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Research Article

Factors Contributing to Adult Knowledge of Science and Technology

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Abstract: Historically, most efforts to improve public knowledge of science and technology have focused on improvements in K-12 schooling, although post-secondary education and informal education have also been mentioned as important factors. Currently, little empirical data exist to determine how or when to best leverage science and technology education energies and resources. This article examines a range of factors potentially contributing to adult knowledge of science and technology. Results from a telephone survey of 1,018 adult residents in greater Los Angeles, California (United States) showed that adult free-choice learning experiences such as reading books and magazines about science and technology, using the internet, and watching science related documentaries and videos were the strongest predictors of self-reported knowledge of science and technology. Privilege, especially higher income and being male, was also an important factor, as were workplace experiences and childhood experiences outside of school. Although formal schooling was a significant predictor of this knowledge, it explained less variance in knowledge than most other factors. This research provides initial data on which to base discussions about how best to support public education in science and technology. © 2013 Wiley Periodicals, Inc. J Res Sci Teach 50: 431–452, 2013

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In an increasingly scientific and technological world, the need for a citizenry engaged in and appreciative of science and technology has never been greater. Learning about science and technology has increasingly become a part of the daily lives of many citizens that has been fueled largely by new digital technologies and media. There has also been a relentless blurring of the boundaries of where, when, and how people learn about science and technology that they know and use every day (Carnegie Corporation of New York, 2009; National Science Board, 2012). Despite considerable investment of resources in science and technology improvement and efforts by many organizations and agencies over the years, a range of indicators suggest that public understanding of science and technology remains well below expectations (Carnegie Corporation of New York, 2009; National Science Board, 2012). This suggests not only the need for continued efforts, but arguably the need to consider different approaches for enhancing knowledge of science and technology. In particular, it would seem that there needs to be a thorough and open assessment of all sources contributing to public knowledge of science and technology, and an objective determination of their relative efficacy.

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A widely agreed on theoretical foundation for how to support public understanding of science and technology is currently lacking. However, considerable focus in the area of public understanding of science research and practice has revolved around the concept of "science literacy," which is a generalized body of scientific understanding and capabilities, historically described as a combination of knowledge and a set of scientific practices and habits of the mind (American Association for the Advancement of Science, 1994; Brown, Reveles, & Kelly, 2005; National Research Council, 1996, 2012). Although there are disputes about exactly what science and technology issues the "science literate" individuals should know, most efforts to measure science literacy have assumed that public knowledge of science and technology represents one reasonable indicator of overall science literacy (e.g., National Science Board, 2012). However, comprehensive theories for how public knowledge of science and technology should be achieved have generally been absent. Arguably, this absence of theory on how science and technology knowledge is acquired stems from the fact that historically, almost all efforts to understand and improve public knowledge of science and technology have begun with the explicit or implicit assumption that formal schooling, particularly elementary and secondary but also post-secondary, provides the vast majority of contribution (e.g., Alberts, 2009; Carnegie Corporation of New York, 2009; Coble & Allen, 2005; Committee on Science, Engineering, and Public Policy, 2007; Honda, 2011; Lederman & Malcom, 2009; National Academies of Science, 2011; Obama, 2009).

Recent arguments have been made suggesting that out-of-school experiences also make critical and perhaps even more important contributions to public learning (Bell, Lewenstein, Shouse, & Feder, 2009; Falk & Dierking, 2010; Nature, 2010; Stocklmayer, Rennie, & Gilbert, 2010). Although most educators readily acknowledge that these more informal experiences have the potential for contributing to public knowledge of science and technology, there remains considerable debate about the relative importance of these contributions. Other factors beyond schooling and informal/free-choice experiences may also impact public knowledge of science and technology. Particularly important in an increasingly scientific and technological world is the role played by the workplace. Given that increasing numbers of jobs require knowledge related to science and technology, it stands to reason that workplace related learning in these fields should contribute an increasing share of public knowledge of these fields (Bayer, 2012). Also of long standing concern by many in the education field has been the influence of privilege and equity, especially the impact on science learning that factors such as income, race, ethnicity, and gender might play (Bayer, 2012; Demie, Butler, & Taplin, 2002; Haycock, 2001; Howard, 2002; National Research Council, 2012; Pellino, 2001; Sacker, Schoon, & Bartley, 2002). Most scholars, therefore, would conclude that the primary influences on public knowledge of science and technology are likely to be contributions made by one or some combination of formal schooling, informal out-of-school experiences, workplace activities, and socioeconomic characteristics (e.g., income, race, gender). Given that public investments in science and technology education worldwide number in the billions of dollars, if not trillions of dollars annually, the answer to the question of how these various educational sources individually and collectively contribute to public science literacy is not trivial.

The Case for Formal Education/Schooling

Although many academics and practitioners decry the current state of school based education in science and technology, and only a few seem to ardently defend that current efforts are all that they could be, most still begin with the assumption that formal schooling represents the single most fundamental contributor to public science learning (e.g., Alberts, 2009;

Carnegie Corporation of New York, 2009; Coble & Allen, 2005; Committee on Science, Engineering, and Public Policy, 2007; Honda, 2011; Lederman & Malcom, 2009; Obama, 2009). School has been asserted by some to be the only place where science and technology is taught cumulatively and as a coherent set of disciplines (e.g., Banilower, Smith, Pasley, & Weiss, 2006; Johnson, 2010). Miller's (2010) research on public science literacy, however, suggested that elementary and secondary school education actually contribute little to public understanding of science, and that most of the variance in adult literacy in science and technology is explained by additional science education that occurs at the post-secondary level (e.g., colleges, universities). From the perspective of an adult lifespan, however, these opportunities are limited in time and scope, and many adults even in relatively educated societies such as the United States (U.S.) never participate in post-secondary education and even fewer take any specific post-secondary science courses (U.S. Census Bureau, 2010). However, if formal schooling, both pre-college and post-secondary, is indeed the major contributor to public knowledge of science and technology as many have suggested, then independent of quality there should be a relationship between the quantity of schooling in which an individual has participated (e.g., years of schooling) and his or her knowledge of science and technology.

