Age, Generation, Education and Change in the American Public Understanding of Science: 1979-2006

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Abstract

Most countries emphasize a comprehensive science education, partly because they anticipate it produces well-trained employees, and partly because science-literate citizens can understand and participate more fully in science-related policy. Moreover, such adults should better resist pseudoscience appeals. Yet many industrial and government leaders and educators complain that Americans' science knowledge is poor. My research tracks U.S. adult basic science literacy from 1979 to 2006 using the National Science Foundation Surveys of Public Understanding of Science and Technology (total *n* ~24,000). Because many factors vary simultaneously over time, simple conclusions about change, and how education affects science literacy, are ambiguous. For example, recent generations are better educated and have had more science exposure. Although period, cohort and age effects are confounded in "one-shot" cross-sectional surveys, they can be at least partly disentangled in repeated cross-sectional data.

I study how age, generation, gender, and educational variables affected several dimensions of adult understanding of science. Over and above formal educational achievements, public understanding of science rose over time and by generation. Unfortunately more recent birth cohorts also appear more credulous about pseudoscience. Disaggregation by age and cohort produces different conclusions than simply considering change over time. Furthermore, cohort adjusted effects differ from those of generation alone. The findings identify gaps that formal education should address as well as processes that may occur over the life cycle. Possible explanations for generational change include more sophisticated methods of U.S. science education and increased availability and ease of accessing science and technology information.

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This research examines how generation and age, net of gender, high school science and math, and college science, affected American adult civic science literacy (CSL), using the National Science Foundation Surveys of Public Understanding of Science and Technology 1979 to 2006. In 2007 alone, U.S. science and technology research and development expenditures exceeded *350 billion dollar*s (U.S. Bureau of the Census: 2009, Table 769). Yet many industrial leaders, educators, scientists, and politicians believe our youth are unprepared for college, that a "brain drain" occurs from science to other educational areas, and that adults cannot discuss science at the level of a major newspaper (Burris, 2006; Gates 2005; Miller, 2000, Lemonick, *et al.,* 2006; Seymour, 2006). These criticisms ensue despite sizable changes in science education.

Although U.S. adults express considerable science interest, some issues, e.g., genetic engineering, require basic knowledge that many lack (Kumar & Chubin, 2000). Given investments in public discourse, education, and research and development, it is vital to understand continuities from formal education to adult CSL. Adults raise children, educate youth and formulate actions from school board decisions to international policy. Adult CSL can be critical for intelligent policy discussions and a supportive research climate (Allum, Sturgis, Tabourazi & Brunton-Smith, 2008).

A different challenge emanates from pseudoscience purveyors, e.g., psychics or "creationists," who vie for public legitimacy, political clout, and consumer dollars. It is often tacitly assumed that those lacking science literacy cannot distinguish "real" from ersatz science, thus risking exploitation from pseudoscience practitioners.

Issues in Science Knowledge and Pseudoscience Belief

In international science comparisons, American students appear mediocre (Schmidt, McKnight & Raizen, 1997, U.S. Department of Education, 2007). Yet Kadlec, Friedman & Ott

(2007) found that Midwest parents and secondary students were sanguine about science instruction and student preparation. Students depicted their science courses as dull and "largely irrelevant". Kadlec*, et al*. describe an "urgency gap" between "leaders" and "experts" versus parents and students about science education. Perhaps complacency occurs because students *do* elect more math and science than before (U.S. Department of Education, 2007). Simultaneously, recent generations are more technologically fluent (Losh, 2010; Pew Research Center, 2007).

Pseudoscience belief among Americans (*including* secondary school science teachers) also causes concern; its levels may be remaining stable or even increasing (Eve & Dunn, 1989; 1990; Goode, 2000; National Science Board, 2002). Pseudoscience beliefs are "cognitions about material phenomena that claim to be 'science,' yet use non-scientific evidentiary processes [e.g.,] authoritative assertion…anecdote… or unelaborated 'natural' causes" (Losh, Tavani, Njoroge, Wilke & McAuley, 2003). Many adults, sometimes majorities, believe that astrology is scientific, and "extraterrestrials" visit a "6000-year-old Earth" (Davis & Smith, 2009; Gallup News Service, 2001). Although reading a horoscope can be fun, pseudoscience is rife with untested "cures" or unsubstantiated reports of "flying saucers".

Although some scholars find that studying pseudoscience helps explore basic science literacy (Goode, 2000; 2002; Martin, 1994), educators generally avoid teaching it (Lilienfeld, Lohr, & Morier, 2001). Beliefs in *Biblical* creation or ghosts can provide a "back door" scaffold to understand layperson conceptualizations about science, by identifying evidence citizens find compelling and causal mechanisms they believe operate in the material world. Despite its popularity and costs, very little research assesses American adult pseudoscience support.

What's Happened with Science Education?

Science education, and ultimately science literacy, is assumed to stimulate pseudoscience rebuff. However, educational *level* inconsistently predicts these beliefs, depending on the domain addressed (Taylor, Eve, & Harrold, 1995). Furthermore, many influences on pseudoscience attributed to degree level instead result from other causes either correlated with educational achievement, or products of it (e.g., science factual knowledge, Losh, *et al*., 2003).

As noted earlier, modern Americans *are* better educated, and thus they have more formal science exposure (U.S. Department of Education, 2007). Only 25% of 1940 adults completed high school and 5% had at least a baccalaureate; by 2004, *85%* had graduated high school and 29% had a BA (National Center for Educational Statistics, 2004: Table 8; U.S Department of Education, 2007). However, since most Americans still do not graduate college, recent changes in elementary and secondary school science education remain important.

By the late 20th century, U.S. schools began de-emphasizing factual memorization, focusing more on science inquiry, hands-on experience, and the context of science and technology (AAAS, 1993; Gess-Newsome, 2002; Schiebiner, 1999; Sunal & Sunal, 2003). Although evidence is mixed that these approaches increase performance at different grade levels (Burkam, Lee & Smerdon., 1997; Gess-Newsome, 2002; Lee & Burkam, 1996; Lilienfeld, *et al.*, 2001; Moss, Abrams & Kull, 1998; Scanlon, 2000), at least some changes may "trickle through" to better science understanding among *more recent generations* of adults.

In this research, I track six generations over 11 to 28 year periods, disaggregating "generation" and age effects on adult science literacy dimensions, net of gender and educational variables. Although "chronological age" is often a predictor for CSL, it still receives cavalier treatment, typically as a vague background factor, but cohort remains mostly ignored. "Young adults" at almost any time consistently appear more interested or knowledgeable in science than older ones (National Science Board, 2008).

