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Pathways from parental stimulation of children's curiosity to high school science course accomplishments and science career interest and skill

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ABSTRACT

Curiosity is fundamental to scientific inquiry and pursuance. Parents are important in encouraging children's involvement in science. This longitudinal study examined pathways from parental stimulation of children's curiosity per se to their science acquisition (SA). A latent variable of SA was indicated by the inter-related variables of high school science course accomplishments, career interest, and skill. A conceptual model investigated parental stimulation of children's curiosity as related to SA via science intrinsic motivation and science achievement. The Fullerton Longitudinal Study provided data spanning school entry through high school ($N = 118$). Parental stimulation of curiosity at age 8 years comprised exposing children to new experiences, promoting curiosity, encouraging asking questions, and taking children to a museum. Intrinsic motivation was measured at ages 9, 10, and 13 years, and achievement at ages 9, 10, and 11 years. Structural equation modelling was used for analyses. Controlling for socio-economic status, parental stimulation of curiosity bore positive and significant relations to science intrinsic motivation and achievement, which in turn related to SA. Gender neither related to stimulation of curiosity nor contributed to the model. Findings highlight the importance of parental stimulation of children's curiosity in facilitating trajectories into science, and relevance to science education is discussed.

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Parental stimulation; children's curiosity; science courses; career interest; and skill; Fullerton Longitudinal Study

Introduction

Entry into science careers is of critical global importance (Alberts, 2013; National Academy of Sciences, 2010; National Research Council, 2012; Osborne, Simon, & Collins, 2003). Across nations, there have been concerns about attracting students to enter science careers (e.g. DeWitt, Archer, & Osborne, 2014; Freeman, Marginson, & Tytler, 2015; National Academy of Sciences, 2010; Said, Summers, Abd-El-Khalick, &

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Wang, 2016), as well as fostering science achievement throughout the school years (Freeman et al., 2015; Kelly et al., 2013; Maltese, Potvin, Lung, & Hochbein, 2015; National Center for Education Statistics, 2012; Provasnik et al., 2012; Tai, Liu, Maltese, & Fan, 2006). For example, results of the 2011 assessment (the most recent available) of the Trends in International Math and Science Study (TIMSS) indicated that fewer students reached science achievement benchmarks at grade 8 compared to grade 4 signifying that at 8th grade, more students were behind than in 4th grade (Martin, Mullis, Foy, & Stanco, 2012). Therefore, science achievement and career entry are both of major concern.

International research reveals that students' attitudes and motivation towards science, which are related to science achievement, often wane across school years, and enrolment in non-compulsory science courses diminishes during high school (e.g. Bennett & Hogarth, 2009; Gottfried, Fleming, & Gottfried, 2001; van Griethuijsen et al., 2015; Osborne et al., 2003; Said et al., 2016; Tytler, 2014). As pervasive as this trend is, such decline is not inevitable. For example, in the Science Aspirations and Career Choice (ASPIRES) project, a study conducted in England, it was found that students' enjoyment of school science did not decline across grades 6 through 8, and across this grade span, students tended to view scientists positively. However, despite students continuing to enjoy school science, and holding positive attitudes towards science, there was a slight decrease in their desire to become a scientist across these years (DeWitt et al., 2014). DeWitt et al. (2014) and Archer et al. (2010) attribute this discrepancy between enjoyment of science and likelihood of entry into science as a profession to not developing a science identity, that is, not seeing oneself as a scientist. These findings are consistent with the lack of persistence in science, technology, engineering, and math (STEM) during college that has been raised as a major concern (Graham, Frederick, Byars-Winston, Hunter, & Handelsman, 2013). The issue is a shortage of young people aspiring to be scientists. To attract students and maintain their involvement in science, it is vital to determine early factors that facilitate and support pathways to this endeavour.

One such factor may be the early stimulation of children's curiosity because it is viewed as a fundamental attribute of students' involvement in science as well as their aspirations to become a scientist. In his editorial in *Science*, Turner (2014, p. 449) contended that curiosity is what drives scientists to get 'out of bed in the morning' and inspires young people to enter science careers. Furthermore, he stated that 'it all begins with a burning desire to know' (p. 449). A survey of scientists by Venville, Rennie, Hanbury, and Longnecker (2013) revealed that when asked to respond to an open-ended question regarding what influenced them to study science, curiosity about the world was the most prevalent response. In a study with high school students, it was found that those majoring in science, and those intending to major in science in college, evidenced greater intellectual curiosity than non-science majors (Tamir, 1988). Hence, curiosity clearly plays an important role in propelling students towards scientific involvement and career entry. As noted by Shonstrom (2016), curiosity serves as a 'motivating force behind discovery, exploration, adventure, and learning' (p. xii). In the present longitudinal study spanning elementary through high school, parental stimulation of children's curiosity as it pertains to students' science course involvement and career interest and skill, is examined.

Conceptual foundations

Conceptually, curiosity is a foundation of individuals' science pursuance. Its role in scientific thinking is noted to be 'clear and unquestionably important' (Klahr, Matlen, & Jirout, 2013, p. 235), and literature supports the role of curiosity as a motivator as well as a characteristic of scientific thinking (Klahr et al., 2013; Markey & Loewenstein, 2014; Ramachandran, 2004; Turner, 2014). Conceptualisations of curiosity are consistent in defining it as the desire for knowledge acquisition (e.g. Alexander & Grossnickle, 2016; Grossnickle, 2016). Curiosity has been included in the development of scientific standards and goals of organisations such as the American Association for the Advancement of Science (Jirout & Klahr, 2012; Klahr et al., 2013). Curiosity as a basis for children's initial and ongoing study of science has been incorporated into the Next Generation Science Standards as a foundation for a developmental progression starting with children's curiosity about how the world works, and providing a basis for continued knowledge of science (NGSS Lead States, 2013).

