children have different subjective reference points at which varying levels of uncertainty are most likely to motivate exploration. As discussed above, curiosity is most likely to occur when there is a “medium” or optimal amount of uncertainty in the environment, resulting in an inverted-U shape relationship between curiosity and uncertainty. Our theory suggests that the *peak* of this inverted-U shape differs for individual children, and that value can be thought of as a child’s curiosity level. The curiosity level suggested here indicates what level of uncertainty is *most likely* to result in curiosity, or a child’s uncertainty preference level. In other words, when a child has a choice of exploring between different levels of uncertainty, the curiosity score gives an indication of which level he or she will choose, and how much uncertainty is explored throughout the assessment.

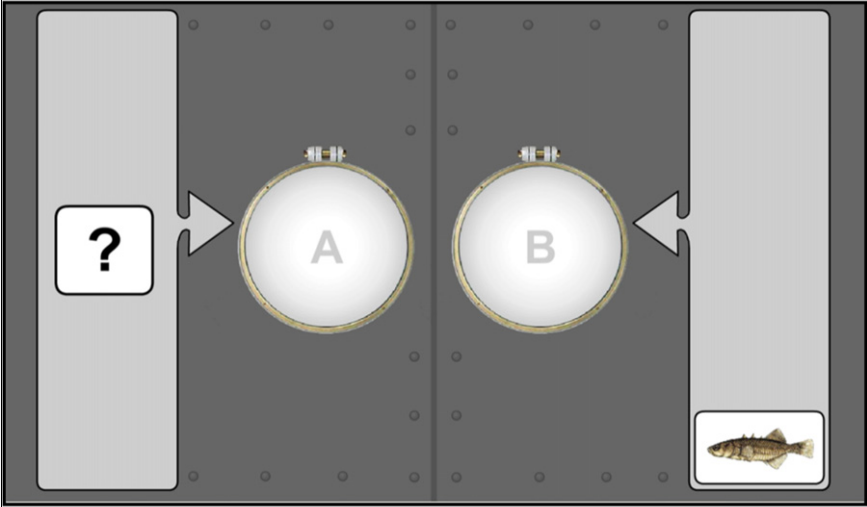
Curiosity as uncertainty preference can be assessed using a forced choice protocol, requiring children to choose from among a set of options to explore, with the only difference between those options being different levels of uncertainty. Children who prefer lower levels of uncertainty are defined as being less curious. These children may feel overwhelmed with high levels of uncertainty in the environment or be intimidated by any uncertainty at all, and feel most capable of resolving lower levels of uncertainty. Children who prefer to resolve greater amounts of uncertainty are defined as being more curious. The measure described below was designed to assess the specific value of uncertainty preference for each child. The basic structure is similar to the exploration game described earlier, with several trails on which children can choose to explore one of two levels of uncertainty. The task was revised so that the two uncertainty levels between which children could choose to explore would begin by being extremely different (one option with no uncertainty and the other with maximum uncertainty), and then become more narrow, including seven levels of uncertainty instead of three, until the difference between the two information gaps was minimal. By increasing the levels of possible

uncertainty, we are able to estimate a much more precise level of uncertainty preference, which can be used as a measure of individual differences in curiosity.

A novel measure of children's curiosity level

In the current measure of children's curiosity, we record children's actions on an exploration game called "Underwater Exploration!" This task is administered on a computer, and data are logged automatically. Children are told that they will be exploring to see many different kinds of fish by looking out of the windows of a submarine. They are told that the submarine has two closed windows and that

Maximum (left), Minimum (right):



Medium (two different levels):