Findings here will show that the generational construct provides valuable information about CSL and that earlier research using only the variable "age" can mislead. Thus I juxtapose assumed but unexamined "adult development issues" (i.e., "age") versus cohort experiences. *S*imply studying CSL over time tells us our past, age effects in a single period photograph the present, but generation can inform us about future trends as recent cohorts age and replace earlier ones.

Issues of Age and Generation

My emphasis on generation is not just semantics. Social changes occur many ways; it is important to disentangle them. *Aging* can produce change: perhaps senior adults find it harder to assimilate science advances due to slower working memory, memory decay or even midlife presbyopia, which makes reading small print difficult (Boyd & Bee, 2009; Woolfolk, 2007). Thus, media accommodations for seniors could boost science literacy. Second, *cultural transformations* can occur. More positive fictitious treatments of scientists or wider dissemination of scientific discoveries could motivate an entire society, irrespective of age or generation, to become more knowledgeable.

In *cohort replacement on concomitant variables*, generations differ on specific attributes, which in turn directly predict CSL. For example, "Baby Boomers" are better educated than earlier generations and education raises adult CSL; as "Boomers" replace earlier cohorts, overall CSL should improve because of enhanced schooling among this large cohort. Here, cohort analysis directs our attention to educational rather than aging variables.

Finally in *direct cohort effects*, a specific generation experiences relatively unique events, predisposing its members to adopt particular behaviors or information. This study takes such an approach. For example, adults born before World War I experienced early electronic communication, early air travel and world wars; "Millennials" born in the 1980s matured using computers and the 'Web at school (U.S. Bureau of the Census, 2008: Table 253); thus ease of

Internet science information access could foster CSL among Millennial adults.

Generation can relate to *what kind* of science education a student received. Although changes in science education methods began roughly 30 years ago, the initial impact was largely limited to major research universities. Allowing at least 10 years for these perspectives to diffuse to other post-secondary institutions means that any cohort effects on CSL from these educational changes would begin with “Generation X” and be more pronounced among Millennials.

“One-shot” cross-sectional analyses of a general population survey inevitably confound age and cohort. Simultaneous estimates of age, cohort *and* period effects present logical and statistical problems because any of these three variables depends upon the other two. However, with several sequential studies, cohort and age effects can be partially disentangled. Although there are statistical attempts to handle multivariate estimation (e.g., Glenn, 2005; Mason, Winsborough, Mason & Poole 1973; Mason & Brown, 1975), in this study I build and track synthetic cohorts, contrasting generational with age effects, leaving period changes largely reflected in the joint age and cohort patterns.

If American science education innovations contribute to adult CSL, then not only should knowledge rise among more recent cohorts, *but cohort effects on understanding science inquiry should be particularly pronounced*. Similar effects may occur for how generation affects pseudoscience belief. Because cohort intertwines with educational factors (Carlson, 2008; more recent cohorts have more formal schooling, including greater science and math exposure), I control several educational variables;.

RESEARCH QUESTIONS:

How does generation, compared with age and net of gender and educational variables, affect understanding science inquiry and knowing basic science facts in American adults?

How does generation, compared with age and net of gender, educational and knowledge variables, affect pseudoscience support among American adults?

METHODS

The National Science Foundation Surveys

The most comprehensive set of U.S. adult "science literacy" surveys is the NSF Surveys of Public Understanding of Science and Technology 1979-2006 (directed by Jon Miller, 1979-1999; ORC-MACRO, 2001; and Davis & Smith, 2009). The *total archive*, monitoring several science literacy dimensions, comprises 23,906 unweighted (23,994 weighted) interviews in 12 probability samples (1979; 1981; 1983; 1985; 1988; 1990; 1992; 1995; 1997; 1999; 2001; 2006). The series also has considerable detail on adult educational achievements. Although the 1979 and 2006 surveys were conducted in person, those in between used Random Digit Dialing[1].

Measures: Basic Science Knowledge

I measured knowledge three ways. Cognitive processes underlying factual memorization differ from those for science inquiry. For example, facts can show memory decay, especially if they are mostly irrelevant to adult daily lives. However, inquiry processes apply to many science areas; thus understanding science processes should "age better" than factual memorabilia.

First I used an index comprising either eight (1988 and 1990) or nine closed format questions (1992-2006; see Table 1 for all questionnaire items) about basic science facts taught in elementary school and reviewed in middle school (Cain, 2002; Sunal & Sunal, 2003), e.g., a true-false item asks whether "antibiotics kill viruses and bacteria." Balanced response items ask whether the earth goes around the sun or vice versa. These have been called the "**Oxford items**" (Allum, *et al*., 2008). The index score is the percent correct out of the total. The remaining two measures speak more to science inquiry.

Table 1 about here

[1] Only 2006 respondents with landlines or cell phones—95% of the sample—are analyzed to maximize comparisons with the 1981-2001 RDD surveys.

Second is an **applied probability score** of the percent correct for either four (1988 - 2001) or two items[2] (2006) about a couple planning a family who carry genes for a hereditary illness. Third is a **methods** question (1995-2006): whether researchers should test a new medication by: (1) giving it to 1000 patients or (2) giving 500 patients the new drug with a 500 patient control group.

Measures: Pseudoscience Support

Three **pseudoscience** belief items include: (1) whether astrology was rated very, somewhat or not at all scientific (asked 1979 to 2006; very and somewhat responses were combined); (2) a true/false item suggesting some UFOs are alien spacecraft (1985, 1988, 1990 and 2001); and an evolution *support* item (dichotomized as “true” versus “false/other”; 1985 to 2006).

I treat these items as separate domains, first because they represent distinct dimensions: traditional pseudoscience; a modern “sci-fi” item; and a straightforward endorsement of evolution. Second, prior research indicates these items have different predictors; e.g., inerrant religiosity negatively correlates with evolution support, but there is no *a priori* reason to expect it to predict UFO responses. Finally, these items do not empirically cluster (r, astrology and evolution = 0.06; r, astrology and the UFO item = 0.10; r, evolution and UFO items = 0.12).

Constructing Birth Cohort and Age Categories

There is sizeable debate over when cohorts begin or end (Carlson, 2008; Glenn, 2005, Pew, 2007). Rather than one constant interval (e.g., 20 years), cohorts are often created using time duration *and* significant events occurring when individuals could experience them. For example, most Millennials would not remember “the Reagan White House astrologer” (Quigley,

[2] The percentage score is used for the Oxford items and the applied probability score to standardize for the different numbers of items asked over time. Coefficient Alpha for the Oxford items is 0.68 with each item contributing about equally to the coefficient. Indices from the earlier studies were shortened for the 2006 NSF Surveys, based on IRT and other measurement analyses reported in Bann & Schwerin, 2004.