Starting in infancy, there is evidence of curiosity in behaviours such as novelty seeking, exploration, persistence, and question asking (Klahr et al., 2013; Markey & Loewenstein, 2014; Moch, 1987; Voss & Keller, 1983) all of which signify inquisitiveness. Whereas curiosity is innate (Engel, 2011, 2015; Jirout & Klahr, 2012), and evidence suggests a neural basis associated with it (Gruber, Gelman, & Ranganath, 2014), environmental experiences facilitate or impede curiosity, which ultimately have significant developmental and educational outcomes (Engel, 2011, 2015; Klahr et al., 2013; Markey & Loewenstein, 2014; Voss & Keller, 1983). Because curiosity exists in young children, parents play a fundamental role in its development. Stimulating curiosity through experiences such as encouraging children to ask questions and exposing them to novel experiences (e.g. Baram-Tsabari, 2015; Chin & Osborne, 2008; Engel, 2015) would be expected to facilitate and launch trajectories towards science during their education. The role of parents in stimulating children's interest in learning about science has been endorsed by the National Science Teachers Association. The position advanced is that involvement of parents and other caregivers is crucial to children's interest in and learning of science at home, school, and in their community (National Science Teachers Association, 2009).

Because curiosity involves a desire for seeking information in the absence of extrinsic reward (Klahr et al., 2013; Markey & Loewenstein, 2014), it is theoretically considered to be an aspect of intrinsic motivation, which is pleasure inherent in learning without receipt of an external reward (Berlyne, 1971; Gottfried, 1985; Gottfried et al., 2001; Koballa, Glynn, Abell, & Lederman, 2007). Academic intrinsic motivation incorporates curiosity in its conceptualisation, defined as enjoyment of school learning characterised by an orientation towards mastery; curiosity; persistence; task-endogeny; and the learning of challenging, difficult, and novel tasks (Gottfried, 1985; Gottfried et al., 2001). Academic intrinsic motivation is exceptionally important for school achievement because the intrinsic pleasure inherent in the learning process is critical to promoting advancements in cognitive processing and mastery (Gottfried, 1985; Gottfried et al., 2001; Berlyne, 1971; Hunt, 1971; Nolen & Haladyna, 1990).

Empirically, academic intrinsic motivation is positively associated with academic achievement. Students with higher academic intrinsic motivation evidence consistently higher mastery and performance across subject areas, including science, with respect to higher standardised achievement test scores, report card grades, and ratings of student achievement by teachers and parents on standardised inventories. They are more likely to enrol in challenging and higher level high school courses, attain higher high school grade point averages, and achieve a higher level of educational attainment. These relations are pervasive, as they generalise across types of achievement measures, different informants, as well as being independent of IQ. Furthermore, they are apt to view themselves as being more academically capable, have higher academic self-concepts, lower academic anxiety, and are perceived by their teachers as being more intrinsically motivated, harder working, learning more, happier, and more well behaved in the classroom than students with lower academic intrinsic motivation (Gottfried, 1985, 1990; Gottfried & Gottfried, 2011; Gottfried, Gottfried, & Guerin, 2006; Gottfried, Marcoulides, Gottfried, & Oliver, 2013; Gottfried, Nylund-Gibson, Gottfried, Morovati, & Gonzalez, in press; Lazowski & Hulleman, 2016; Lepper, Corpus, & Iyengar, 2005; Spinath & Steinmayr, 2008, 2012). Because of the extensive literature indicating the significance of academic intrinsic motivation to student achievement, it was selected to be included in the conceptualisation and model described below.

Science intrinsic motivation is a distinct dimension relative to academic intrinsic motivation in other subject areas from childhood through adolescence (Gottfried, 1985; Gottfried et al., 2001; Gottfried, Marcoulides, Gottfried, & Oliver, 2009). It is particularly relevant to study as related to curiosity stimulation because of the theoretical foundation that curiosity provides for science intrinsic motivation and achievement. In accord with this perspective, Hazari, Sonnert, Sadler, and Shanahan (2010) found that the strongest predictor of physics identity in college students was desire to pursue a career that would provide them with intrinsic career fulfilment. These researchers concluded that 'We want students to be internally driven and to feel motivated simply by the enjoyment of learning and working with physics concepts' (Hazari et al., 2010, p. 994). Thus, it is expected that children whose parents stimulate their curiosity would subsequently evidence higher intrinsic motivation and achievement in science.

Research has focused on parents' encouragement of children's science interest and entry into the field of science by explaining the importance and value of science as a discipline of study and career, placing children in science activities such as extracurricular classes or programmes, or encouraging science hobbies. Such parental encouragement is related to their children's enrolment in science courses and career interests (e.g. Archer et al., 2012; Dabney, Chakraverty, & Tai, 2013; Harackiewicz, Rozek, Hulleman, & Hyde, 2012; Sjaastad, 2012; Tytler, 2014).

Present research and conceptualisation of the longitudinal progression model

This study investigated the specific role of parental stimulation of children's curiosity per se in facilitating their entry into science. This is important because stimulation of curiosity would be expected to enhance motivational and cognitive/learning processes (see Gruber et al., 2014; Kidd & Hayden, 2015; Shonstrom, 2016) that provide a foundation for pursuing science in high school. Furthermore, the pathways from childhood through high school by which parental stimulation of curiosity proceeds towards science acquisition (SA) remain to be determined. In this research, a new construct is introduced labelled 'SA'. This higher order construct is defined as follows: by the end of high school, students have acquired a level of accomplishment in their high school science courses as well as having acquired science career interest and scientific skill. The construct is higher order, in that SA is an overarching construct indicated by the three related components of science course accomplishments, science career interest and skill. Therefore, SA encompasses science achievement and students' proclivity towards entry into the field of science.

Children's decisions to enter STEM fields are largely formed by age 14 years (Archer et al., 2012; Maltese & Tai, 2010; Tai et al., 2006; Tytler, 2014). Family experiences have been identified as a major contributor to students' pursuit of and attitudes towards science, a conclusion based on international findings (Archer et al., 2012; Tytler, 2014). In a review, Tytler (2014) contended that such experiences prior to age 14 years are important for students' pursuit of science, and suggested the need to understand formative influences on student interest and career aspirations. Therefore, parental influences are essential to investigate (Archer et al., 2012; Tytler, 2014), as this information would be helpful to develop initiatives for involving students in science. Despite the theoretical significance of curiosity for science and the importance of parents in facilitating children's pursuit of science, there is an absence of longitudinal research investigating the role of parents' stimulation of children's curiosity as related to their subsequent high school science course accomplishments and science career interest and skill (i.e. SA). This longitudinal research extends from childhood through high school, which includes the formative years prior to age 14 years, and allows for the determination of the long-term role of parental stimulation of curiosity.