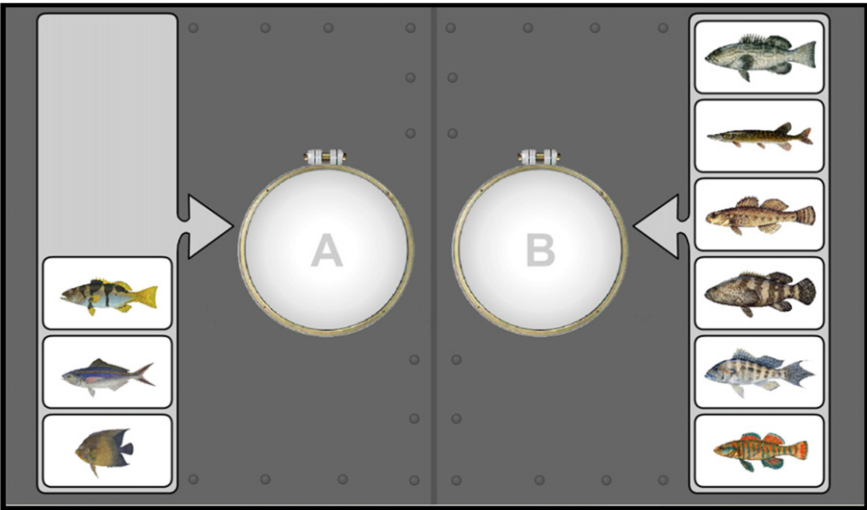


Fig. 1. Examples of the different Information Gaps (IGs) in the exploration game.

each window has a specific fish outside of it. The only way to see which type of fish is outside of each window is to open it (see Fig. 1). Adjacent to each window is some information about what type of fish might be outside of the window, and that information is varied (from 1 to 7 fish, or a question mark) in order to manipulate the level of uncertainty associated with each trial. Each task item compares two information gaps between which the child must choose. The IGs are:

Minimum: There is no information gap; the type of fish the child will see if he/she chooses to explore this option is shown in the side bar corresponding to the window.

Medium: The child knows that the fish outside of the window in this option is going to be one of several possibilities, indicated by a set of possible fish displayed vertically along the corresponding side of the screen. Sets range from two to six possibilities, providing a more precise measure of exploratory preference than similar, previous studies.

Maximum: The child is given no information about what type of fish will be outside of the window. There is a question mark in place of the set of possible fish, which gives no information about what fish will be outside of that window. The child is told that it could be “any kind of fish.”

Training

After a brief introduction to the game, children are given instruction on interpreting the information given on each trial. The training takes less than 5 min and is done on the computer screen by showing the main task items: closed windows that can be opened to reveal a fish and the sidebars that show the fish that might be outside of each window, or the question mark symbol. The child learns about the rules of the game (that he or she can open only one window on each trial) and sees an example of each type of stimuli with an explanation of the information that can be inferred from it. For example, a window with a single fish on the corresponding side of it will be displayed (minimum information gap), and the child will be told that whenever a window has a single fish in its set, the picture shows the exact same fish that will be outside of that window. Similar instructions are given for the two other objects: medium information gap – the set of fish and maximum information gap – a question mark. The child completes a short manipulation check to ensure understanding of the task and receives additional instructional feedback if needed.

Exploration game

For each trial, children are presented with a submarine with two windows, and the child is prompted to notice the information given about the possible fish corresponding to each window. For example: “On this turn, look at the sides of the screen to see what fish might be outside of each of the windows. Now tell me, which one of the windows would you like to open?”

Children indicate which window they choose to explore, and the experimenter clicks to open it and reveal the fish outside of that window, or the child may click if he or she chooses to. The child is given a total of 18 chances to explore in situations with different combinations of Information gaps (IGs).

The task is adaptive in that it presents children with comparisons of IGs based on their previous choice of exploration. All children go through a series of six sets, each set containing three trials. Each trial is a comparison of two different IGs that the child is asked to choose between. Within each set, the IGs are the same. The sets begin with the two extreme IGs, minimum and maximum, and the difference between the two levels narrows as children progress through the steps, until set six, in which the comparison is between levels only one degree different from each other. For example, if the child sees a set of items with two fish on one side and six fish on the other side, and then twice of three times chooses the side with two fish to explore, the next set of trials will have the options of two fish on one side and five fish on the other side. See Fig. 2 for a chart of all possible paths a child might follow through the space of possible choices.