1990; Regan, 1988) featured in considerable late night talk show humor in the late 1980s.

One example of these debates is the "Baby Boom", which scholars agree *began* in 1946. Some end it in 1957, when *birth rates* peaked, others in 1961, when the *number of births* peaked, still others in 1964, when completed fertility dropped below three children. Since "Generation X" is generally agreed to begin in the early 1960s, I ended "the boom" in 1961. I created six cohorts: **"Gen Y,"** often called **"Millennials"**, born 1979 – 1988; **"Generation X"** (1962 – 1978); **"Baby Boom"** (1946 – 1961); **"The Lucky Few"**[3] (1930 – 1945); **Post World War I** (1918 – 1929); and **WW I** (1891 –1917). I coded 86 respondents born before 1891 to "missing" because of their scarcity and because dementia increases after age 80.

For cross-tabulations and analysis of variance, five age categories approximately correspond to U.S. government usage: 18-24; 25-34; 35-44; 45-64; and age 65 and over. Although age group and cohort correlate (r = 0.65) because older adults in the years of the surveys tend to be from earlier cohorts, some independence still exists between the two variables.

Gender and Educational Predictors

Gender is an important predictor of science interest, careers, and knowledge (Aldrich, 1978; Burkam, *et al*., 1997; Fox & Firebaugh, 1992; National Science Board, 2008). *Degree level* was coded: high school or less; two-year college degree; baccalaureate; or advanced degree. Exposure to high school biology, physics or chemistry, and level of high school math, was available 1990-2001**.** High school math was coded 1 (none; general or business math); 2 (algebra I or geometry); or 3 (algebra II, calculus, precalculus or statistics). I summed high school science courses (0-3).[4] The number of *college* science courses ranges from 0 to 10 or more.

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[3] Carlson (2008) adopts this term because this relatively small generation matured during a period of affluence following World War II, thus enjoying considerable educational and occupational opportunities.

[4] This sum is a conservative estimate because courses omitted from the NSF questionnaire (e.g., ecology) could not be included.

RESULTS

Cohort and Education

Data from the NSF Surveys agree with other U.S. educational achievement reports over time. More recent sample cohorts had more education: 87% of the WW I cohort had at most high school completion compared with 67% of "Gen X" adults (many Millennials had not finished their schooling). 9% of the earliest cohort had at least a BA compared with 18% of "Gen Xers" and 24% of "Baby Boomers" ($X^2_{(15)}$ = 907.50 Cramer's *v* = 0.11, p < .001). Similarly, high school math exposure increased: 51% of WW I adults had at most "general" or "business" math, compared with 8% of Millennials. In contrast, 41% of Millennials had advanced math, compared with 8% of the earliest cohort ($X^2_{(10)}$ = 952.88 *v* = 0.19, p < .001).

Formal exposure to science also rose. Over twice as many Millennials as the earliest cohort had high school biology (87% vs. 36%, $X^2_{(5)}$ = 995.03 Φ = 0.27, p < .001); triple the percentage had chemistry (69% vs. 20%, $X^2_{(5)}$ = 531.41 Φ = 0.20, p < .001). Comparable figures for physics were 39% versus 22% ($X^2_{(5)}$ = 114.60 Φ = 0.09, p < .001).[5] The grand mean of high school science classes was 1.43, but recent cohorts clearly had more courses, from 0.77 among the WW I cohort to 1.95 among Millennials ($F_{5,\ 13200}$ = 163.90, p < .001 η = 0.24.) Because recent generations more often attended college, they also elected more college science. The WW I cohort averaged 0.41 college science classes compared with Baby Boomers (1.64), "Gen X" (1.58) or Millennials (who, at 1.09 classes, were still completing their formal education, cohort $F_{5,\ 20708}$ = 169.63 p < .001, η = 0.20).

Cohort, Age, Education, and Basic Civic Science Literacy (CSL)

Table 2 shows three CSL measures over time. The "Oxford Items" and experimental drug

[5] It is unclear whether the oldest cohort meant physics, or perhaps a physical science, e.g., "earth science".

item clearly rose over time (Oxford items: $F_{7, 15354} = 28.01$ $p < .001$ $\eta = 0.11$; drug item: $F_{4, 9275} = 17.87$ $p < .001$ $\eta = 0.09$). The one-way ANOVA for the probability score was statistically significant ($F_{7, 15347} = 7.92$ $p < .001$ $\eta = 0.06$), but the relationship was slightly curvilinear.

Table 2 about here

Given that recent cohorts had more (science and math) education they should score higher on CSL. However, *will cohort effects hold net of educational and other variables?* Figure 1 provides one example using the evolution item, showing both unadjusted generational effects, and then those adjusted for control variables.

Figure 1 about here

To illustrate how cohort influenced CSL, net of gender, age, high school and college math and science, (and for pseudoscience items, science knowledge), I use a presentation program often linked to analysis of variance: Multiple Classification Analysis. MCA adjusts for other factors and covariates in an ANOVA equation, to produce, for example, "net generational effects". What typically happens in MCA is that adjusted cohort differences shrink compared with one-way ANOVAs, which omit controls for other predictors of the dependent variable.

In this example, unadjusted cohort effects suggested that recent generations most often supported evolution. One-way ANOVAs indicated that Millennials endorsed evolution 13% more often than the WW I cohort (49 - 36 percent). However, controlling for age, gender and educational variables shrinks the difference between these two extremes so that *in the adjusted results Millennials actually were the least likely in terms of **net** cohort effects to say evolution is "true"* (net cohort differences were not statistically significant).

Table 3 presents the three science knowledge variables by cohort and age, while Figure 2 shows the MCA *adjusted cohort* effects on the Oxford items, applied probability score, and experimental drug item. Controlling gender, degree, high school math, *n* high school science and *n* college science courses, younger adults from more recent generations knew more basic science facts (mean correct on the Oxford items was 60.5%). In the two-way ANOVA, age had modest effects, but cohort had sizable effects net of controls, and the entire model had considerable predictive utility (age $F_{4, 13188} = 7.57$ $p < .001$; cohort $F_{5, 13188} = 81.65$ $p < .001$. **Total** $\eta = 0.56$).