The primary question addressed in this research is: Does parental stimulation of children's curiosity have long-term pathways to their SA during high school? This question is based on the theoretical view that curiosity is a foundation of scientific inquiry and pursuance of science. Hence, stimulation of curiosity furnished the initial condition in the model for the subsequent pathways. Recent research indicates that early experiences have long-term effects on subsequent outcomes including education and cognition, not necessarily directly, but through intervening or mediating variables (e.g. Bornstein, 2015; Gottfried, Schlackman, Gottfried, & Martinez, 2015). Thus, this served to formulate the structural

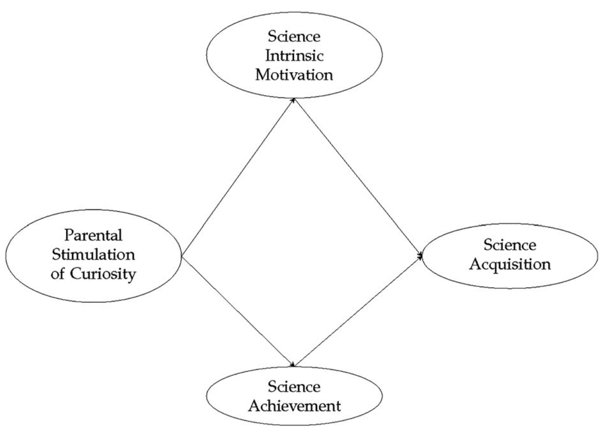

Figure 1. Structural portion of the longitudinal progression conceptual model from parental stimulation of children's curiosity to high school SA.

portion of the conceptual model illustrated in Figure 1 (Ullman, 2012). The structural equation model (SEM) tested the longitudinal progression from parents' stimulation of children's curiosity to subsequent science intrinsic motivation and achievement, which, in turn, related to SA because achieving and being motivated in science would be expected to subsequently enhance SA. Hence, the hypothesis tested was that parental stimulation of children's curiosity positively relates to their high school SA via science intrinsic motivation and achievement.

Methods

Participants

Data derived from the Fullerton Longitudinal Study (e.g. Gottfried & Gottfried, 1984; Gottfried et al., 2006, 2013), an ongoing long-term investigation in which 130 children were followed from infancy into early adulthood. Infants were selected from notifications of all births from hospitals surrounding the university. Families were invited to participate prior to the infants' 1-year birthday. Infants free of neurological and visual problems, of normal birth weight, and whose parents spoke English were eligible to enter the study. In the course of investigation, participants were administered a battery of standardised tests in the university laboratory. Additionally, parents responded to standardised home environmental inventories.

Socio-economic status (SES) of families was determined by the Hollingshead Four-Factor Index of Social Status (see Gottfried, Gottfried, Bathurst, Guerin, & Parramore, 2003; Hollingshead, 1975). This extensively used index is based on mothers' and fathers' level of education and occupational ranking. SES varied ranging from semi-skilled workers with no high school degree through professionals. The gender ratio of the participants was approximately equal (52% males/48% females). Ethnicities included 117 White, 7 Latino, 1 Asian, 1 East Indian, 1 Hawaiian, 1 Iranian, and 2 Interracial children. This reflected the demographics of the area at the outset of the investigation.

Over the course of study, participants' retention was high with at least 80% returning for any assessment and with no evidence of attrition bias (Guerin, Gottfried, Oliver, & Thomas, 2003). When the investigation was launched, participants resided in proximity to the research site. Geographic mobility has long been known to be common and expected in extensive longitudinal projects (Harway, Mednick, & Mednick, 1984). As anticipated, the study sample gradually resided throughout the United States. This is important to note because the findings are not restricted to a specific school, school district, or region. Furthermore, participants attended public as well as private schools.

Measures

Parental stimulation of curiosity

When participants were age 8 years, mothers responded to questions pertaining to environmental stimulation. Mothers were respondents for the present study because they were typically the parent who brought the child to the research site and were most consistently involved in reporting about family activities. The rationale, selection, and analyses of the curiosity items are explained in the data analysis section.

The resulting four curiosity items are described as follows, and were selected because they comprise parental stimulation of children's seeking new knowledge (e.g. Chak, 2007; Shonstrom, 2016). Three were answered on a 6-point scale (*not at all true* to *very true*, or *never* to *always*) from the Home Environment Survey (Gottfried, Gottfried, Bathurst, & Guerin, 1994): I try to expose my child to new experiences on a weekly basis; On a weekly basis, I try to expose my child to experiences that will make him/her curious; How often do you encourage your child to ask questions about new ideas on a weekly basis? The fourth item is dichotomous and from the Home Observation for Measurement of the Environment Inventory (HOME; Caldwell & Bradley, 1984): family member has taken child, or arranged for child to go to a scientific, historical or art museum within the past year. Higher values on items correspond to higher stimulation of curiosity. Alpha coefficient for these items is .80.

Science intrinsic motivation

The Children's Academic Intrinsic Motivation Inventory (CAIMI; Gottfried, 1986; Gottfried et al., 2001), a published and psychometrically well-established measure assessing academic intrinsic motivation as defined above was used to assess science intrinsic motivation from administrations at ages 9, 10, and 13 years. The CAIMI is the only published scale to appraise academic intrinsic motivation in specific subject areas, with a separate scale for appraising science intrinsic motivation. It has been used in research internationally and translated into several languages (Gottfried, 2009). The science scale was selected for this research due to its alignment with the conceptual issues and its psychometric strength (Gottfried, 1986; Gottfried et al., 2001). This scale comprises 26 items, resulting in a total score, with higher scores representing greater science intrinsic motivation. These ages were chosen as they represent the same developmental time frame as the measurement of science achievement. As noted, this particular age period is pivotal in the development of children's decision to enter STEM fields (Archer et al., 2012; Maltese & Tai, 2010; Tai et al., 2006; Tytler, 2014) and was selected as the optimal time frame for assessing science intrinsic motivation in this study. Example items answered on a 5-point scale from *strongly agree* to *strongly disagree* are: I enjoy learning new things in science; I like to find answers to questions in science. Alpha coefficient for the science intrinsic motivation scale is .90.