The Case for Informal or Free-Choice Learning Experiences

Across a lifetime, only a small fraction of time is actually spent in classrooms (Stevens & Bransford, 2007). What has been referred to as the informal science and technology education infrastructure (Falk, Randol, & Dierking, 2008) is vast and increasingly becoming a regular and popular feature of modern life that makes important contributions to public learning in science and technology (Bell et al., 2009; Falk & Dierking, 2010; Falk & Needham, 2011; Falk, Storksdieck, & Dierking, 2007). Public informal or free-choice science learning is supported by an array of non-school educational sources such as museums, zoos, aquariums, television, books, magazines, internet websites, and a host of other sources. Although the reach and opportunity for informal education to contribute to public understanding of science and technology are vast, it has been suggested that this free-choice learning is not always systematic and is often variable (Miller, 2010). In addition to institutional support of free-choice science and technology learning, home-based experiences are also an important contributor to public science and technology learning (Bayer, 2012; Department for Children, Schools, and Families, 2008; Fehrmann, Keith, & Reimers, 1987). If free-choice learning experiences contribute to public understanding and knowledge of science and technology, then independent of the quality of these experiences there should be a relationship between the kinds and quantity of informal experiences that an individual has and his or her knowledge of science and technology, both as a child and later as an adult.

The Case for Workplace Experiences

Science and technology related jobs have and will likely continue to be the most rapidly expanding sector of the worldwide economy (Bureau of Labor Statistics, 2010). Although the vast majority of these jobs require some kind of formal post-secondary schooling or training, virtually all also involve considerable job-specific training that is mostly provided by employers (Bayer, 2012; O'Leonard, 2009). Expenditures by the business community and military on work related training currently exceed all public expenditures on formal education (O'Leonard, 2009). Although these training activities are typically quite focused, it seems reasonable to assume that individuals in these jobs come away with not just specific knowledge and skills, but potentially also an enhanced understanding and interest in science and technology in general. If workplace experiences related to science and technology strongly contribute to public understanding and knowledge, then independent of the nature or quality of those experiences there should be a relationship between whether or not an individual is employed in a science and technology related occupation and the extent of his or her science and technology knowledge.

The Case for Privilege

There is an alternative possibility for explaining adult learning and knowledge of science and technology that is not directly attributable to many of these other sources. More important for explaining adult knowledge of science and technology may be socioeconomic or demographic factors such as an individual's income, race, ethnicity, and gender (e.g., Demie et al., 2002; Haycock, 2001; Howard, 2002; Pellino, 2001; Sacker et al., 2002). Individuals with privilege and opportunity such as those from the majority population (e.g., in the U.S., being white), males, and those with higher income or social status may have the most knowledge of science and technology regardless of sources of this knowledge. For example, privilege and particularly how this affects learning during summer vacations has been shown to explain a disproportionately high percentage of the variance in school performance between low and high income children (Alexander, Entwisle, & Olson, 2007; Downey, Von Hipple, & Broh, 2004). If this is true, it would be expected that these types of demographic characteristics will be related to knowledge of science and technology, and these relationships will be present independent of years of schooling, amount of participation in informal or free-choice education experiences, and experiences derived from the workplace.

This article, therefore, examines contributions that formal schooling, informal/free-choice education experiences, workplace experiences, and socioeconomic privilege make to adult self-reported knowledge of science and technology. By necessity, this article should be viewed as a preliminary, coarse-grained effort to determine the relative contributions that each of these factors make to public science and technology understanding. Undoubtedly, reality is a highly complex mélange of multiple factors, but given that empirical evidence related to these types of fundamental contributions has been almost nonexistent (Miller, 2010), the scope of this article is limited purposefully to this relatively narrow goal.

Methods

Data Collection

To examine sources contributing to adult knowledge of science and technology, data for this article were obtained in 2009 from a telephone survey of Los Angeles (L.A.), California (U.S.) adult residents over the age of 18. The foundation for this survey was a series of qualitative and quantitative interviews conducted in the L.A. area over the previous decade (e.g., Falk & Amin, 1997; Falk, Brooks, & Amin, 2001; Falk & Needham, 2011). Participants were drawn from random samples of residents in five racially, ethnically, and socioeconomically different L.A. sub-communities: Canoga Park, El Monte, Santa Monica, Torrance, and South Central L.A. These communities were selected to be collectively representative of the diversity of greater L.A. residents. The telephone survey was pretested with a sample of 30 residents to check for question clarity and interviewer consistency. The survey took an average of 19 minutes to complete and was conducted in the late morning and early evening hours, usually between 10:30 a.m. and 9:30 p.m. (Pacific Time) 7 days a week over a 6 week period (January 28 to March 9, 2009).

The sample was selected using the two-stage method of random digit dialing to ensure that each resident had an equal chance of being selected to participate (Vaske, 2008; Waksberg, 1978). The first stage involved obtaining a list of all land and cellular telephone area codes and prefixes for these five communities. For each area code and prefix combination, all possible choices for the next two numbers were added to construct a list of all possible 8 digit numbers of the 10 digits in telephone numbers. These combinations of eight digits represent primary sampling units (PSU). Software was then used for randomly assigning two additional digits to randomly selected PSUs. After the number was dialed, the PSU was retained for more calls if it was a residential number. If the number was a business or not a working residential number, the PSU was eliminated from further sampling. In the second stage, additional last two digits were selected randomly within each valid PSU. Up to four attempts were made for each number to determine its viability and obtain a completed survey. This two-stage non-directory sampling design attempts to eliminate any potential bias or coverage error associated with selection directly from telephone directories (Dillman, 2000; Vaske, 2008; Waksberg, 1978).