Selection of the same information gap on all three trials within a set is considered a “firm preference”; the choice of one level on two trials and the other on one trial within a set is considered a “soft preference”. The sets are designed to narrow the individual child’s preferred UL, until a specific preference level can be determined.

On the first set, the child’s choice of either minimum or maximum on at least two of the three trials will determine the comparison they will see in the second set. If the maximum level is chosen at least two times, the child sees the maximum level compared to the medium level, with a set of

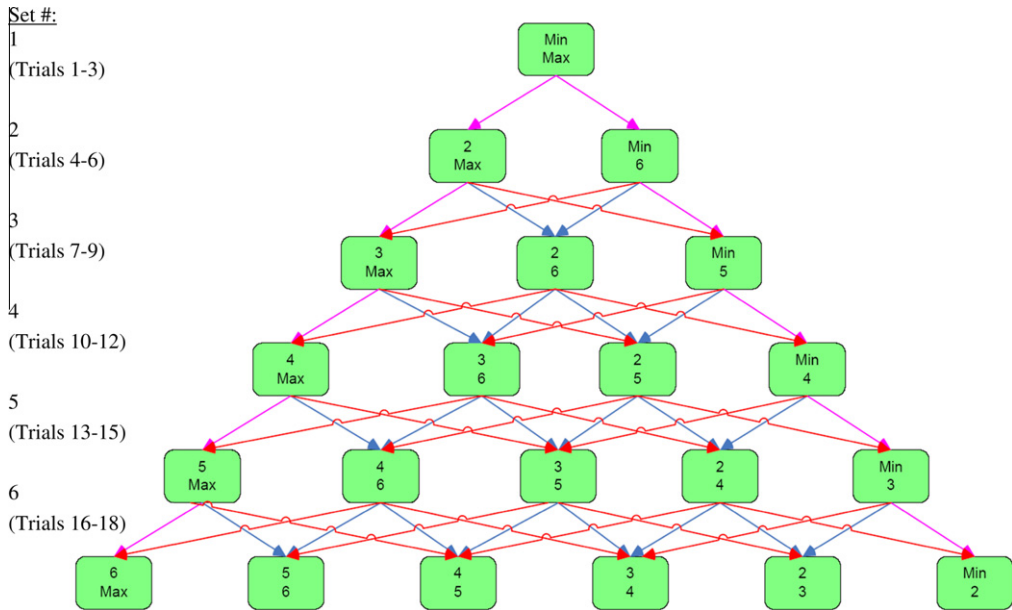


Fig. 2. Trial selection paths for the exploration game (pink and red lines indicate “firm” preference, blue lines indicate “soft” preference). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

two possibilities. If the minimum level is chosen at least two times, the child sees the minimum level compared to the medium level, with a set of six possibilities. On the second set, a firm preference for either the minimum or maximum level, meaning the child chose it on all of the three possible opportunities, will lead to the same extreme level again, this time compared to a medium level with a set one degree closer to the extreme level preferred. For a firm minimum preference on set two, set three contains trials with the minimum level, and a medium level with a set of five possibilities. For a firm minimum preference on set two, set three will contain trials with the maximum level, and a medium level with a set of three possibilities. If a soft preference is made on either of the possible combinations in set two, set three will contain trials with a medium level with a set of two possibilities, and a medium level with a set of six possibilities. In Fig. 2, the firm preference path is indicated by the blue lines, and the soft preference path is indicated by the red lines, with purple lines where the path is the same for either a soft or firm preference. Subsequent sets will use the child’s preferred information gap on the three trials, and whether that preference was firm or soft, to determine the next set.

Several constraints were placed on the program to ensure a diverse set of stimuli, as well as to avoid confusion of the task. The two fish outside of the windows on a submarine are never the same fish. Additionally, if two sets of possible fish are shown on the same trial, the fish included in each are mutually exclusive. All fish outside of the windows and in the sets are randomly selected from a set of 60 total fish, which were chosen based on recognizable differences so that the fish are easily distinguishable from each other. All fish images were realistic sketches, so the background of each image was the same, and possible favorable characteristics, such as color, were not salient features of the images.