Science achievement

Teachers rated students' academic performance/achievement specifically in science at ages 9, 10, and 11 years on a 5-point scale from *far below grade level* to *far above grade level* on the Teacher Report Form (Achenbach & Rescorla, 2001) of the Child Behavior Checklist, a widely used, published, and psychometrically well-established scale. Higher scores designate higher achievement. Test–retest reliability for academic performance is .93. The initial two ages are identical with measurement of science intrinsic motivation, albeit the last age was measured at 11 years, not 13 years. Although not entirely symmetrical, these measurements are comparable, in that they span the formative years prior to 14 years, and hence they place within the same developmental period deemed important for the decision about pursuing science in later years.

Science high school course accomplishments

Science course accomplishments for grades 9 through 12 were directly assessed from official high school transcripts comprising number of science courses completed; number of specialty courses taken [Advanced Placement (AP), International Baccalaureate (IB), and Honours]; and highest level of science courses attained (Dalton, Ingels, Downing, Bozick, & Owings, 2007). These were included in the latent variable called Science High School Course Accomplishments.[1] The AP, IB, and Honours courses provide more challenging and rigorous coursework than regular courses. AP courses are at the college level with the potential for students to receive college credit (The College Board, 2016). IB courses are provided by schools qualified by the International Baccalaureate Organisation, and participating schools are worldwide. The IB programme and courses follow the educational principles put forth by this organisation including nurturance of curiosity, skills for inquiry and research, lifelong learning, and inspiring students to ask questions, set challenging goals, and persist in achieving them (International Baccalaureate Organization, 2013). Honours courses are offered at the same level as regular classes, but are more advanced and challenging by covering additional topics in depth (The College Board, 2016).

This ecologically valid procedure was based on a comparable approach shown to be valid with regard to modelling math course accomplishments (Gottfried et al., 2013). High school course accomplishments indicated how far and to what level of challenge and mastery students have advanced in their science studies, hence being aspects of the level of SA. By including these three measures, the science course accomplishments latent construct taps persistence, mastery, and learning of challenging science material. It also indicates students' affinity for the field of science. This analytical approach provides a more comprehensive and conceptual assessment rather than relying on a single measure such as number of courses taken, which has been noted as a limitation of prior research (Gottfried et al., 2013). Higher science course accomplishments indicate students' greater involvement and persistence in pursuing progressively more advanced, challenging, and difficult science. Conceptualising science course accomplishments as a construct also provides for a more psychometrically sound representation rather than using a single measure, an approach in accord with definitions of latent variables advanced by Bollen (2002) and Raykov and Marcoulides (2006).

All transcripts were coded by two independent teams of two coders each. This procedure enabled determination of inter-rater reliability. A third team of two coders assessed the percentage of agreement of the coding of each course between the two teams. Inter-rater reliability was high, with 97.34% agreement. Discrepancies were due to course titles needing clarification from the schools. These were resolved by calling the schools, and consensus, resulting in a subsequent 100% agreement. The number of courses comprised the total number of courses in semesters (two semesters per academic year). Number of specialty courses designated as AP, IB, and Honours on transcripts comprised this measure. Because schools vary with regard to offering these courses, this specialty designation was developed to be inclusive of these options across schools. All participants had the opportunity to enrol in advanced and specialty science courses. The scoring system used for science course sequences attained ranged from 1 (no high school science or low academic science) to 6 (e.g. chemistry II, physics II, advanced biology, or AP and IB classes in these fields) utilising the sequence rubrics provided by Dalton et al. (2007).

Science career interest and skill

In the last year of high school, participants reported their science interest and skill level on the Campbell Interest and Skill Survey (CISS; Campbell, Hyne, & Nilsen, 1992), a published and psychometrically well-established scale assessing career interest and skill across a variety of domains. The CISS was included because it allowed examination of the theoretical model examining parental stimulation of curiosity as related to students' interest in pursuing science as a profession, as well as their scientific skill. CISS interest items are rated on a 6-point scale from *strongly like* to *strongly dislike.* CISS skill items are rated on a 6-point scale from *expert: widely recognised as excellent in this area* to *none: have no skills in this area.* These items are scored on standardised interest and skills scales. The science interest scale indicates strength of attraction for entering science professions, such as being a laboratory researcher, and doing scientific experiments. The science skill scale provides an estimate of self-confidence in performing well in scientific activities, such as designing a laboratory experiment, setting up controls, collecting data, and applying the appropriate statistics. Science interest and skill scales comprised seven and three items, with alpha coefficients of .88 and .81, respectively. Higher scores correspond to higher science career interest and scientific skill.

Socio-economic status

Information for the Hollingshead Four-Factor Index was assessed via parents at ages 5, 6, and 7 years. This served to construct the antecedent latent variable of SES used in the model.

Results

Data analysis

Exploratory factor analysis of curiosity items

From an initial pool of 11 items involving curiosity-enhancing experiences, a factor analysis was conducted. Maximum likelihood extraction with quartimax rotation was performed through comprehensive exploratory factor analysis (Browne, Cudeck, Tateneni, & Mels, 2009) on the 11 items. Prior to extraction, a polychoric correlation matrix was estimated to account for the dichotomously scored items from the HOME inventory (Caldwell & Bradley, 1984). Eigenvalues of the sample polychoric correlation matrix indicated the presence of four factors. A four factor solution fit the data, $\chi^2(17) = 16.90$, $p = .461$, with a root mean square error of approximation (RMSEA) of .00 with a 90% confidence interval ranging from .00 to .111. The four-factor solution was also supported by Horn's (1965) parallel analysis. Specifically, the modified version of the parallel analysis suggested by Glorfeld (1995) to reduce the likelihood of over-retention using the recommended 95th percentile of the set of null distributions of the eigenvalues was conducted with 5000 iterations using the 'paran' package (Dinno, 2012) in R (R Core Team, 2014). The factors accounted for approximately 28%, 15%, 12%, and 11% of variance, respectively. Because the first factor accounted for the largest proportion of the variance, only the variables loading significantly on the first factor were utilised for the present research. This factor comprised four items which formed the latent variable utilised in the model. All four items cohesively pertained to parents furnishing experiences to enhance their child's opportunity in seeking new knowledge. This is in accord with conceptions of curiosity as seeking knowledge presented above, and consistent with parents' and teachers' views of curiosity as seeking knowledge (Chak, 2007).