There were 16 interviewers who conducted these telephone surveys and they were trained using lectures, role playing, project briefings, and video training according to techniques and standards established by the Council of American Survey Research Organizations (CASRO) and other guidelines (e.g., Dillman, 2000; Vaske, 2008). Instruction focused on survey goals and objectives, handling survey questions, interview length, termination points and qualifiers for participation, reading of the survey and interviewer instructions, reviewing any skip patterns, and any probing or clarifying techniques necessary for specific questions. All surveys and responses were randomly monitored using Computer Assisted Telephone Interviewing (CATI) software to ensure interviewer quality and consistency. This software allowed the researchers to listen in on a random sample of interviews without interviewer knowledge with the goal of maintaining quality control over greetings, neutrality, ability of following survey scripts, prompting techniques, and professionalism. Any quality control issues were addressed with supplemental training for improvement, warnings, additional monitoring, or termination of interviewers.

In total, 1,018 adult residents completed the telephone survey (response rate = 24.8%) with 8% completing it in Spanish and 92% in English. This response rate is consistent with most telephone surveys conducted recently in the U.S. (see Connelly, Brown, & Decker, 2003; Dillman, 2000; Vaske, 2008 for reviews). Results are reported at the 95% confidence level and the sampling error is $\pm$3.1% for the entire sample. This means that if the survey was conducted 100 times on different samples from this population selected in the same way, the findings would be within $\pm$3.1% of each other 95 out of the 100 surveys (Dillman, 2000; Vaske, 2008).

A nonresponse bias check was conducted with a random sample of individuals who denied responding to this initial telephone survey. This nonresponse check was conducted to examine any potential differences between respondents and nonrespondents of the initial telephone survey, the extent that the sample was representative (i.e., selectivity of sample), and whether data needed to be weighted to ensure that the sample was representative of and generalizable to the larger target population of the study area. A sample of 75 individuals who denied participation in the initial telephone survey was telephoned a second time and asked a smaller subset of survey questions. No statistical evidence ($p > 0.05$) of differences between respondents to the initial telephone survey and this nonresponse bias check was found. An effort was made to include cellular telephones in the sample, but they still represented less than 10% of the sample. To minimize any potential bias, therefore, the data were weighted by U.S. Census data to be comparable to current data from the greater L.A. area.

Analysis Variables

Dependent Variable. Respondent *self-reported knowledge of science and technology* was measured by asking ''how much would you say that you know about science and technology.'' Answers were close-ended and contained four response options: ''nothing at all,'' ''a little,'' ''a moderate amount,'' and ''a great deal.'' This question was asked early in the survey before asking any of the other questions used in this article to avoid potential order effects or starting point bias. For analysis purposes, responses were collapsed into a dichotomous variable where both ''nothing at all'' and ''a little'' were coded as 0 = ''know little or nothing,'' and both ''a moderate amount'' and ''a great deal'' were coded as 1 = ''know a moderate amount or great deal.''

Independent Variables. This survey instrument was designed to support more than one research question. As described in Falk and Needham (2011), for example, one purpose of the survey was to measure changes in public knowledge relative to two indicator concepts associated with experiences at a particular science center. Individuals were asked to answer two open-ended science knowledge questions by defining the terms ''homeostasis'' and ''giant kelp.'' Both of these concepts represent relatively specialized areas of knowledge and neither would have likely been chosen in and of themselves as singular indicators of public understanding of science, but given that the results were available from these two conceptual knowledge questions, they were opportunistically utilized as one way for objectively assessing validity of the single dependent measure of self-reported knowledge.[1] These questions were asked toward the end of the survey because it was possible that they could have influenced responses to other questions in the instrument. Respondents did not receive any feedback from telephone interviewers regarding the correctness of their definitions, although they were asked how confident they were in their responses. Open-ended responses to these questions were recorded verbatim in lists, phrases, and short sentences. Ten human physiology and biology professionals, five for each question, were queried separately and asked to provide a range of acceptable definitions for these two concepts and to identify any specific terms or attributes related to each concept that would need to be present in a definition for it to be deemed acceptable. Results were compiled into a final scoring rubric and given that no significant discrepancies among experts arose, it obviated the need for a second round of validation. All respondent definitions were then compared against this rubric and categorized as either incorrect (coded as 0) or correct (coded as 1).

In addition, *formal education* was measured by asking respondents ''what is the highest grade of school that you have completed'' and responses were recorded on a close-ended 10-point scale from ''no schooling completed'' to ''doctoral degree.'' *Childhood free-choice learning experiences* were measured by asking how often respondents participated in nine different activities when they were a child. These activities are listed in Table 3 and were measured on close-ended four-point scales from ''not at all'' to ''a lot.'' *Adult free-choice learning experiences* were measured by asking how often respondents currently participated in 10 different activities during their free time. These activities are also listed in Table 3 and were measured on close-ended six-point scales from ''never'' to ''daily.'' Order of these activities for both childhood and adult free-choice learning was randomly rotated in the survey to avoid potential order effects and patterns in responses. These variables measuring both childhood and adult free-choice learning experiences were selected based on existing literature on educational leisure activities (e.g., Falk et al., 2008; U.S. Census Bureau, 2007) and an analysis of the range of out-of-school science experiences funded by the U.S. National Science Foundation's Informal Science Education portfolio (Sladek, 1998). *Workplace experiences* associated with science and technology were measured with three close-ended questions drawn from existing government surveys (U.S. Census Bureau, 2007): (a) "not including computer equipment, do you use science or technology on a regular basis in your work or for your current occupation" (0 "no," 1 "yes"), (b) "how much did work or on-the-job training help you become informed or knowledgeable about science or technology" (four-point scale from "not at all" to "a lot"), and (c) "would you describe your current work or occupation as science or technology related" (0 "no," 1 "yes"). *Privilege* variables included age (open-ended, in years), gender (0 "female," 1 "male"), three dummy variables associated with race (Hispanic, Black, Asian), and income ("was your household's total annual income in 2008, before taxes, below or above US $50,000 [U.S. median income at the time of this survey]; coded 0 "below," 1 "above").