Validation of current measure

To validate the measure, we tested for relationships between our estimate of children’s curiosity levels and their scores on several other widely used measures of cognitive and social aspects of

Table 3

Curiosity task validation measures.

Measure	Description
Preschool Learning Behaviors Scale (PLBS) (McDermott et al., 2000)	Teacher-report measure with 29 items to assess three areas of learning behaviors: competence motivation, attention/persistence, and attitudes toward learning
Devereux Early Childhood Assessment (DECA) (LeBuffe & Naglieri, 1999)	Measure provides standardized scores on behavioral concerns, initiative, self-control, attachment, and protective factors. For example, one item included in this domain is, "Tries or asks to try new things"
Learning Express (LE) (McDermott, et al.,)	
Peabody Preschool Vocabulary Test (PPVT) (Dunn & Dunn, 1997)	Standardized measure of children's vocabulary, to be used as another indication of academic achievement
Adjustment Scales for Preschool Intervention (ASPI) (Lutz et al., 2002)	This measure provides data on preschool students emotional and behavioral adjustment. It includes scores for: aggressive behavior, low energy, shyness, oppositional behavior, and inattention

preschool children. These include both convergent measures: Preschool Learning Behaviors Scale (PLBS; McDermott, Green, Francis, & Stott, 2000) and executive functions (Willoughby, Blair, Wirth, Greenberg, & the FLP Investigators, 2010), and several divergent measures: Devereux Early Childhood Assessment (DECA; LeBuffe & Naglieri, 1999), Learning Express (LE; McDermott, et al., 2009), Peabody Preschool Vocabulary Test (PPVT; Dunn & Dunn, 1997), and the Adjustment Scales for Preschool Intervention (ASPI; Lutz, Fantuzzo, & McDermott, 2002; see Table 3).

Procedure

Approximately 200 children in 24 Head Start classes participated³. The mean age was 56 months, and there was an equal proportion of males to females. The majority of the population was African American, and all participants were low-SES. The curiosity task was administered individually in a quiet area of the children's school. The computer program automatically logged all mouse-click responses for the 18 exploration trials with the participants' ID number. Scores were computed for total uncertainty explored, number of more-uncertain choices, and final preferred level of uncertainty.

Results⁴

The preferred level of curiosity can be calculated by three different methods: total uncertainty explored, total number of more-uncertain choices explored, and final preferred level of uncertainty. The total uncertainty explored had the largest scale and provided the greatest variability and precision, resulting in the greatest reliability, so that is the variable used for the validation analyses. The three scores were analyzed together for measures of measurement reliability, however. A significant, positive correlation was calculated between each of these measures, suggesting reliability of the task (Pearson r values = .826–.870, $ps < .001$). Additionally, performance on the first nine items correlated with choice on the second nine items, indicating internal consistency, even with the adaptive nature of the task ($r = .234$, $p = .001$). Scores were not correlated with participant age or different between genders ($p = .653$ and $.118$, respectively).

The hypothesized convergent measures included competence motivation (PLBS), attention/persistence (PLBS), attitudes toward learning (PLBS), total PLBS score, inhibition, cognitive flexibility, working memory, and initiative. The curiosity measure correlated significantly with competence motivation, attention/persistence, attitudes toward learning, and PLBS total score, with r values from .133 to .176, p values = .013–.063. When controlling for the PPVT score, which is commonly used as indication of IQ, these correlations remained significant, with higher r values of .193–.280, p

³ The sample was part of a larger research study directed by Daryl Greenfield, Department of Psychology at the University of Miami. All validation measures were collected by the University of Miami researchers or by the teachers if the measure was a teacher rating scale, during the 2008–2009 school year.

⁴ A more detailed report of these results can be found in Jirout (2011).

values = .002–.031. The expected divergent measures of curiosity were behavioral concerns (DECA), protective factors (DECA), vocabulary (LE), mathematics (LE), listening comprehension (LE), alphabet (LE), vocabulary (PPVT), aggressive behavior (ASPI), low energy (ASPI), shyness (ASPI), oppositional behavior (ASPI), and inattention (ASPI). Correlational analyses indicated no significant relationships between the behavioral curiosity measure and any of the divergent measures (all p values > .1).