Measurement of the longitudinal progression model

In the conceptual model, which comprises the structural and measurement representations (see Figure 2), the latent variables are presented in ovals and the measured variables in rectangles (Ullman, 2012). The model begins with the latent variable of parental stimulation of curiosity at age 8 which has four indicators (exposure to new experiences, promote curiosity, encourage questions, and take to museum) showing paths to the latent variables science intrinsic motivation with indicators measured at ages 9, 10, and 13 years, and science achievement with indicators measured at ages 9, 10, and 11 years. Science intrinsic motivation and science achievement show paths to the latent variable SA. This higher order latent variable is indicated by science high school course accomplishments, science career interest, and scientific skill, all of which were obtained at the end of high school and are empirically inter-related. The latent variable of science high school course accomplishments comprises variables specifically related to coursework including the number of science courses, number of AP/IB/Honours science courses, and highest level of science courses taken. In sum, this study tested the conceptual model whereby, parental stimulation of curiosity at age 8 relates to SA in high school

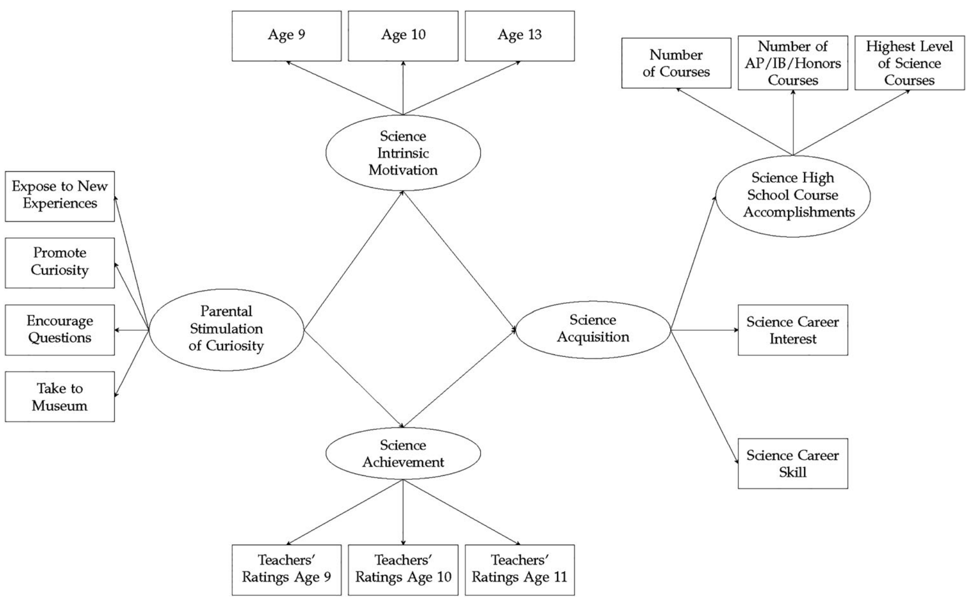

Figure 2. Measurement portion of the longitudinal progression conceptual model from parental stimulation of children's curiosity to high school SA.

via prior science intrinsic motivation and science achievement during childhood to early adolescence. The analyses that follow present an empirical evaluation of the proposed model.

Because SES and child gender could potentially play a role with respect to parental stimulation of curiosity, both were assessed as covariates to establish the unique role of parental stimulation of curiosity to subsequent pathways independent of these two variables. The terms effects and pathways (or paths) are used throughout in a statistical sense regarding the contribution of variables in the model under investigation, without implying a causal priority of one over the other. This approach is consistent with that reported by Dotterer, McHale, and Crouter (2009) and Gottfried et al. (2013).

Descriptive analyses

Means, standard deviations, and Pearson product moment correlations of all measured variables are presented in Table 1. Positive and significant correlations emerged, indicating that it was appropriate to proceed with model estimation based on the conceptual model, $p < .05$. These measured variables, with the exception of gender, served as indicators for constructing the latent variables. It should be noted that the primary advantages of using latent variables are that they incorporate unequal weights for items measuring the latent variable which allows for differences in the metrics of the observed variables, and factor scores are adjusted for measurement error, thereby permitting the testing of interrelations among hypothesised constructs when observed variables are measured with error (Bollen, 1989, 2002).

Model estimation

There were no univariate or multivariate outliers, and none of the measured variables was significantly univariately skewed as evaluated through R (R Core Team, 2014) and EQS 6.2 (Multivariate Software, 2008). Additionally, Mardia's (1974) normalised coefficient of kurtosis was −.84, indicating that the data were multivariate normal, and maximum likelihood estimation would be appropriate (Bentler, in press). However, as expected in long-term longitudinal research, measured variables included in the present study contained between 6.7% and 37.3% missing data. Little's missing completely at random (MCAR) (Little, 1988) test as implemented in the BaylorEdPsych package in R (Beaujean, 2012) was used to evaluate the missing data mechanism and revealed that the data were missing completely at random, $\chi^2(452) = 490.09$, $p = .105$, indicating maximum likelihood imputation using Fisher standard errors would be appropriate. Furthermore, robust fit indices and standard errors were interpreted to accommodate the sample size of $N = 118$. A study sample of this size has been deemed to be moderate and sufficiently large for modelling longitudinal data (Bentler, 2007; Liu, Rovine, & Molenaar, 2012).

Latent variable analyses were performed using the EQS 6.2 software (Multivariate Software, 2008). For model identification purposes, the first path from each latent variable to an indicator was fixed to 1.0, as is standard procedure. All other paths depicted in Figure 2 as well as error variances of measured variables and disturbance terms of the latent variables were freely estimated. Finally, all paths not shown in Figure 2, including correlations among errors, were fixed to 0, and thus, not estimated.

These analyses compare a proposed hypothetical model with a set of actual data. The closeness of the hypothetical model to the empirical data is evaluated statistically through

Table 1. Intercorrelations, means, and standard deviations for study variables.