Results

Descriptive and Bivariate Results

In total, 43% of respondents self-reported that they knew "little or nothing" about science and technology, whereas 57% felt that they knew "a moderate amount or great deal" about these fields. As an indicator of validity for this self-report dependent variable, respondents who provided a correct definition of the term "homeostasis" reported significantly higher knowledge of science and technology than those who did not define this term correctly, $\chi^2 = 66.62$, $p < 0.001$ (Table 1). In total, 83% of those who correctly defined this term considered themselves to know a moderate amount or great deal about science and technology, whereas only 51% of those who did not define this term correctly reported this moderate or high level of knowledge about these fields. The phi (ϕ) effect size was 0.25 and using guidelines from Cohen (1988) and Vaske (2008) for interpreting these types of effect sizes, this result suggests that the magnitude of this statistical difference was "medium" or "typical," respectively.

Similarly, those who correctly defined "giant kelp" also reported significantly higher knowledge of science and technology than those who did not define this term correctly, $\chi^2 = 9.01$, $p = 0.003$, $\phi = 0.09$ (Table 2). In total, 77% of respondents who correctly defined "giant kelp" felt that they knew a moderate amount or great deal about science and technology, whereas only 56% of those who did not define this term correctly reported moderate or high knowledge about these fields. Taken together, these results show that respondents who

Table 1
Differences in respondent self-reported knowledge of science and technology by whether they could correctly define "homeostasis"

	Definition of "Homeostasis"[a]	
Knowledge of Science and Technology	Not Correct (%)	Correct (%)
Know little or nothing	49	17
Know a moderate amount or great deal	51	83

[a] $\chi^2 = 66.62$, $p < 0.001$, $\phi = 0.25$.

Table 2
Differences in respondent self-reported knowledge of science and technology by whether they could correctly define "giant kelp"

	Definition of "Giant Kelp"[a]	
Knowledge of Science and Technology	Not Correct (%)	Correct (%)
Know little or nothing	44	23
Know a moderate amount or great deal	56	77

[a]$\chi^2 = 9.01$, $p = 0.003$, $\phi = 0.09$.

perceived themselves as having higher knowledge of science and technology were, as would be expected, more likely to correctly define these two somewhat random science concepts.

In total, 47% of respondents had a college (e.g., bachelors, masters, doctorate) or professional degree (e.g., law, medical, veterinary; Table 3). The bivariate comparison between this formal schooling and self-reported knowledge of science and technology showed that those with a higher level of education felt that they were significantly more knowledgeable about these fields, $\chi^2 = 91.05$, $p < 0.001$, $\phi = 0.31$. In total, 73% of those with a degree perceived themselves as knowing a moderate amount or great deal about science and technology, whereas only 27% of those with a degree felt that they knew little or nothing about these fields.

Bivariate comparisons between self-reported knowledge of science and technology, and all nine variables measuring childhood free-choice learning experiences showed that respondents who participated in these activities "some" or "a lot" of the time when they were children were more likely to feel that they knew a moderate amount or great deal about science and technology than little or nothing about these fields (Table 3). For example, 74% of respondents visited libraries when they were children and were significantly more likely to feel that they knew a moderate amount or great deal about science and technology (63%) than felt they knew little or nothing about these fields (37%). This pattern was consistent across all nine childhood free-choice learning experiences and was statistically significant for eight of these items, $\chi^2 = 12.42$–55.30, $p < 0.001$, $\phi = 0.11$–0.24.

A similar pattern was also evident for relationships between self-reported knowledge of science and technology, and the variables measuring adult free-choice learning experiences (Table 3). Respondents who participate in these activities "weekly" or "daily" as adults were more likely to feel that they knew a moderate amount or great deal about science and technology than little or nothing about these fields. For example, 61% of respondents read books, magazines, and/or newspapers not for school on a weekly or daily basis, and these individuals were significantly more likely to feel that they knew a moderate amount or great deal about science and technology (73%) than little or nothing about these fields (27%). This pattern was consistent across all 10 items measuring adult free-choice learning experiences and was statistically significant for eight of these items, $\chi^2 = 11.02$–159.51, $p = 0.026$ to <0.001, $\phi = 0.07$–0.40.

Bivariate comparisons between respondent self-reported knowledge of science and technology, and their workplace experiences showed that those who often used science and technology for work, received "some" or "a lot" of work or on-the-job training in these fields, and/or were employed in a related field were more likely to feel that they knew a moderate amount or great deal about science and technology than little or nothing about these fields (Table 3). Among the 46% of respondents who often used science or technology for work, for

Table 3
Bivariate relationships of variables influencing self-reported knowledge of science and technology

	Knowledge of Science and Technology					
	Know Little or Nothing	Know a Moderate Amount or Great Deal	Total[a]	χ^2 Value	p-Value	Effect Size (ϕ)
Formal education model[b]						
Education	27	73	47	91.05	<0.001	0.31
Childhood free-choice learning experiences model[c]						
Go to libraries	37	63	74	40.60	<0.001	0.21
Visited museums, science centers, aquariums, zoos	34	66	58	42.28	<0.001	0.21
Read books, magazines, or newspapers	32	68	53	55.30	<0.001	0.24
Family trips/outings to parks or other learning sites	32	68	47	38.43	<0.001	0.20
Participated in scouts, clubs, or other groups	31	69	47	55.04	<0.001	0.24
Watched educational programs on television/video	36	64	42	12.42	<0.001	0.11
Do hobbies or participate in a hobby club or group	27	73	27	38.42	<0.001	0.20
Listen to educational radio programs, tapes, CDs	41	59	16	1.19	0.661	0.01
Take classes outside of formal school	29	71	13	13.25	<0.001	0.12
Adult free-choice learning experiences model[d]						
Programs on television/video about science/technology	34	66	67	69.52	<0.001	0.27
Books, magazines, newspapers not used for school	27	73	61	159.51	<0.001	0.40
Friends or family	33	67	45	29.43	<0.001	0.17
Museums, zoos, aquariums, science centers	33	67	41	30.36	<0.001	0.18
Use the internet to learn about science/technology	22	78	40	128.21	<0.001	0.36
Radio programs, tapes, CDs about science/technology	38	62	33	14.96	0.026	0.07
Activities with organized club, church, religious group	42	58	31	0.34	0.563	0.02
Go to libraries	49	51	21	4.97	0.260	0.04
Go on family trips or outings	39	61	16	11.02	0.013	0.07
Participate in a science/technology related club	21	79	13	32.08	<0.001	0.18
Work place experience model						
Use science/technology often for work (excludes computers)[e]	29	71	46	74.46	<0.001	0.28
Work or on-the-job training[c]	22	78	37	106.85	<0.001	0.32
Current occupation science/technology related[e]	22	78	33	91.33	<0.001	0.30
Privilege model						
Income[f]	28	72	62	93.33	<0.001	0.33
Age[g]	41	59	49	1.45	0.228	0.04