Results of the correlational analyses and internal consistency support the validity of the behavioral measure of curiosity, “Underwater Exploration!” Even when controlling for IQ using the PPVT, children’s exploratory preference was significantly related to their learning behaviors of competence motivation, persistence, and attitude toward learning. In fact, the divergent measures collected suggest that the task is measuring something independent of academic achievement and social personality variables. Measures of inhibition, cognitive flexibility, and one of two working memory tasks did not correlate significantly with the curiosity measure, perhaps because curiosity is independent of executive function, or at least of these specific constructs.

Developmental differences in curiosity. There was no correlation between children’s curiosity and age ($r = .032, p = .653$). This was constant when looking at children by age groups with six month or one year intervals, and using both group mean and median splits of age (all p values > .500). The lack of a relationship between curiosity and age suggests that curiosity assessed as uncertainty preference might be stable across time, and not something that generally increases with age. Although the age range included here was small, similar results with 4–7 year old children in preschools and elementary schools also indicate no relationship between age and uncertainty preference (Jirout, 2011). Though Parvanno (1990, see above) and others have suggested that curiosity decreases with schooling and/or age, and many educational programs claim that early education “fosters” or “promotes” curiosity, the data support neither of these claims. Because curiosity is assessed as uncertainty preference, it is conceivable that an intervention targeted specifically at increasing children’s awareness of and desire for uncertainty could influence children’s preference. While more research is needed to determine whether the type of curiosity we discuss does in fact influence children’s exploration and learning behavior, one study has found a positive relationship between children’s curiosity as defined here and question asking behavior (Jirout, 2011). In this study, children who preferred more uncertainty generated more questions about a science topic, even when controlling for children’s overall verbal responses or only including children who ask at least one question, suggesting this was not just an effect of being more verbal or knowing how to ask a question. More curious children were also more accurate when differentiating between “helpful” and “not helpful” questions to solve a mystery, suggesting that more curious children are not just asking more questions, but can also consider the effectiveness of questions.

Discussion

Although curiosity is an undeniably important aspect of children’s cognitive development, most of the research on measuring curiosity has focused on adults, and has employed predominately questionnaire-type measures that are inappropriate for use with young children. The less extensive literature on children’s curiosity has used a wide variety of different measures that typically lack clear operational definitions, as well as assessments of validity and reliability. Our review of the literature suggests five general classes of definitions for children’s curiosity: (a) as spontaneous exploration, (b) as exploratory preference, (c) as novelty preference, (d) as preference for complexity or the unknown, and (e) as preference for uncertainty and ambiguity. These definitions – discussed earlier in this paper – can be characterized as forming a continuum from a very vague idea of what curiosity is, to a more refined, operationalized definition of curiosity, and ultimately to a very specific type of curiosity: uncertainty preference. Assessing curiosity as spontaneous exploration is a common method, but misses important factors, such as familiarity and stimuli characteristics. Exploratory preference takes the latter of these factors into account, but still ignores familiarity, and the research reviewed in this area was quite vague. Familiarity was included in studies of curiosity as novelty preference, but this work only served as a replication of results already shown to be quite reliable in the field of novelty

preference – which we consider to be independent from curiosity. Assessing curiosity as preference for complexity and the unknown demonstrates that curiosity can be activated by something familiar, but unknown – indicating that it is not novelty or familiarity that is leading to curiosity, but rather uncertainty or ambiguity. The final set of studies in our review focused on uncertainty and ambiguity, taking previous work to a somewhat deeper level. This literature suggests that the intrinsic characteristics of stimuli are less important than the relationship between the stimuli and the individual's knowledge, experience, and understanding of them. These studies suggest that curiosity is a result of cognitive conflict or a gap in knowledge that is elicited from the stimuli or situation, which is the basis for our measurement of curiosity as uncertainty preference.