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Parental stimulation of curiosity																			
1. Exposure to new experiences	–																		
2. Promote curiosity	.79***	–																	
3. Encourage questions	.63***	.66***	–																
4. Take to museum	.29**	.27**	.14	–															
Science intrinsic motivation																			
5. Age 9	.07	.11	.09	.24*	–														
6. Age 10	.15	.18	.17	.20*	.51***	–													
7. Age 13	.20*	.13	.03	.29**	.46***	.48***	–												
Science achievement																			
8. Teachers' ratings age 9	.16	.12	.19	.24*	.18	.20	.31**	–											
9. Teachers' ratings age 10	.16	.20	.13	.26*	.31**	.09	.15	.53***	–										
10. Teachers' ratings age 11	.19	.23*	.13	.20	.18	.08	.09	.53***	.36**	–									
SA																			
11. Number of courses	.14	.20	.19	.21*	.16	.14	.15	.44***	.28*	.38**	–								
12. Number of AP/IB/Honours	.19	.19	.13	.21*	.17	.19	.32**	.51***	.34**	.37**	.57***	–							
13. Science course level	.26*	.29**	.17	.30**	.26**	.31**	.40***	.52***	.36**	.56***	.71***	.63***	–						
14. Science career interest	−.02	.03	.00	.13	.22*	.21*	.30**	.27*	.16	.20	.26**	.25**	.35*	–					
15. Science career skill	.10	.20	.15	.18	.35***	.34**	.40***	.38**	.33**	.34**	.38***	.39***	.45***	.75***	–				
SES																			
16. Age 5	.22*	.30**	.24*	.32**	.18	.23*	.14	.42***	.39**	.34**	.22*	.27**	.36***	.05	.24*	–			
17. Age 6	.13	.20	.19	.30**	.23*	.15	.13	.46***	.38**	.45***	.38***	.30**	.46***	.10	.29**	.84***	–		
18. Age 7	.21*	.27**	.26*	.24*	.17	.24*	.18	.41***	.33**	.36**	.28**	.30**	.41***	.07	.28**	.85***	.93***	–	
Gender																			
19. Gender	.00	.08	.12	.01	−.12	−.02	−.10	−.06	−.06	−.01	.09	−.10	.08	−.17	−.17	.00	.06	−.04	–
Mean	3.74	3.74	4.57	.70	98.93	97.04	91.09	3.43	3.49	3.55	5.67	1.31	4.22	48.96	49.58	47.91	47.80	49.04	1.48
Standard deviation	1.34	1.36	1.22	0.46	18.64	17.50	17.55	0.72	0.91	0.85	1.73	2.42	1.30	13.00	11.69	10.79	11.01	9.49	0.50
N	103	103	103	105	107	107	108	74	74	77	105	105	105	110	110	110	102	108	130

Note: Gender was dichotomously scored as 1 representing males and 2 representing females.
$^{*}p < .05$.
$^{**}p < .01$.
$^{***}p < .001$.

goodness-of-fit indexes and the RMSEA. Yuan–Bentler robust fit statistics [the Yuan–Bentler chi-square, the robust comparative fit index (RCFI), and the Bentler–Bonett non-normed fit index (NNFI)] were interpreted to accommodate the sample size and because maximum likelihood imputation was employed (Bentler, in press). The RCFI ranges between 0 and 1 and compares the improvement of fit of a hypothesised model to a model of complete independence among the measured variables while adjusting for sample size. Values approaching .95 are desirable for the RCFI (Hu & Bentler, 1999). The Bentler–Bonett NNFI (Bentler & Bonett, 1980) is similar to the RCFI, in that it compares the improvement of fit of a hypothesised model to a model of complete independence among the measured variables; however, the NNFI recognises the degrees of freedom of the baseline model when determining model fit and, thus can fall outside of the 0–1 range. The NNFI has the major advantage of reflecting model fit well at all sample sizes (Bentler, in press). As with the RCFI, values approaching .95 are desirable for the NNFI (Hu & Bentler, 1999). The RMSEA for the model was also reported (Browne & Cudeck, 1993). The RMSEA indicates lack of fit per degrees of freedom, controlling for sample size, and values less than .06 indicate a close-fitting model (Hu & Bentler, 1999).

As depicted in Figure 3, the model with 128 degrees of freedom produced a Yuan–Bentler χ^2 of 192.17, an RCFI of .954, a Bentler–Bonett NNFI of .946, and an RMSEA of .065 (90% CI .044–.083), all indicating adequate fit to the data. Power for tests of perfect fit (MacCallum, Browne, & Sugawara, 1996) resulted in .95, which is well above the desired .80 value. Furthermore, the model R^2 of .357 indicated that approximately 36% of the variability in SA during high school can be accounted for by the combination

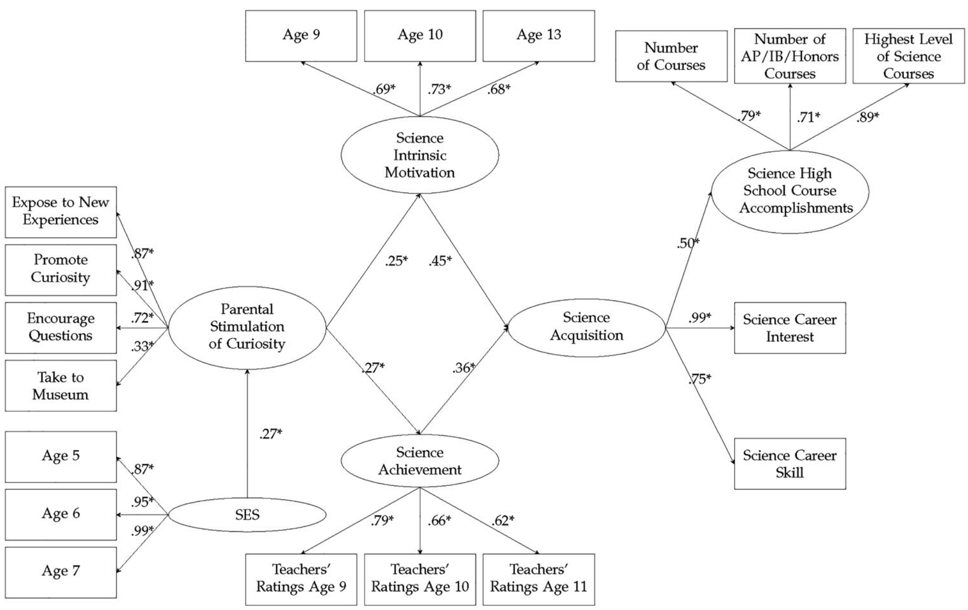

Figure 3. SEM longitudinal progression model from parental stimulation of children's curiosity to high school SA.

of parental stimulation of curiosity at age 8, and science intrinsic motivation and science achievement.