(*Continued*)

Table 3
(*Continued*)

	Knowledge of Science and Technology: Know Little or Nothing	Know a Moderate Amount or Great Deal	Total[a]	χ^2 Value	p-Value	Effect Size (ϕ)
Male	30	70	44	50.70	<0.001	0.23
Hispanic	57	43	25	23.57	<0.001	0.16
Black	62	38	16	27.14	<0.001	0.17
Asian	37	63	10	1.51	0.219	0.04

[a]Totals refer to the proportion of the sample who had at least a college degree, said ‘‘some’’ or ‘‘a lot’’ for each of the childhood free-choice learning activities, said ‘‘weekly’’ or ‘‘daily’’ for each of the adult free-choice learning activities, said ‘‘yes’’ that they use science/technology often for work and their occupation is science/technology related, had an annual household income over US $50,000, were over 40 years of age, were male, were Hispanic, were Black, or were Asian.
[b]Cell entries are percent (%) for those with at least a college degree (e.g., bachelors, masters, doctorate) or professional degree (e.g., law, medical, veterinary).
[c]Cell entries are percent (%) for those reporting ‘‘some’’ or ‘‘a lot.’’
[d]Cell entries are percent (%) for those reporting ‘‘weekly’’ or ‘‘daily.’’
[e]Cell entries are percent (%) for those reporting ‘‘yes.’’
[f]Cell entries are percent (%) for those earning over US $50,000/year (median).
[g]Cell entries are percent (%) for those over 40 years of age (median split).

example, 71% reported that they knew a moderate amount or great deal about science and technology, whereas only 29% felt that they knew little or nothing about these fields. These relationships among workplace experiences and knowledge of science and technology were statistically significant for all three of these items, $\chi^2 = 74.46$–106.85, $p < 0.001$, $\phi = 0.28$–0.32.

There were also relationships between privilege related variables and self-reported knowledge of science and technology. Respondents who were male and/or had an annual income over US $50,000 were more likely to consider themselves as knowing a moderate amount or great deal about science and technology rather than little or nothing about these fields (Table 3). Among male respondents (44%), for example, 70% reported that they knew a moderate amount or great deal about science or technology, whereas only 30% felt that they knew little or nothing about these fields. Likewise, among respondents who earned over US $50,000 a year, 72% reported that they knew a moderate amount or great deal about science and technology, whereas only 28% felt that they knew little or nothing about these fields. Conversely, the majority of Hispanic (57%) and Black (62%) respondents were likely to consider themselves as knowing only a little or nothing about science and technology. These relationships among the six variables measuring privilege and knowledge of science and technology were statistically significant for four items, $\chi^2 = 23.57$–93.33, $p < 0.001$, $\phi = 0.16$–0.33.

Multivariate Results

A series of five separate partial logistic regression models were used for determining the contributions of formal schooling, adult and childhood free-choice education experiences, workplace experiences, and socioeconomic privilege on respondent knowledge of science and technology (Table 4).[2] The first logistic regression model examined the influence of formal education and showed that it had a statistically significant influence on higher self-reported knowledge of science and technology, β (unstandardized) $= 0.46$, Wald $\chi^2 = 116.93$, $p < 0.001$.

Self-reported knowledge of science and technology as a function of childhood free-choice learning experiences was the second logistic regression model (Table 4). Three of the nine variables were statistically significant predictors after controlling for all other variables in the model. Reading books, magazines, or newspapers as a child, as well as participating in scouts, clubs, or other groups as a child were positively associated with higher self-reported knowledge of science and technology, $\beta = 0.25$ to 0.35, Wald $\chi^2 = 14.29$–21.38, $p < 0.001$. Conversely, listening to educational radio programs, tapes, and discs as a child was negatively associated with higher knowledge of these fields, $\beta = -0.18$, Wald $\chi^2 = 4.13$, $p = 0.042$.

The third logistic regression model examined the influence of adult free-choice learning experiences on knowledge of science and technology (Table 4). Five of the 10 variables were significant positive predictors of higher knowledge after controlling for all other variables in the model, $\beta = 0.13$–0.63, Wald $\chi^2 = 4.86$–65.92, $p = 0.027$ to <0.001. These five variables were: using the internet to learn about science and technology, watching television programs or videos about science and technology, going to libraries, participating in a science or technology related club, and reading books, magazines, and newspapers not used for formal schooling.

The three variables measuring workplace experiences were used as independent variables in the fourth logistic regression model, and all of these variables were significant positive predictors of higher self-reported knowledge of science and technology, $\beta = 0.46$–0.59, Wald $\chi^2 = 7.29$–46.63, $p = 0.003$ to <0.001 (Table 4).