Table 3 about here

Figure 2 about here

How age and cohort affected applied probability is less clear. More recent cohorts tended to score higher; age effects were small ($\bar{y} = 78.8\%$, age $F_{4, 13188} = 12.35$ $p < .001$; cohort $F_{5, 13188} = 36.39$ $p < .001$. **Total** $\eta = 0.34$). Cohort affected the experimental drug item but age had no net effect. Compared with 43% of the WW I cohort and 62% of the post-WW I cohort, 84% of "Gen Y" and 80% of Millennials chose the control groups answer. ($\bar{y} = 74\%$, age $F_{4, 9154} = 0.93$ $p = 0.45$; cohort $F_{5, 9154} = 35.15$ $p < .001$. **Total** $\eta = 0.25$).

Cohort, Age and Pseudoscience Support

Data in Tables 4 and 5 are more discouraging. Given recent cohorts have more education, all else equal, they should more often respond, "true" to the evolution question and more often reject astrology or extraterrestrial UFOs. If so, again, do *cohort effects hold net of education, other background variables, plus an adult's level of science knowledge?*

Instead, pseudoscience seems to appeal more to recent generations. Its support over time is shown in Table 4. The apparent reduction in astrology support is illusory; young Millennials in Table 5 were *the most likely* to say astrology was very or somewhat scientific (52%) followed by the WW I generation (49%) with other cohorts in between ($F_{5, 20553} = 14.99$ $p < .001$). 50% of adults aged 18 to 24 endorsed astrology as did 44% of those at least 65, with age groups in between less supportive ($F_{4,\ 20553} = 35.10$ $p < .001$; **Total** $\eta = 0.11$). Interestingly, Table 5 indicates that astrology belief falls with age for every sample cohort, including Millennials.

Tables 4 and 5 about here

By 2006, the percent endorsing evolution was at its lowest ebb in the 21 years the NSF has asked the question. Cohort had nonlinear effects (I added a polynomial cohort-squared term to the regressions presented later). Initially age and cohort separately (younger adults and recent cohorts) appeared to predict evolution support: 52% of 18 to 24 year olds endorsed it, compared with 37% among those 65 and older. 49% of Millennials answered "true" compared with 37% of the WW I cohort (age $F_{4,\ 17290} = 47.55$ $p < .001$; cohort $F_{5,\ 17290} = 3.78$ $p = .002$. **Total** $\eta = 0.11$). Table 5 shows evolution support mostly dropping with age for each cohort. Figure 3 illustrates adjusted cohort effects on pseudoscience beliefs *net of* math and science exposure, gender, degree attainment, and scores on applied probability and the Oxford indices.[6]

Figure 3 about here

Answers to the UFO item show a different curvilinear pattern. The percent answering "true" or don't know peaked among Baby Boomers at 35%, dropping among earlier and more recent cohorts ($F_{5,\ 7613} = 11.09$ $p < .001$). About one-third of those aged 25 to 64 endorsed "UFO-ology" compared with 22% of those at least 65 (age $F_{4,\ 7613} = 14.43$ $p < .001$ **Total** $\eta = 0.12$). The most striking support was found among *young* Baby Boomers: 61% answered "true"—a number that swiftly dropped as this cohort aged.

Adjusted cohort values differ substantially from unadjusted figures. Young Millennials were the most credulous about astrology, equivalent to Baby Boomers and "Gen X" in endorsing extraterrestrials, and *least* often supported evolution. In other words, the most recent American

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[6] Experimental drug responses were excluded here as a predictor because this item was only asked after 1992. Its inclusion would cause severe data loss on all other variables and restrict the UFO-alien analysis to 2001 alone.

generation, *net of educational achievements*, has more basic science knowledge *and* greater pseudoscience susceptibility. What seemed to be greater evolution support among Millennials simply reflects instead increased education among this cohort.

Multivariate Analyses

Table 6A presents standardized beta weights from three regressions on the Oxford index, applied probability score, and experimental question. It also shows additions to the R^2s (ΔR^2) in order from (1) gender and degree level, (2) *n high school* science and math classes, (3) *n college* science classes, and (4) age and birth cohort. Table 6B presents beta weights from the regressions on *pseudoscience* beliefs. Predictors include gender, education, the "Oxford index", applied probability score, age, and generation. A cohort-squared polynomial was added to capture nonlinear effects in Table 6B. I also show ΔR^2 as each group of predictors is added (gender and degree; high school math; high school and college science; two science knowledge measures; and finally, age and cohort.)

Table 6 about here

Generation is a robust predictor of adult CSL. Controlling education and gender, cohort trumped age effects on all three science knowledge variables. It effects were strongest on applied probability and the drug item. High school math, and high school and college science exposure also predicted all three CSL variables. Men had higher Oxford index scores, women slightly more often answered the drug question correctly, and no sex difference occurred on the probability score.

Gender influenced all three pseudoscience beliefs. Women endorsed astrology slightly more; supported evolution slightly less, and linked UFOs to space aliens slightly more. Better-educated adults more often rejected pseudoscience or endorsed evolution, although these effects were weak. Adults with more high school math more often rejected astrology or UFOs and high school science exposure positively (but weakly) predicted accepting evolution. Taking more college science also weakly affected rejecting astrology or endorsing evolution.

Higher Oxford scores predicted rejecting astrology, accepting evolution—but *also* supporting extraterrestrials. Net of controls, older adults more often rejected astrology *and* evolution. Cohort effects (including curvilinear effects on astrology or UFO beliefs) contributed more weakly to the explained variance on pseudoscience beliefs than they did to science knowledge. Generation had no net multivariate effect on the evolution item.

DISCUSSION AND CONCLUSIONS

Quite simply, it is insufficient to just present adult responses over time to assess changes in the public understanding of science. When age and cohort were disaggregated in this study, the results often differed from gross change over time, and adjusted cohort effects differed further still. Recent American generations have more formal schooling, more science and math, and, net of these, greater science knowledge. Alas, this does not translate into pseudoscience rejection. Indeed, the Millennials cohort often seemed the most credulous.

The Cohort Factor

Pundits and scientists often malign U.S. science achievement, concerned that educational quality and citizen basic CSL are declining. *Yet, my analyses, explicitly including generation, find the opposite.* Partly because the average American stays in school longer, they elect more science and math. Between the World War I and Millennial cohorts, advanced secondary math enrollment quintupled; high school biology or chemistry enrollment tripled. Controlling degree level and college science, high school science exposure still improved adult science literacy.

Cohort especially influenced understanding inquiry: its beta weights for the probability and experimental drug measures were stronger than educational effects. In contrast, adult age had virtually no effects on science knowledge. In probably the most important finding in these analyses, it appears *age effects on CSL in a single cross-sectional survey almost certainly reflect generational rather than aging processes*.

