http://doi.org/10.35847/TYamashita.TSmith.SSahoo.PCummins.5.1.4

Research Article

Age, Period, and Cohort Effects on Adult Literacy Skills in the United States

Takashi Yamashita, University of Maryland, Baltimore County
Thomas J. Smith, Northern Illinois University
Phyllis A. Cummins, Miami University

Acknowledgment: This research was in part supported by the Institute of Education Sciences, U.S. Department of Education, through Grant R305A170183 to Miami University and University of Maryland, Baltimore County. The opinions expressed are those of the authors and do not represent views of the institute or the U.S. Department of Education.

Abstract

Adult literacy skills are critical assets of individuals as well as societies in terms of economic (e.g., human capital) and social well-being. Thus, it is important to monitor the long-term trends and sources of skill gain/loss. Yet, temporal sources of adult literacy skill variation are understudied. The current study analyzed three comparable, nationally representative datasets including the 1994 International Adult Literacy Survey; the 2003 International Adult Literacy and Life Skills Survey; and the 2012/2014/2017 Program for the International Assessment of Adult Competencies. Results from the age-period-cohort hierarchical cross-classified random effects model showed significant variation in adult literacy skills across cohorts (1930-1995) and time periods (1994-2017). Possible implications for adult education policies and future research needs were evaluated.

Keywords: Adult literacy, skill variation, human capital

The objective of this study is to document recent trends of adult literacy skills in the United States across time as well as to examine potential temporal sources of literary skill variation—specifically, age, period, and cohort effects. To do this, we analyze nationally representative large-scale assessment data with underutilized cross-classified multi-level modeling approach. A series of previous international studies across economically developed nations showed that adult literacy is one of the most critical indicators of social and economic well-being, not only at the individual level, but also at the societal level (Organization for Economic Co-operation and Development [OECD], 2000, 2019). Results from the current study provide empirical evidence pertaining to recent trends of adult literacy and in turn, inform possible needs for adult education curriculum modifications and education policy interventions.

Correspondence: yamataka@umbc.edu

Theoretical and Policy Perspectives on Adult Literacy

Human capital is a widely accepted critical asset for social and economic advancement in any society (Benhabib & Spiegel, 1994). Human capital often is considered as consisting of individual and collective knowledge, skills, and experience, which jointly maximize economic benefits such as income and employment security of individuals as well as economic growth of nations (Becker, 1993). Basic skills, such as literacy and numeracy, are known to be core components of human capital. Indeed, basic skills seem to promote economic growth as well as, if not better than, common human capital determinants such as average years of education/schooling. Convincing evidence shows that, among OECD nations, improvement in average adult literacy skills are linked to the per capita growth in gross domestic product (GDP; (Coulombe & Tremblay, 2006). Thus, monitoring the trends of literacy skills and identifying reasons for the changes are important from economic and education policy standpoints.

Additionally, other benefits of increasing literacy skills have been documented. In general, economic outcomes have been the main areas of interest in this context. However, Reder (2020) argues that the dominant focus on economic benefits (i.e., neoliberalism) in adult education overlooks other outcomes such as benefits (e.g., increased participations) in social, cultural and civic affairs. International studies show that adult literacy is related to civic engagement, political efficacy, social capital (e.g., trust in governments and communities), and general health (OECD, 2013; Saal et al., 2020; Yamashita & Kunkel, 2015). Therefore, efforts to enhance literacy skills can be pursued not only for economic benefits, but also for benefits in individual and social well-being. Correspondingly, declines in literacy skills at the population-level can serve as a warning sign, both from economic perspectives and a variety of social problem perspectives (Flisi et al., 2019; Murray et al., 2016).

Age, Period and Cohort Effects on Adult Literacy

Some areas of literacy that have seen relatively little research at the national level involve the long-term trends and sources of the changes. Virtually all published studies show that there is a negative relationship between aging and literacy skills (Barrett & Riddell, 2019; Desjardins & Warnke, 2012; OECD, 2016). As the global community is experiencing population aging, research on skill trends over time has current as well as future policy implications that are significant (Desjardins & Warnke, 2012). At the same time, previous findings may over-estimate age effects on literacy skills because other temporal sources of variation— such as period and cohort effects — often are overlooked (Green & Riddell, 2013).