Table 4
*Logistic regression models predicting respondent self-reported knowledge of science and technology**

	Partial Models				Full Model[a]			
	β	Wald χ^2	Odds Ratio	p-Value	β	Wald χ^2	Odds Ratio	p-Value
Formal education model								
Education (highest level completed)	0.46	116.93	1.58	<0.001	0.19	2.63	1.19	0.020
Childhood free-choice learning experiences model								
Go to libraries	0.14	3.04	1.15	0.081				
Visited museums, science centers, aquariums, zoos	0.12	2.02	1.13	0.156				
Read books, magazines, or newspapers	0.35	21.38	1.42	<0.001	0.18	3.23	1.21	0.042
Family trips/outings to parks or other learning sites	0.11	2.11	1.12	0.146				
Participated in scouts, clubs, or other groups	0.25	14.29	1.28	<0.001	0.18	4.29	1.20	0.038
Watched educational programs on television/video	0.07	1.08	1.07	0.298				
Do hobbies or participate in a hobby club or group	0.06	0.56	1.07	0.453				
Listen to educational radio programs, tapes, CDs	−0.18	4.13	0.83	0.042				
Take classes outside of formal school	0.04	0.18	1.04	0.674				
Adult free-choice learning experiences model								
Programs on television/video about science/technology	0.28	10.26	1.32	<0.001	0.38	12.30	1.46	<0.001
Books, magazines, newspapers not used for school	0.63	47.16	1.88	<0.001	0.46	17.20	1.58	<0.001
Friends or family	0.04	0.18	1.04	0.673				
Museums, zoos, aquariums, science centers	0.02	0.03	1.02	0.861				
Use the internet to learn about science/technology	0.39	65.92	1.47	<0.001	0.22	10.64	1.24	<0.001
Radio programs, tapes, CDs about science/technology	0.01	0.05	1.01	0.822				
Activities with organized club, church, religious group	0.02	0.19	1.02	0.664				
Go to libraries	−0.19	12.79	0.83	<0.001				
Go on family trips or outings	0.07	1.02	1.07	0.312				
Participate in a science/technology related club	0.13	4.86	1.13	0.027				
Work place experience model								
Use science/technology often for work (excludes computers)	0.46	7.29	1.58	0.007				
Work or on-the-job training	0.47	46.63	1.61	<0.001	0.35	13.05	1.42	<0.001
Current occupation science/technology related	0.59	8.80	1.80	0.003	0.94	11.56	2.56	<0.001
Privilege model								
Income (over $50,000/year median)	1.14	45.83	3.14	<0.001	0.54	5.67	1.72	0.017
Age (years)	−0.02	8.89	0.98	0.003				
Male	0.93	33.83	2.54	<0.001	1.08	27.62	2.95	<0.001

(*Continued*)

Table 4
(*Continued*)

	Partial Models				Full Model[a]			
	β	Wald χ^2	Odds Ratio	p-Value	β	Wald χ^2	Odds Ratio	p-Value
Hispanic	−1.01	21.09	0.37	<0.001	−0.73	7.75	0.48	0.005
Black	−0.88	13.09	0.41	<0.001				
Asian	−0.46	2.76	0.63	0.097				

*Dependent variable is dichotomous (“know little or nothing,” “know a moderate amount or great deal”). β = unstandardized beta.

[a]Only the statistically significant ($p < 0.05$) variables are shown for the full model. All bivariate interactions among these variables were also examined and only four significantly influenced the dependent variable: (a) income * programs on television/video about science/technology ($\beta = -0.19$, Wald $\chi^2 = 4.46$, odds = 0.56, $p = 0.035$); (b) current occupation science/technology related * use the internet to learn about science/technology ($\beta = 0.47$, Wald $\chi^2 = 5.48$, odds = 1.59, $p = 0.019$); (c) current occupation science/technology related * Hispanic ($\beta = 1.64$, Wald $\chi^2 = 5.91$, odds = 5.14, $p = 0.015$); and (d) work or on-the-job training * Hispanic ($\beta = -0.65$, Wald $\chi^2 = 5.69$, odds = 0.52, $p = 0.017$). No other interactions among the independent variables in the full model significantly influenced the dependent variable.

The fifth logistic regression model examined the influence of items related to privilege on self-reported knowledge of science and technology (Table 4). Five of the six variables were statistically significant predictors of this knowledge after controlling for all other variables in the model. Being male and having an annual income over US $50,000 were positively associated with higher self-reported knowledge of science and technology, $\beta = 0.93$ to 1.14, Wald $\chi^2 = 33.83$ to 45.83, $p < 0.001$. Age, being Hispanic, and being Black were negatively associated with higher knowledge of these fields, $\beta = -0.02$ to -1.01, Wald $\chi^2 = 8.89$–33.83, $p = 0.003$ to <0.001.

The final logistic regression model examined the combined influence of all of these statistically significant variables measuring formal education, childhood and adult free-choice learning, workplace experiences, and socioeconomic privilege on self-reported knowledge of science and technology (Table 4). Eleven variables across all five of these factors significantly influenced knowledge of science and technology after controlling for all other variables in the model; one item measuring formal schooling, two variables measuring childhood free-choice learning experiences, three items measuring adult free-choice learning, two variables related to workplace experiences, and three items associated with socioeconomic privilege, $\beta = -0.73$–1.08, Wald $\chi^2 = 3.23$–27.62, $p = 0.042$ to <0.001. Of these 11 variables, the odds ratios indicated that being male, currently working in a science or technology related job, and having a high income had the largest effects on self-reported knowledge of science and technology. Male respondents were almost three (2.95) times more likely than females to feel that they knew a moderate or great deal about science and technology. Respondents currently working in a science or technology related job were 2.56 times more likely than those not working in these fields to report a high degree of knowledge, and individuals earning over US $50,000 per year were 1.72 times more likely than those earning less than this amount to feel that they knew a moderate or great deal about science and technology. The weakest significant predictors of this knowledge were formal schooling (odds ratio = 1.19), childhood participation in scouts or other groups (odds ratio = 1.20), and reading books, magazines, or newspapers as a child (odds ratio = 1.21).

All possible bivariate interactions among these significant independent variables in this full model were also examined and only four of these interaction effects significantly influenced self-reported knowledge of science and technology: (a) income * programs on television or video about science and technology ($\beta = -0.19$, Wald $\chi^2 = 4.46$, odds ratio = 0.56, $p = 0.035$); (b) current occupation is science or technology related * use the internet for learning about science and technology ($\beta = 0.47$, Wald $\chi^2 = 5.48$, odds = 1.59, $p = 0.019$); (c) current occupation is science or technology related * Hispanic ($\beta = 1.64$, Wald $\chi^2 = 5.91$, odds = 5.14, $p = 0.015$); and (d) work or on-the-job training * Hispanic ($\beta = -0.65$, Wald $\chi^2 = 5.69$, odds = 0.52, $p = 0.017$). These interactions mean that the effect of one variable on self-reported knowledge of science and technology changes slightly depending on the level of the other variable. No other bivariate interactions among independent variables in the full model influenced self-reported knowledge.