Unfortunately, education and knowledge among recent generations provide little resistance to pseudoscience susceptibility. Net of controls, Millennials most often endorsed astrology. Perhaps they were too young to remember jokes about Nancy Reagan's astrologer, who advised the Reagans when to have surgery and cast the horoscopes of Cold War adversaries (Quigley, 1990). More recent cohorts also more often believed UFOs were alien spacecraft. Although cohort had no net effect on evolution support, Millennials had the lowest *adjusted* percent saying evolution is "true." And those scoring higher on the Oxford index more often rejected astrology or endorsed evolution—but slightly more often *agreed* with the UFO item.[7]

Net of education and cohort variables, older adults had slightly *higher* Oxford index and applied probability scores, arguing against memory or other cognitive "decay" as Americans age. Indeed, within each cohort, seniors endorsed astrology or "UFO-ology" less; perhaps adults learn through experience that many folk tales, e.g., zodiac compatibility, don't "deliver" and that extraterrestrials are unlikely. On the other hand, evolution beliefs may reflect religious attitudes not measured here (e.g., inerrant religiosity) that may increase with age. Furthermore, "creationist" and "Intelligent Design" challenges to American K-12 science education escalated during the 1900s, perhaps creating a true period effect for adults from all cohorts.

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[7] The lack of high school science and math effects in the final equations for pseudoscience support occur because these variables predict the Oxford Index. A structural equation model could disentangle these educational effects *but is tangential to these analyses*, which focus on the net effects of birth cohort or generation.

Education Factors

Increased exposure to math and science consistently fostered adult science knowledge. High school exposure rivaled the influence of college science; wisely so, since even among Generation X, only one- third had any kind of post-secondary degree. For most, high school may be the last time educators *formally* influence science literacy.

Education variables had stronger effects than age or generation on evolution responses. Although evolution is not addressed in *every* high school or *every* science course, [rejecting] evolution was nonetheless the only pseudoscience-related topic here likely to be studied in a formal education setting. K-12 curricula ignore most pseudoscience beliefs, including "sci-fi" fantasies. Perhaps educators are too embarrassed to address such topics. School administrators may fear even raising these issues partially legitimates them. And, as Eve and Dunn (1989; 1990) note, many educators personally *hold* pseudoscience beliefs, thus seeing nothing that needs modification. This pedagogical vacuum leaves students free to construct beliefs from alternative sources without any formal correction or authoritative skepticism.

Historically, the well educated glean scientific and technological information earlier than others. However, some early information can be false or misleading, which may be reflected in the space fantasies often apparently unsquelched by a college education or basic science knowledge. If an individual lacks specialized particulars explaining new technological or scientific advances, one marvel (e.g., time travel) may seem as plausible as another (e.g., genetic splicing). In an era when science becomes highly specialized and technology seemingly miraculous, beliefs about extraterrestrial visitation or "alternative medicine" may continue unless the educational system explicitly tackles them.

Men knew more science facts than women, and held fewer pseudoscience beliefs (although gender effects were small). I have noted (Losh, 2001; Losh, *et al*., 2003) that some pseudoscience belief does not necessarily support a "science deficit" model (Bauer, Allum, & Miller, 2007). For example, these analyses and others report women support astrology more, *net of education variables and science knowledge*. This may occur partly because most women still rely on male financial support. If much of women's economic well-being depends on their male partners, by claiming to help select "the right mate," astrology may provide its adherents with a superficial sense of control. If formal education ignores such beliefs, they can easily continue, reinforced by ubiquitous daily horoscopes and popular television programs.

Altogether, the impact of age, generation, education and science knowledge on different CSL facets make sense. When classrooms address a topic, e.g., inquiry understanding—or evolution, formal education variables influence adult CSL. When the pseudoscience sector is absent from formal education, age and cohort assume more importance. Diminished pseudoscience beliefs as adults age e.g., astrology, may reflect life experiences. On the other hand, cohort effects (e.g., extraterrestrials) draw our attention to the influence media can wield when formal education abdicates the topic.

Why Cohort Change?

There are two likely possibilities for the simultaneous increase among recent generations in science knowledge—and some pseudoscience support. The first addresses science education changes, which have diffused to K-12 educators, emphasizing more science inquiry, contextual issues, and "how scientists think". This explanatory inference is indirect at best, because we only know *which* high school science and math courses respondents took *and not how* these were taught. Unfortunately, if academic jargon (e.g., "emphasis on inquiry") were included in general public surveys it is doubtful that adults would recognize it, or remember how their high school teachers addressed science topics to tell us more. Nevertheless, these analyses suggest that more recent graduates received a more fruitful U.S. science education than in the past.

More recent generations also more often attended college; there, they receive an appreciation of scientific methods from *several* disciplines. *Nearly every basic college text in the social, educational or behavioral sciences now includes at least one chapter on systematic methods of study*, thereby reinforcing student experiences in “other” science courses.

Regrettably, by educators ignoring pseudoscience topics, mass media rush to fill the gaps, invoking a second possible explanation of cohort effects on adult CSL. Media can ridicule pseudoscience phenomena, e.g., the “White House astrologer”. On the other hand, it’s predictable that young Baby Boomers, who matured on *Twilight Zone* and *Star Trek*, linked UFOs to alien spacecraft. In other research, I have noted that boys, especially, fed a diet of *Power Rangers*, infuse their drawings of scientists with superhuman powers (Losh, Wilke & Pop, 2008). More recent generations more often access satellite or cable television, and the Internet, both brimming with uncorrected sci-fi fantasies.

The results from this study suggest recent changes in science education may have boosted *adult* science knowledge. They support those who wish to see such innovations continue and extended to U.S. *college* science courses, hopefully to forestall the “brain drain” among talented undergraduates away from science careers (e.g., Burris, 2006). At a time when there are potential spending cuts on science education, it is important to highlight possible positive consequences, indirect though these may be, of pedagogical changes.

On the other hand, it is sobering to see the disarrayed assertions among United States industrial, government, and educational leaders. It is comparatively easy to sketch an “idealized” science curriculum—especially if proponents don’t know about *already occurring* changes in science education, and science and math advances among our students. Parents and teachers who recognize these improvements (regardless of further desired developments) may resent what they see as jabs at student achievements, and over emphases on math and science education. None of these parties seem aware of advances in cognitive science that assert both domain knowledge (e.g., science facts) and critical thinking skills are required to educate new generations of Americans. Clearly, increased communication across these domains is needed to bridge the sizable gaps among them.