In the context of literacy, age effects refer to the variation in literacy skills due to aging-related physiological changes, cumulative social/educational experience, and social role transitions across life stages (Yang & Land, 2008). The particular cohort, which is defined by the specific time period when one was born may explain a portion of the variation across time in literacy (Desjardins & Warnke, 2012). Cohort effects refer to differing literacy skills due to the unique life experiences across cohorts. In contrast, period effects represent the impact on individuals of all ages due to the changes in social, cultural, economic and physical environments (Yang & Land, 2008).

The examination of adult literacy and potential temporal sources of literacy variation is timely. First, the well-known demographic trend of

an aging population warrants a need for better understanding of the associations between age, cognitive skills, and adult literacy skills. Starting 2011, a rapid increase in the older population aged 65 years and older in the United States (9% in 1960s and 15% in 2014) has been driven by the large Baby Boomer cohort (born between 1946 and 1964), whereby, in 2014 over 22% of the labor force was aged 55 years and older (Mather et al., 2015). Second, the Great Recession of 2007-2009 has impacted the access to formal education and labor force participation in the overall population has done so disproportionately across different cohorts (Kalleberg & Von Wachter, 2017). Specific cohort members such as Millennials may have experienced formal education differently than other cohorts. Moreover, relevant education policies (e.g., the Higher Education Act of 1965 and the American Recovery and Reinvestment Act of 2009) most likely altered access to higher education in general and across cohorts such as Baby Boomers and Millennials, in particular (Evans et al., 2019). Although the objective of the current study is not to examine any specific historical event or cohort; age, period, and cohort effects are important pieces of information to facilitate interpretation of adult literacy trends.

Recent Empirical Studies

To date in the 21st century, only a handful of national-level studies on adult literacy trends involving examination of age, period and cohort (APC) effects have been conducted in the United States. Yang and Land (2008) analyzed the 15 waves (1974-1996) of cross-sectional data from the General Social Survey (GSS; Smith et al., 1972-2014), using cross-classified random effect models, and found that there were period and cohort effects on the 10-item verbal test scores among adults in the United States. Green and Riddell (2013) examined two waves of cross-sectional data from the 1994 International Adult Literacy Survey (IALS) and the 2003 International Adult Literacy and Life Skills Survey (ILASS) using a series of ordinary least squares (OLS) and quantile regression models, and found that literacy skills decline in individuals as early as their late 20s, and the rate of skill decline accelerates in later life. Also, their analyses showed that successive cohorts tend to have lower literacy skills than previous cohorts. Murray, Binkley and Shillington (2016) analyzed two waves of the U.S. cross-sectional data from the 2003 IALSS (aka ALL) data and 2012 Program for the International Assessment of Adult Competencies (PIAAC) using regression models, and reported that there were literacy skill declines in all cohorts (26-65 years of age, by 10-year increments). Kim (2018) analyzed PIAAC data from 17 OECD nations including the United States, and found that older cohorts were more likely to have lower literacy skills than younger cohorts. The findings from Kim (2018) do not necessarily imply that older cohorts had lower literacy skills than younger cohorts when they were the same age, but do provide a snapshot of the age group differences in literacy. Barrett and Riddell (2019) used IALS, ALL, and 2012 PIAAC data using OLS and quantile regression analyses, and found that the literacy skills declined with age, starting in the mid-20s, and the successive cohorts were more likely to have lower literacy skills.