Absent an operational definition and measure of children's curiosity, it is impossible to assess curiosity's influence on children's learning, the success of educational interventions aimed at increasing curiosity, or the general developmental pattern of curiosity in children. In this paper we have described a novel operational definition of curiosity – the threshold of desired uncertainty in the environment which leads to exploratory behavior – and the resulting measure of curiosity in children. In developing our measure, the information gap theory appeared to be the optimal option for studying children's curiosity, especially in education. Research using this theory of curiosity found that, in adults, curiosity is motivated by information gaps and leads to exploratory behavior in order to satisfy the curiosity. The relationship between the size of the information gap and the level of curiosity resembles an inverted U-shaped function, consistent with earlier theories of curiosity. These same findings were observed in our studies of curiosity in children. We developed a definition and measure of curiosity in children consistent with the information gap theory and demonstrated its validity with both convergent and divergent measures. Our measure provides an individual difference variable of children's preference for uncertainty as an assessment of children's curiosity, and like similar individual difference variables, curiosity does not seem to be related to age. We consider the measure to address children's 'breadth' curiosity as a more stable, domain general construct. We anticipate that this approach to measuring curiosity will enable us to assess gradual, long-term change in curiosity, such as from the beginning to the end of a school year, which allows us to assess the influence of educational programs on curiosity. Our measure is consistent with Loewenstein's criteria in that it clearly defines and addresses the dimensionality of curiosity and identifies uncertainty preference as a main factor that determines the level of curiosity. Consistent with the information gap theory, we accept Loewenstein's explanation of why people voluntarily expose themselves to curiosity: when exposure is voluntary, the pleasure of resolving uncertainty outweighs the unpleasant feelings associated with it. While our definition would suggest that the presence of uncertainty is a situational determinant of curiosity, we also emphasize that we are measuring curiosity as a more stable trait, and hope to explore the situational determinates of curiosity in the future by assessing it as 'state curiosity' as well.

As we suggest in the introduction, an operational definition of curiosity in preschool children is a necessary first step toward understanding the nature and development of children's scientific curiosity, as well as to study the extent to which any early childhood science program really does increase children's scientific curiosity. While the measure described here is quite different from children's typical and spontaneous real-world exploratory behavior, uncertainty preference on our proposed curiosity measure is expected to generalize to exploration and learning behaviors. Some initial work has supported this hypothesis. The relationship between children's curiosity on the task described here and their question asking behavior was recently assessed. Children who were considered to be more curious were better at recognizing both effective and ineffective questions, and generated more questions about a science topic than less curious children, even when controlling for verbal ability (Jirout, 2011). While this result is promising, it is only a first step at addressing the asking a specific type of question asking for a problem-solving task (Jirout, 2011). This result could suggest that high- and low-curious children learn very similarly, though these results are limited to a very structured type of task, and further work is needed in order to generalize to more typical learning tasks. There is also some initial support for the effectiveness of using uncertainty to make educational gaming experiences more motivating. Children preferred educational computer games with uncertainty over without uncertainty, and games with uncertainty seemed to be more effective for learning (Howard-Jones & Demetriou, 2009). Future work should further explore the types of learning conditions that are most

effective for both high- and low-curious children, and how uncertainty can be used to lead to more engaging learning opportunities.

Conclusion

Previous literature on children's curiosity includes vague definitions of what curiosity is and inconsistent measures that often lack validity and reliability. A synthesis of this literature and adoption of the information gap theory of curiosity (Loewenstein, 1994) led to an operational definition and a validated measure of curiosity in children that is consistent with previous research, but also is explicit in what is being assessed. This measure allows for future research to produce results that can enhance the theory of curiosity. This type of scientific curiosity is stable, with similar scores across children of different age groups and school grades, and is positively related to children's verbal and nonverbal question asking behavior. We hope that researchers interested in developing measures of curiosity will continue investigating ways of assessing the more dynamic aspect of curiosity as a state. By using both this type of measure and the one we present here, it will be possible to address more applicable problems in education, such as the development of curiosity and whether the goals of science curricula, early education programs, and standards and legislation on early childhood education are achieving their goals of producing curious children.

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