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TABLE 1: Questions used to measure adult public understanding of science

A. Factual Questions (asked 1988-2006)

1. The center of the Earth is very hot. Is that true or false?

2. All radioactivity is manmade. Is that true or false?

3. It is the father's gene that decides whether the baby is a boy or a girl. Is that true or false? (Available after 1990.)
4. Lasers focus sound waves. Is that true or false?
5. Electrons are smaller than atoms. Is that true or false?
6. Antibiotics kill viruses as well as bacteria. Is that true or false?
7. The continents on which we live have been moving their location for millions of years and will continue to move in the future. Is that true or false?
8. Does the Earth go around the Sun, or does the Sun go around the Earth?
9. How long does it take for the Earth to go around the Sun: one day, one month or one year? (Only asked to those responding Earth goes around the Sun.)

B. Inquiry Items (asked 1988 – 2006)

I. Now, think about this situation. A doctor tells a couple that their genetic makeup means that they've got one in four chances of having a child with an inherited illness. 1. Does this mean that if their first three children are healthy, the fourth will have the illness? (Not asked in 2006.)
2. Does this mean that if their first child has the illness, the next three will not?"
3. Does this mean that each of the couple's children will have the same risk of suffering from the illness?
4. Does this mean that if they have only three children, none will have the illness? (Not asked in 2006.)

II. Now, please think about this situation. Two scientists want to know if a certain drug is effective against high blood pressure. The first scientist wants to give the drug to 1000 people with high blood pressure and see how many of them experience lower blood pressure levels. The second scientist wants to give the drug to 500 people with high blood pressure, and not give the drug to another 500 people with high blood pressure, and see how many in both groups experience lower blood pressure levels. Which is the better way to test this drug? (Asked from 1995 forward.)

C. Pseudoscience items (asked 1979-2006)

Would you say that astrology is very scientific, sort of scientific, or not at all scientific?

Some of the unidentified flying objects that have been reported are really space vehicles from other civilizations. (Asked 1985-2001.)

Human beings, as we know them today, developed from earlier species of animals. Is that true or false? (Asked from 1985 forward.)

Source: The National Science Foundation Surveys of Public Understanding of Science and Technology.

ANALYTIC TABLES

TABLE 2: Civic Science Literacy Variables over Time 1988-2006

Year → Civic Literacy Variables	1988	1990	1992	1995	1997	1999	2001	2006
Oxford Qs mean %	55.9	56.0	59.0	60.0	60.0	61.3	63.6	64.0
Probability Score %	82.2	77.5	79.6	77.2	77.3	78.7	80.3	80.8
Drug Question %correct				69	73	73	79	79
Minimum n	2041	2033	2000	2006	1999	1881	1574	1818

TABLE 3: Civic Science Literacy Variables by Age and Cohort

A. "Oxford Questions" Index Mean % Correct Scores by Cohort and Age Group 1988-2006

Cohort → Age	WW I	Post WW I	Lucky Few	Baby Boom	"Gen X"	Millennials
18-24	--	--	--	--	61.3	65.8
25-34	--	--	--	61.1	63.5	68.0
35-44	--	--	67.5	65.0	64.8	--
45-64	--	51.4	56.4	65.3	--	--
65+	42.9	46.9	50.9	--	--	--

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B. Applied Probability Mean % Correct by Cohort and Age Group 1990-2006

18-24	--	--	--	--	80.9	79.8
25-34	--	--	--	83.8	84.3	82.0
35-44	--	--	89.8	82.9	82.0	--
45-64	--	75.0	79.1	81.9	--	--
65+	60.0	65.5	69.6	--	--	--

C. Experimental Question Mean % Correct by Cohort and Age Group 1995-2006

18-24	--	--	--	--	82	83
25-34	--	--	--	69	79	88
35-44	--	--	--	76	81	--
45-64	--	--	67	76	--	--
65+	43	62	63	--	--	--

Please see text for tests of statistical significance.

TABLE 4: % Pseudoscience Support 1979-2006

Year → Responses	1979	1983	1985	1988	1990	1992	1995	1997	1999	2001	2006
Astrology Scientific	50.0	49.0	42.6	40.5	39.7	38.2	40.0	40.9	41.0	44.2	35.1
Evolution True			45.2	45.9	44.8	45.1	43.8	43.7	45.3	53.3	42.8
Aliens-UFOs			42.8	24.9	24.3					29.6	
Minimum n	1635	1645	2018	2041	2033	2000	2006	1999	1881	1574	1818

TABLE 5: Cohort and Age Group Effects on Pseudoscience Variables

A. % Astrology is "Very" or "Somewhat" Scientific by Cohort and Age Group 1979-2006

Cohort → Age	WWI	Post WWI	Lucky Few	Baby Boom	"Gen X"	Millennials
18-24	--	--	--	51	49	52
25-34	--	--	62	42	41	38
35-44	--	--	43	38	37	--
45-64	66	46	37	33	--	--
65+	48	42	42	--	--	--

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B. % Agreeing Some UFOs Really Space Ships by Cohort and Age Group 1995-2001

18-24	--	--	--	61	31	25
25-34	--	--	--	38	27	--
35-44	--	--	47	31	25	--
45-64	--	26	31	33	--	--
65+	19	24	29	--	--	--

% Agree, "Human beings…developed from earlier species" by Cohort and Age Group 1985-2006

18-24	--	--	--	49	53	51
25-34	--	--	--	50	49	39
35-44	--	--	48	49	46	--
45-64	--	37	40	45	--	--
65+	37	37	39	--	--	--

Please see text for tests of statistical significance.