Based on the recent studies on the adult literacy skills and APC effects, there are consistent as well as mixed findings and methodological approaches (Barrett & Riddell, 2019; Green & Riddell, 2013; Kim, 2018; Murray et al., 2016; Yang & Land, 2008). First, the negative associations between age and literacy are consistent in previous studies, and suggest curvilinear relationships (Desjardins & Warnke, 2012). Additionally, cohort effects on literacy likely exist in the United States (Green & Riddell, 2013;

Yang & Land, 2008), as well as European nations (Flisi et al., 2019). However, the direction of cohort-literacy relationships has yet to be established. On one hand, successive cohorts have lower literacy skills than previous cohorts (e.g., Barrett & Riddell, 2019; Green & Riddell, 2013). On the other hand, certain cohorts seem to have lower literacy than other cohorts regardless of the time order (Yang & Land, 2008). It also should be noted that younger adults consistently show higher literacy than older adults when any particular time point (i.e., snapshot) is examined (Barrett & Riddell, 2019; Murray et al., 2016). However, the differences in literacy across cohorts at one time point could be due partially to APC effects. There are only a few studies that have specifically examined period effects on literacy in the United States, but these effects have not been explicitly documented (Yang, 2006; Yang & Land, 2008).

With regard to the methodological approaches, all recent studies that include the United States used some combination of IALS, ALL, and PIAAC (Barrett & Riddell, 2019) and, with a few exceptions, GSS (Yang & Land, 2006, 2008) data. Arguably, IALS, ALL, and PIAAC provide the most sophisticated recent U.S. historical literacy assessment data at the national level (see the methods section for more details about the literacy assessment). The synthetic cohorts with 5- or 10-year birth year increments are the most conventional cohort classifications (Yang & Land, 2008). All studies adopted graphical and model-based approaches (e.g., Green & Riddell, 2013; Yang & Land, 2008). Namely, the estimated literacy skills by age, period, and cohort were visualized to document the trends and to identify patterns and, then, APC effects were quantified as the estimated coefficients in statistical models. Linear effects of age, gender, social groups (e.g., race/ethnicity), educational attainment, and early life socioeconomic environment (e.g., parents' or guardians' educational attainment), as well as non-linear effects of age consistently have been considered in previously-published model-based approaches (Desjardins & Warnke, 2012; Hanushek et al., 2013; Kim, 2018; Yang & Land, 2008).

Research Objective

Building on the existing research, the objective of this study was to document APC effects on adult literacy using nationally representative U.S. data from the 1994 IALS, 2003 ALL and 2012/2014/2017 PIAAC data, which allow methodological approaches that were previously less feasible. To date, there are only two published APC-related studies (Barrett & Riddell, 2019; Desjardins & Warnke, 2012) that utilized data from IALS, ALL and PIAAC. In addition to IALS and ALL, the current study was designed to advance the APC analysis of adult literacy by using the most recent data from 2012/2014/2017 PIAAC restricted use file (RUF), which provides data at additional time points, and more precise measures such as continuously-measured age that are not available in the public use file (PUF; National Center for Education Statistics, 2015). Specific sources of temporal variation (APC effects) in adult literacy in the United States were estimated.

Methods

Data

Data were obtained from 1994 IALS, 2003 ALL, and 2012/2014/2017 PIAAC. The current study focused on the U.S. data although all three surveys provide internationally representative data. IALS, ALL, and PIAAC each used complex sampling designs and sophisticated assessment methods to collect data on literacy and demographic, socioeconomic, and other (e.g., education participation, skill use, health) characteristics of adults between the ages of 16 and 65 years (except for the 2014/2017

PIAAC data, which included an additional age group of 66-74 years old). More details about each study have been published by the National Center for Education Statistics (National Center for Education Statistics, n.d.) and elsewhere (Paccagnella, 2016). IALS U.S. data and ALL U.S. data (international version) were obtained from Statistics Canada upon the approval of the data use agreement. The ALL (U.S. version) and PIAAC U.S. RUF data were obtained from the U.S. Department of Education, Institute of Education Science (IES), National Center for Education Statistics (NCES; license #17080026). Although the PUF data files with limited age information (i.e., categorized rather than continuous age measures) were available, the restricted files with the continuous age measure were necessary for the objectives of this study. Additionally, the reason that both the international and U.S. versions of the ALL data were used was to obtain both the rescaled literacy measure and continuously measured age variable, which were only separately available.