Of the five initial partial logistic regression models, the adult free-choice learning experiences model explained the most variance in self-reported knowledge of science and technology (Nagelkerke $R^2 = 39\%$) and correctly classified 75% of respondents in terms of their level of this knowledge (Table 5). The privilege model accounted for 23% of the variance and correctly classified 69% of respondents, followed by the workplace experiences model that explained 20% of the variance and correctly classified 67% of respondents. The formal education and childhood free-choice learning experiences models each explained the least amount of variance in self-reported knowledge of science and technology (both 17%) and each

Table 5
Comparison of partial and full logistic regression models

					Self-Reported Knowledge of Science and Technology Percent Correctly Classified (%)		
Models	χ^2	df	*p*-Value	Nagelkerke R^2	Know Little or Nothing	Know Moderate Amount or Great Deal	Overall
Formal education	133.08	1	<0.001	0.17	63	69	66
Childhood free-choice learning experiences	126.61	9	<0.001	0.17	54	76	66
Adult free-choice learning experiences	323.95	10	<0.001	0.39	66	83	75
Work place experience	152.61	3	<0.001	0.20	67	66	66
Privilege	152.95	6	<0.001	0.23	56	80	69
Full model[a]	369.43	17	<0.001	0.51	72	84	79

[a]All bivariate interactions among significant variables in the full model were also examined and only four significantly influenced the dependent variable of self-reported knowledge of science and technology (see Table 4). With these interactions included in the full model, the percent correctly classified increased only slightly (Nagelkerke $R^2 = 0.57$, "know little or nothing" = 77%, "know moderate amount or great deal" = 86%, "total" = 82%).

correctly classified the fewest respondents (both 66%). The final combined model that included 11 variables across all five factors (i.e., formal education, childhood and adult free-choice learning, workplace experiences, socioeconomic privilege) explained 51% of the variance in self-reported knowledge of science and technology, and correctly classified 79% of respondents (72% in the "know little or nothing" group, 84% in the "know a moderate or great deal" group). By including the four significant bivariate interactions in this full model, the variance explained and percent correctly classified increased only slightly (Nagelkerke $R^2 = 57\%$, 77% in the "know little or nothing" group, 86% in the "know moderate amount or great deal" group, 82% in total).

Discussion

These results suggest that multiple sources significantly contribute to adult self-reported knowledge of science and technology. Adult free-choice learning experiences such as reading books and magazines about science and technology, using the internet, and watching science related documentaries and videos were collectively the strongest predictors of self-reported knowledge of science and technology. Privilege, especially higher income and being male, was the second most important factor. Workplace experiences related to science and technology were also a major contributor to adult knowledge of science and technology. Although years of formal schooling and participation in childhood free-choice learning experiences also emerged as significant predictors of adult science and technology knowledge, each explained considerably less of the variance than other factors, in particular participation in adult informal/free-choice learning experiences.

Even though these are preliminary and course-grained findings, they raise important questions about the prevailing assumptions held by most science and technology professionals, educators, and policy makers about the relative importance of formal education/schooling. It is important to state though that contrary to what some might immediately assume, these results did not indicate that formal schooling is unimportant; total years of schooling significantly impacted adult self-reported knowledge of science and technology, as would be predicted. These results, however, clearly showed the importance of other life experiences on adult science and technology knowledge, in particular free-choice experiences both in childhood and adulthood, as well as science-related employment.

These findings do not allow direct inferences about exactly how these various experiences influence or interact with adult science and technology knowledge, and it cannot be determined what the directionality or relationship is among these various factors. For example, do individuals who engage with free-choice experiences during childhood self-select to work in science-related fields? Does knowledge of science and technology predict engagement with free-choice science and technology experiences, or is the reverse true? Does success in school pre-dispose individuals to participate in childhood and then adult free-choice learning experiences, or does interest developed outside of school pre-dispose individuals to become more engaged in school? Although there were several direct effects and only a few interactions among various factors and variables in their influence on self-reported knowledge of science and technology, these questions still remain because of the inherent complexity of multiple factors that influence human learning. Interactions among these factors were evident in this study, but were not as strong and in many cases statistically insignificant in comparison to the direct effects. Still, it seems reasonable given what is known about the complex and iterative nature of learning (e.g., Falk & Needham, 2011; OECD, 2012), that many of these factors are associated in important and mutually reinforcing ways. Even assuming that reality is almost certainly more complex than these findings suggest, there is no escaping the fact that adult free-choice experiences explained more than twice the variance of formal schooling. These findings do not conclusively prove that out-of-school free-choice experiences contribute more to long-term public understanding of science and technology than do more formal in-school experiences. By the same token, however, insufficient data exist to refute this claim. Either way, these findings provide support for those who argue that informal/free-choice science learning experiences, for both children and adults, warrant increased attention and potentially greater support.

The findings also appear to support the contention that social inequalities in public understanding of science and technology exist in the U.S. Given that males and those with higher incomes were more likely to report higher knowledge about science and technology, and Hispanic and Black respondents felt that they had less knowledge about these fields, particular attention and concerted effort are needed to ensure that future formal and informal science and technology education efforts actively promote equity of opportunity for all individuals. Although there is evidence that males tend to provide higher self-reported knowledge than females (e.g., Lichtenstein & Fischoff, 1977; Many, Howard, Cardell, & Lewis, 2002) and this could reduce the importance of this particular result, other studies have found that these self-report biases among males are actually overstated and not dependably in one direction (e.g., Baer, Rinaldo, & Berry, 2003; Paulhus, Harms, Bruce, & Lysy, 2003). Therefore, caution is advised when interpreting this result. This study also highlights the synergistic nature of learning in science and technology where learners function within a complex system of human and material resources. This is a system, however, that we only somewhat understand. More research is needed on the cumulative and complementary influences of all sources of learning across an individual's lifetime and real progress in public education will require such an approach.