TABLE 6

A. Standardized Multiple Regression Effects on Civic Science Literacy Variables

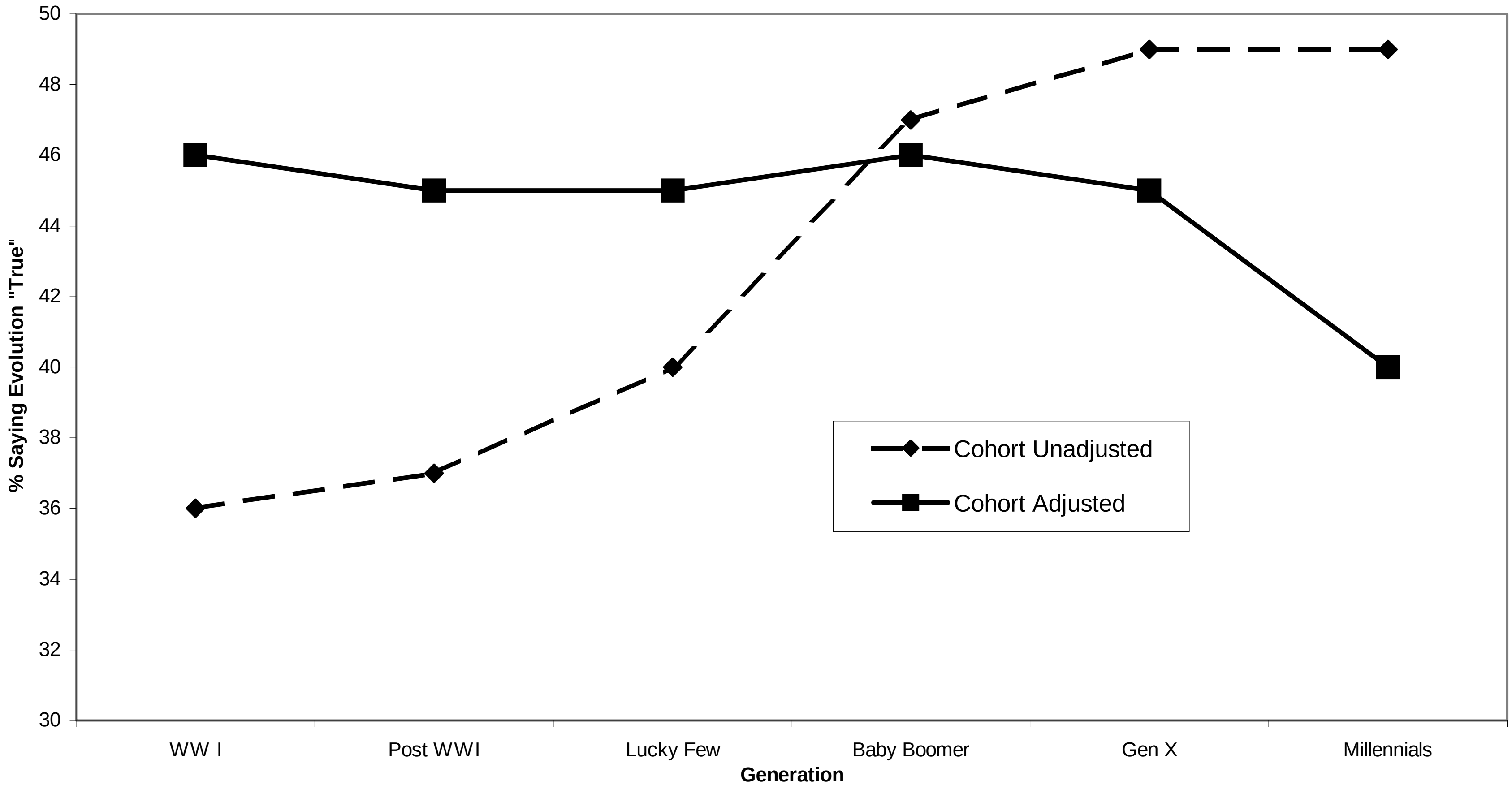
Predictors / Dependent Variable→	Oxford Qs	Probability Score	Drug Question
Gender (Male = 1)	0.14***	0.01	-0.02*
Degree Level	0.13***	0.08***	0.04**
High School Math	0.14***	0.14***	0.10***
Number High School Science Courses	0.13***	0.05***	0.03*
Number College Science Courses	0.21***	0.07***	0.05***
Age	0.07***	0.04*	0.02
Generation	0.18***	0.16***	0.15***
R^2 Gender and Degree Level	0.183***	0.042***	0.016***
Δ R^2 High School Math and Number High School Science Courses	0.084***	0.041***	0.023***
Δ R^2 Number College Science Courses	0.027***	0.003***	0.002***
Δ R^2 Generation and Age Categories	0.014***	0.014***	0.017***
Total R^2	0.309***	0.101***	0.058***
R	0.556	0.318	0.241
n	13,205	13,205	9,171

B. Standardized Multiple Regression Effects on Pseudoscience Support Variables

Predictors / Dependent Variable→	Astrology Scientific	Evolution True	UFO-Alien Spaceship
Gender (Male = 1)	-0.04***	0.06***	-0.04*
Degree Level	-0.05***	0.09***	-0.07**
High School Math	-0.06***	0.00	-0.07**
Number High School Science Courses	0.00	0.03**	-0.02
Number College Science Courses	-0.04***	0.05***	-0.03
"Oxford" question index	-0.15***	0.13***	0.07***
Probability score	- 0.07***	0.00	0.02
Age	-0.09***	-0.09***	0.07
Generation	-0.23***	0.01	0.30**
Generation Squared Term	0.21***	0.04	-0.41***
R^2 Gender and Degree Level	0.037***	0.041***	0.006***
Δ R^2 High School Math and Number High School Science Courses	0.007***	0.008***	0.003**
Δ R^2 Number College Science Courses	0.004***	0.003***	0.000
Δ R^2 Knowledge and Probability Scores	0.021***	0.012***	0.006***
Δ R^2 Generation and Age Categories	0.011***	0.004***	0.011***
Total R^2	0.080***	0.068***	0.023***
R	0.283	0.261	0.160
n	13,205	13,205	3,569