Figure 3 provides the standardised parameter estimates, representing beta weights (one-way arrows). All measured variables loaded significantly on their respective latent variables, $p < .05$. SES positively and significantly related to parental stimulation of curiosity ($\beta = .27$, $p < .05$) indicating that families with higher SES provided more stimulation of curiosity. Because SES served as a covariate in the current model, all remaining paths were interpreted after controlling for SES. Gender was also investigated as a potential covariate, but did not significantly contribute to the final model, scaled $\chi^2_{\text{difference}} = 19.43$ ($\Delta\text{df} = 14$), $p > .05$ (Ullman, 2006) nor to stimulation of curiosity, $p > .05$. An additional model estimating the direct effect of parental stimulation of curiosity at age 8 on SA in the presence of science intrinsic motivation and science achievement did not significantly improve model fit [scaled $\chi^2_{\text{difference}} = 0.001$ ($\Delta\text{df} = 1$), $p > .05$], producing a non-significant direct path, $p > .05$.

Parental stimulation of curiosity significantly and positively related to science intrinsic motivation ($\beta = .25$, $p < .05$) and science achievement ($\beta = .27$, $p < .05$), indicating that increases in parental stimulation of curiosity were associated with subsequently more science intrinsic motivation, and higher scores in science achievement. Furthermore, both science intrinsic motivation ($\beta = .45$, $p < .05$) and science achievement ($\beta = .36$, $p < .05$) significantly and positively related to SA during high school. In addition, parental stimulation of curiosity had a significant indirect effect ($\beta = .21$, $p < .05$) on SA in high school. Components of these indirect effects include the paths from parental stimulation of curiosity to science intrinsic motivation and science achievement, indicating further – and in accordance with the conceptual model – that more parental stimulation of curiosity was associated with higher levels of SA.

Discussion and conclusions

This research contributes to the literature by elucidating the longitudinal pathways by which parental stimulation of children's curiosity during elementary school relates to their SA during high school. Within the long-term longitudinal progression, parental stimulation of curiosity related to high school SA via the dual pathways of science intrinsic motivation and science achievement. Whereas stimulation of curiosity did not bear a direct path to SA, it did so indirectly through its positive and significant direct relations to science intrinsic motivation and achievement which, in turn, related to SA. This supported the conceptualised longitudinal progression model, and the theoretical connectedness between stimulation of curiosity per se and science intrinsic motivation and achievement.

As noted in the introduction, theories of curiosity conceptualise it as the desire for seeking information in the absence of extrinsic rewards (Klahr et al., 2013; Markey & Loewenstein, 2014). Curiosity involves intrinsic motivation, learning, addressing uncertainty, and knowledge acquisition (Alexander & Grossnickle, 2016; Grossnickle, 2016; Gruber et al., 2014; Shonstrom, 2016). Academic intrinsic motivation, the pleasure inherent in learning, incorporates curiosity in its conceptualisation along with mastery, persistence, and learning of challenging, difficult, and novel tasks; and there is a pervasive relation between academic intrinsic motivation and achievement across a variety of measures (e.g. Gottfried, 1985; Gottfried et al., in press). The theoretical connectedness between parents' stimulation of children's curiosity and their academic intrinsic motivation and academic achievement received empirical support. Parents' provision of experiences that enhance curiosity has benefits for their children's science involvement that traverse elementary through high school.

The longitudinal pathways originating from stimulation of curiosity to science intrinsic motivation and achievement and then to SA were assessed taking into account gender and SES as covariates in the initial phase of the model. Gender bore no significant relation to stimulation of curiosity and did not contribute to the model. However, SES related significantly to parental stimulation of curiosity. Parents relatively higher in education and occupational status were more likely to provide curiosity-stimulating experiences to their children. However, with SES controlled in the model, parental stimulation of curiosity significantly related to subsequent pathways, indicating that it is the experience of curiosity stimulation that contributes to children's science intrinsic motivation and achievement, and in turn, SA. Hence, the findings highlight the importance of proximal experience provided by parents in stimulating their children's curiosity beyond the distal variable of SES. Regardless of parents differing in SES, provision of curiosity stimulation is important for students' subsequent SA. The finding of proximal environment relating to children's cognitive development beyond SES has been well founded in the developmental literature (see chapters in Bornstein & Bradley, 2003 and Gottfried, 1984) and now with the present research is evident with respect to educational success in science.

Stimulating curiosity

Parental stimulation of curiosity was characterised by items not specifically oriented towards science, but towards stimulating the process of curiosity in and of itself. These curiosity-stimulating items can be best conceptualised as exposing children to novel experiences, enhancing the desire to learn, and seeking information by encouraging questions. All of these items reflect the construct of seeking knowledge, which is a foundation of scientific inquiry. These items involved the role of the parent as instrumental in furnishing these experiences. Whereas the items were responded to by mothers, of which three of four pertained to them directly, it is not asserted that the provider of such stimulation need be only mothers. This stimulation could be implemented and supported by fathers, siblings, or extended family, and their contributions are worthy of future research. This research underscores the significant role parents play in stimulating curiosity as it relates to science educational outcomes.

Research has suggested that by age 14 years, decisions have been formed about entering STEM fields, and it is important to determine the antecedent factors that may be influential (Archer et al., 2012; Tai et al., 2006; Tytler, 2014). This investigation revealed that parental stimulation of curiosity as early as age 8 years had positive and significant direct pathways to science intrinsic motivation and achievement across these formative years through early adolescence, which subsequently related to high school SA. This SA construct encompassed science course accomplishments indicated by the number of courses taken; the number of AP, IB, and Honours courses completed; and advancement through the science sequence, all of which involve persistence, mastery, and learning of challenging science tasks. Furthermore, the construct also comprised students' science career interest and skill. SA has clear implications for advancement in science beyond high school. Students who take more and higher level science courses in high school, and are more skilled along with a stronger interest in science as a career, would have a greater inclination to pursue science in their postsecondary education (e.g. Gottfried, 2015; Tai et al., 2006; Trusty, 2002; Wang, 2013). Thus, provision of parental stimulation of curiosity as early as age 8 has implications for their child's long-term trajectories into science. Future research should seek to ascertain whether parental stimulation of curiosity experiences during preschool (or earlier) reveal earlier roots and pathways for subsequent SA.