Clearly and as stated above, these results cannot be taken as the definitive case for what factors contribute to adult knowledge of science and technology because this study, like all studies, possesses limitations. One limitation would be the validity of using self-reported knowledge as the primary dependent measure, but two lines of evidence suggest that this measure, although not perfect, may actually be a reasonably valid proxy for public understanding of science and technology. First, the significant correlations between self-reported knowledge of science and technology and the ability of respondents to accurately define science-related terms (i.e., giant kelp, homeostasis) implies some degree of construct or internal validity. More importantly, a number of studies from various disciplines have established that self-report data are not perfect, but are actually reasonable surrogates for more direct measures, especially when using survey data (Chan, 2009; Gonyea, 2005; Vaske, 2008).

The comparatively weaker performance of formal schooling as a predictor of adult science and technology knowledge could cause some to question the validity of the formal education measure in this study, especially utilizing total years of schooling rather than years of school-based instruction specifically in science and technology or some measure of the quality of science and technology instruction (e.g., Miller, 2010). This issue could be countered, however, by pointing out that the formal education measure in this study was exactly comparable to all of the other measures, as all variables were course grained indicators of quantity rather than fine grained measures of quality. Undoubtedly, quality does matter, but it remains a question for future research to determine the extent that including quality measures in this type of analysis (whether measures of formal, free-choice, or workplace experiences), would dramatically influence the basic patterns observed.

It is also important to clarify the informal/free-choice learning constructs used in this study. For some in the science education community, it is a common perception that informal education experiences primarily build shallow and ephemeral encounters with science, stimulating interest and potentially motivating individuals to pursue further engagement with science, but rarely directly building knowledge. Arguably, this perception was partially reinforced by a recent National Research Council study (Bell et al., 2009) and is primarily a consequence of the organizational and financial dominance, particularly in the U.S., of a small part of the vast informal infrastructure, which is the science center community in particular, but also broadcast media. These two communities have historically garnered the lion's share of public and private "informal" funding and the majority of public recognition as informal education providers. They have also been the site of a disproportionate share of the informal learning research. There is growing evidence, however, that these informal settings are clearly important, but represent just the proverbial tip of the free-choice learning iceberg. As the data from this study reinforce, a large amount of out-of-school science learning occurs through on-line resources, reading books and magazines, and through interpersonal relationships among friends, family, clubs, and other groups. Similar findings have been reported by others (e.g., Azevedo, 2011; Miller, 2010).

Taking a more asset-based approach to public understanding of science (e.g., Brown et al., 2005; Falk & Dierking, 2010; Falk et al., 2007; Roth & Lee, 2002; Roth & Van Eijck, 2010) suggests that a large majority of Americans engage in some kind of in-depth science-related experience throughout their lives with most beginning during adolescence (e.g., Azevedo, 2011). The trajectory of this science learning might initially involve broadcast media such as many of the science-related programs developed over the past two decades, visits to science centers or similar institutions, or perhaps a particularly inspiring school teacher. Ultimately, as an individual's own expertise develops, these resources are increasingly replaced by a vast array of other educational tools including books and magazines, the internet, individuals with expertise, and other media and resources. Science centers, museums, media, and the kinds of experiences that these settings engender are critical constituents of the informal science education sector, but it should not be assumed that they fully embody this vast and complex sector.

There is an issue regarding generalizability of these findings. Although there is no obvious reason to believe that residents of the greater L.A. area are significantly different relative to their learning behaviors and knowledge associated with science and technology than residents of many other communities, the data clearly only represent this one locality. Given the pioneering nature of this study, however, these findings provide a useful initial baseline for understanding the relative contributions that various educational sources make to adult knowledge of science and technology. There is no doubt that future efforts, particularly longitudinal or panel studies designed to assess the influence of both quantity and quality of learning experiences across an individual lifetime, will reveal a more complete and complex picture of how and why the public learns science, and how this influences knowledge. The relative contributory patterns suggested by this research, however, provide a useful framework for understanding the lifetime science learning journey. In addition to providing a foundation for further research, these data can also provide a departure point for science education discussions related to resource distribution, equity, and national policy. Although findings from this or any study are certainly not a sufficient basis for changing policy, it is hoped that these results coupled with findings from a growing body of other research might be sufficient impetus to justify serious debate about the wisdom of current policies that view formal schooling as the single most effective strategy for advancing public knowledge and interest in science and technology.

In fact, the primary take home message of this article is that the data broadly support the contention made in the introduction that public science education is supported not by a single major resource (e.g., formal schooling), but rather by a vast array of resources that includes schools, free-choice learning experiences, and the workplace. Data presented here suggest that all of these sources contribute significantly to knowledge of science and technology, and these sources along with indicators of privilege reinforce each other. To create a citizenry who are more knowledgeable and interested in science and technology requires building all parts of the infrastructure and focusing on all citizens, not just a few parts and some individuals. There has been increasing rhetorical acknowledgement about the importance of this kind of broad, multi-sector strategy (e.g., Bell et al., 2009; Falk & Dierking, 2010; Obama, 2009), but there has been relatively little real substantive movement in this direction. Formal schooling continues to be the instrument of choice for virtually all local, state, and national efforts for enhancing public interest and understanding of science, and there appear to be no significant proposals to distribute more equitably any resources related to support of science and technology education beyond schools. It is hoped that this study might provide some impetus for changing the nature of the debate on these issues. Although strategies for addressing the need for supporting improved public understanding of science and technology appear mired in the past, the need for a scientifically literate society continues to grow.

Notes

[1]Although these two questions were clearly random, a case could be made that these concepts are no worse than other seemingly random questions that the public is consistently asked in current public understanding of science instruments.

[2]Logistic regression is considered by many to be the most popular approach for modeling single binary outcomes such as low and high self-reported knowledge of science and technology (see Agresti, 1996; Vaske, 2008 for reviews). In addition, testing saturated models of all possible direct effects and bivariate interactions (e.g., correlating errors of all variables) as was done in this article would likely lead to under-identified models with these data using other commonly used multivariate statistical approaches.

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