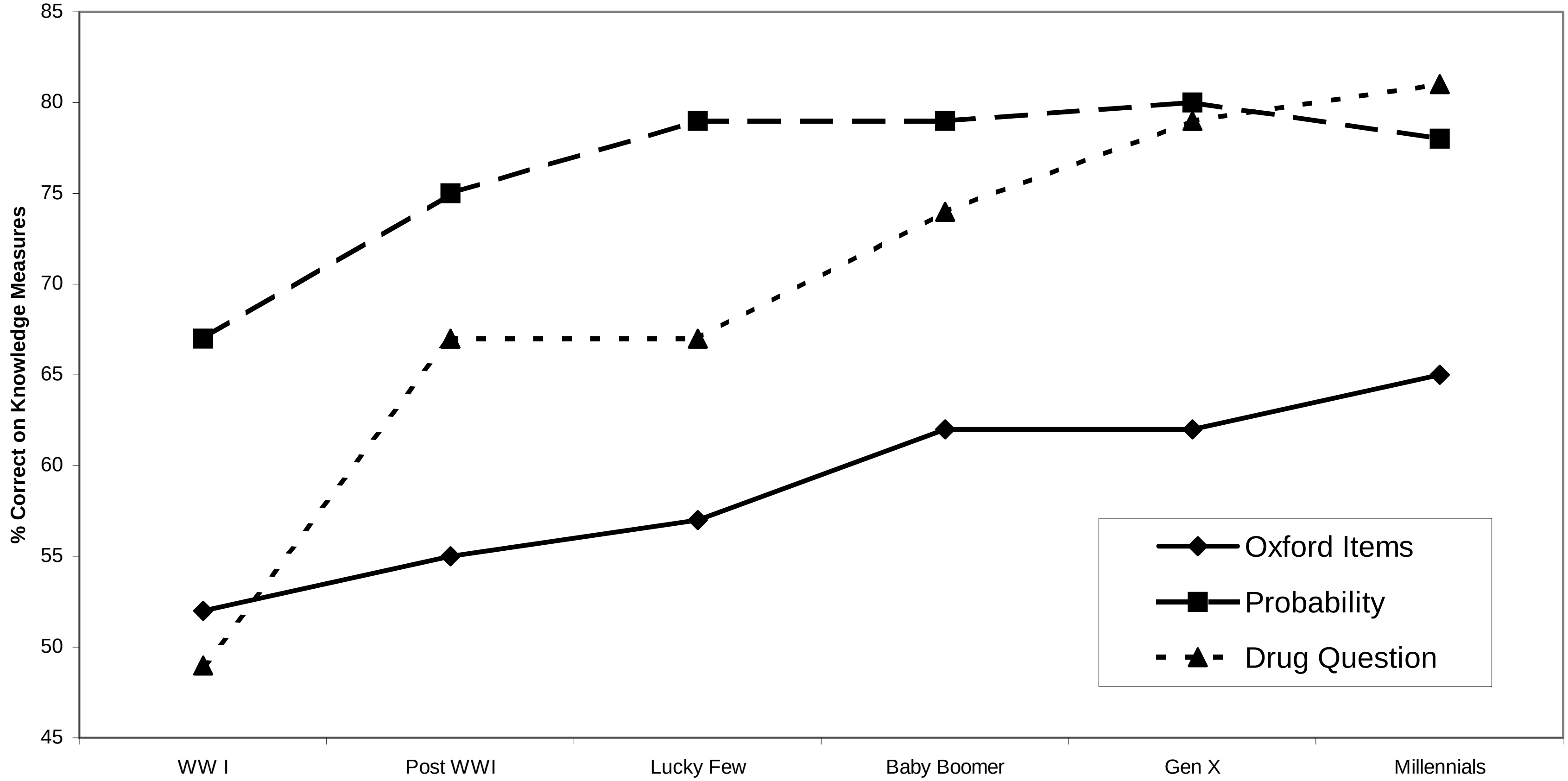
* $p < .05$ ** $p < .01$ *** $p < .001$

Figure 1: Adjusted and Unadjusted Cohort Effects on % Saying Evolution "True"



Adjusted for Gender, Degree Level, High School Math, N High School Science, N College Science, Age Category

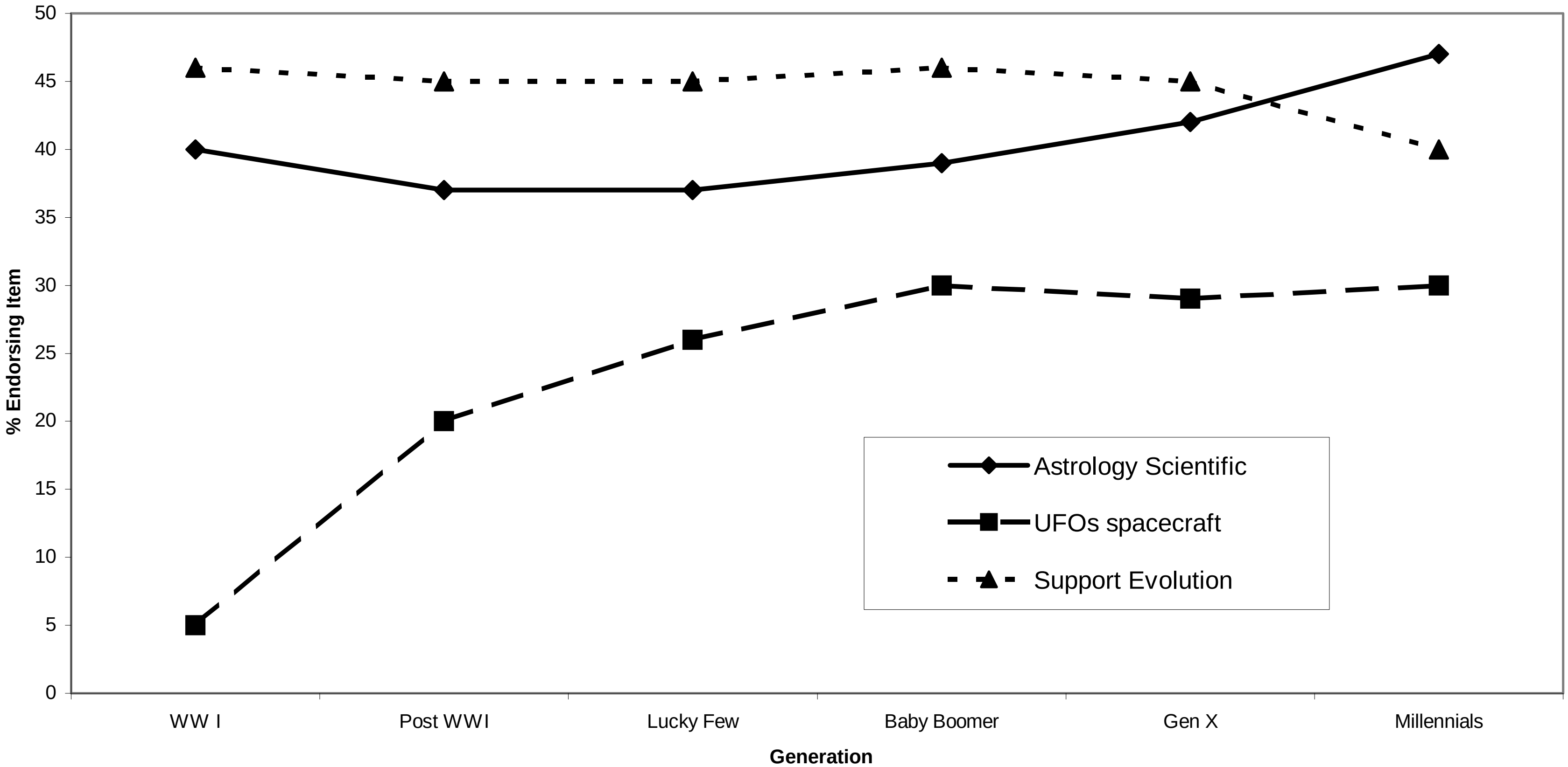
Figure 2: Adjusted Cohort Effects on Science Knowledge Measures



Generation

Adjusted for Gender, Degree Level, High School Math, N High School Science, N College Science,Age Category

Figure 3: Adjusted Cohort Effects on Pseudoscience Items



Adjusted for Gender, Degree Level, High School Math, N High Schol Science, N College Science,Age Category, Oxford Score and Probability Score