Recent research has shown stability of parents' provision of cognitive enrichment experiences from early childhood through adolescence as well as ongoing transactions of these experiences between parents and children in children's academic achievement (Sy, Gottfried & Gottfried, 2013). Therefore, it is plausible that parents who stimulate young children's curiosity are likely to provide ongoing and diverse curiosity enrichment experiences across the school years that relate to science intrinsic motivation, achievement, and SA. This may reflect parents' notions, values, or beliefs about the role of stimulation in enhancing children's motivation and cognitive development (Gottfried et al., 2015). However, the fact remains that both theoretically and empirically, there was a specific cross-time connection between parents' stimulation of curiosity and SA, controlling for parental SES. Additionally, as a function of stimulating children's curiosity, children themselves may subsequently bid or press parents for curiosity-stimulating and pleasurable experiences, such as science hobbies, camps, and extracurricular classes.

Stimulation of curiosity may also engender children's interest in science which could also serve as a potential link in the trajectory towards SA (e.g. Ainley & Ainley, 2015; Maltese & Tai, 2010; Tai et al., 2006). Therefore, parents who provide early curiosity-stimulating experiences are likely to launch a foundation for continuous experiences that foster and support children's entry into science. Future research may be oriented towards determining how specific curiosity stimulation by parents relates to other aspects of parental encouragement of science.

Parents' stimulation of children's curiosity may set them on a course for developing a science identity, that is, viewing themselves as having a self-definition, or affinity for involving themselves in science activities, and ultimately identifying as a scientist (Brown, Reveles, & Kelly, 2005; Gee, 2000–2001; Lemke, 2001). Hence, curiosity may serve not only as a foundation for children's SA, but it may also facilitate the development of a science identity towards seeking out science activities, and desiring to enter a science career. SA, which was indicated by science course accomplishments, and science career interest and skill, may reflect science identity because of students' engagement in higher level courses, and their expressed attraction to science as a profession (e.g. DeWitt et al., 2014; Master, Cheryan, & Meltzoff, 2016; Perez, Cromley, & Kaplan, 2014).

Strengths, limitations, and future research

Strengths of this research pertain to the long-term prospective nature of the outcomes as well as being based on multiple sources of data. First, children's science intrinsic motivation was assessed via self-reports during childhood through early adolescence. Their science career interest and skill were also based on self-reports during high school. Second, science achievement during childhood and early adolescence was reported by their teachers across this time frame. These data were from different teachers across grades and different schools. Third, science course accomplishments were derived from objective, ecologically valid, transcript data obtained directly from different high schools. Finally, it should be noted that parents reported on the stimulation of curiosity, but on none of the outcome variables. Therefore, parents' reports were valid because they related to data emanating from various sources. In sum, the present results are founded on multiple sources of data supporting the validity of these longitudinal findings.

In light of the fact that variation in SES was positively and significantly related to parental stimulation of curiosity, it may also be the case that ethnic/cultural differences exist. Such differences have been found in the home environmental literature (Bradley, Corwyn, Burchinal, McAdoo, & García Coll, 2001), although ethnicity may be confounded with SES. A limitation of the present research was that the study sample was a predominantly White population with a small inclusion of other ethnicities. Future research should be conducted across various ethnic groups to determine whether the amount of stimulation of curiosity provided by parents and the pathways elucidated in this study generalise across different groups. This may be one explanation for the differential entrance into science for students of different ethnicities (Dalton et al., 2007; Schultz et al., 2011). By the same token, generalisability of these long-term longitudinal findings should be appraised with international samples because of the worldwide issue of attracting, recruiting, and maintaining students into science careers (Hazari et al., 2010; Sjaastad, 2012, 2013; Tai et al., 2006).

Implications for science education

The present research has important implications for the role of parents' stimulation of children's curiosity in science education. As noted in the introduction, curiosity has been incorporated into the standards for science education put forth by the American Association for the Advancement of Science (Jirout & Klahr, 2012; Klahr et al., 2013), and in the Next Generation Science Standards (NGSS Lead States, 2013). The results of this study support this inclusion inasmuch as when parents stimulate their children's curiosity, children evidence greater science intrinsic motivation, higher science achievement, and are more engaged in science course-taking and science career interest and skill during the high school years. This is in accord with the position of the National Science Teachers Association (2009) that parents and other caregivers play a critical role in children's pursuance of science. As indicated by the findings, stimulation of curiosity within the parental context transferred to science within the educational context. Therefore, it is essential to determine how to interface parents' roles as stimulators of their children's curiosity with educational science curriculum. Because it has been noted that teachers rarely consider curiosity as a priority to encourage in their students (Engel, 2011, 2015), there is even more reason to incorporate parents as partners with schools. Thus, it is of utmost importance to ascertain how to best integrate and dovetail parents with schools to facilitate and support students' development towards science. To this end, disseminating the findings contained herein to educators at all levels and internationally regarding the significant role parents play in stimulating children's curiosity may in itself be a proactive intervention for enhancing students' entry into science. Educators, in turn, need to encourage and advise parents about the significant role they play in stimulating children's curiosity and subsequent pursuing of science. The items utilised in the present parental stimulation of curiosity measure could serve as a framework for intervention.

The power of parental stimulation of children's curiosity cannot be emphasised enough. This is evident with respect to the upbringing of the Wright brothers known for their pioneering historical contributions to aeronautics, flight, and successful development of the first powered airplane. When Orville Wright was questioned about having any special advantages in the brothers' upbringing, he responded emphatically 'the greatest thing in our favor was growing up in a family where there was always much encouragement to intellectual curiosity' (McCullough, 2015, p. 18).

Note

1. Because grade point average in science, as in any other subject, is not adjusted for level, type, or number of courses, it was not included in the analyses as it did not elucidate the construct of science high school course accomplishments as defined above.

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