Given the survey periods (year and month) and the distributions of respondents (2011-2012, 2013-2014, and 2017), PIAAC data were classified by year (2012, 2014 and 2017). From the original data (N_{IALS} = 3,050; N_{ALL} = 3,420; and $N_{PIAAC2012}$ = 4,890, $N_{PIAAC2014}$ = 3,580, and $N_{PIAAC2017}$ = 3,480), participants younger than 18 years old at the time of the survey (n = 940), cases with missing values in the measures of interest (n = 360) and/or ineligible participants (n = 40) who belonged to cohorts born prior to1930 (see below for the cohort measure) were excluded. The final sample size of the pooled data was N = 17,220 (see Table 1 for the total sample sizes for each survey). Also, based on the birth year and survey year, the participants were cross-classified into unique sub-groups (see Table 1 for the sub-group sample sizes).

Measures

In PIAAC, literacy was defined as "... understanding, evaluating, using and engaging with written text to participate in the society, to achieve one's goals and to develop one's knowledge and potential" (OECD, 2011, p. 8). The literacy definition in PIAAC is broader than those (i.e., prose and document literacy) used in IALS and ALL. However, OECD (2019) reports that literacy scores are comparable across three surveys. Specifically, OECD states "...the Survey of Adult Skills was designed to be linked psychometrically with IALS and ALL in the domain of literacy..." and "...analysis of data from the field trial and from the main data collection confirmed that results from IALS, ALL and the Survey of Adult Skills could be placed on the same scale in literacy..." (p. 84). The rescaled literacy proficiency measure based on the performance assessment was expressed in the form of 10 plausible values (each ranging from 0-500 points) estimated using multiple imputation. More technical details regarding the skill assessment and estimation are published elsewhere (Goodman et al., 2013).

Age was recorded in years and re-scaled to 10-year increments to facilitate efficiency of estimation and interpretability. After grand-mean-centering, the squared value of this variable was computed to capture a non-linear relationship with literacy (Yang & Land, 2006). The periods consisted of the five survey years, including 1994, 2003, 2012, 2014, and 2017. From the pooled data, fourteen cohorts (1930-1995) were defined with the 5-year synthetic cohort. Use of 5-year synthetic cohorts is a common practice in social science (Yang & Land, 2008). Due to the limited sample sizes (less than 40), cohorts consisting of individuals born prior to 1930 were excluded from this study.

Covariates were selected based on the relevant research (e.g., Barrett & Riddell, 2019; Desjardins

& Warnke, 2012). Gender was a dichotomous measure (1 = *female* and 0 = *male*). Educational attainment was the dichotomous coded as 1 = *college education* (including associate, bachelor's, graduate, and professional degrees) and 0 = *less than college education*. Race/ethnicity was coded as a set of three dichotomous (0/1) dummy variables contrasting Black, Hispanic, and Others with a reference group (White). Nativity indicated whether the participant was born in the United States (coded as 1) or outside of the United States (coded as 0). All measures were grand-mean centered, except for educational attainment (group-mean centered; see Yang & Land, 2008) in the models for the interpretation purposes. In multilevel models, centering dichotomous variables is recommended because of the known advantages for interpretation of intercepts, addressing issues of possibly highly correlated intercepts and slopes, and facilitating the variance estimation process (Hox, 2010; Raudenbush & Bryk, 2002).

Statistical Analysis

Descriptive statistics of all variables of interest were computed, employing the IDB analyzer application (International Association for the Evaluation of Educational Achievement, 2016), which takes the sampling weights, replicate weights, literacy plausible values, and specific replication methods (paired jackknife with 80 replications of the U.S. data) into account and generates macro SAS code. Descriptive statistics for literacy proficiency also were computed by APC. To quantify the APC effects, we employed a hierarchical APC cross-classified random effects model (HAPC-CCREM; Yang, 2006; Yang & Land, 2008). HAPC-CCREM can be considered as an application of multilevel modeling with the individual and cohort/period group levels. Individuals were considered nested within the cells that were cross-classified by the 5-year cohort and period in this study (see Table 1). Technical details of the HAPC-CCREM have been published elsewhere (Yang, 2006; Yang & Land, 2008). The models were estimated using the Bayesian method with Markov Chain Monte Carlo (MCMC) algorithm in Mplus version 8.

Results

The weighted statistics based for the sample (Table 2) showed that the mean literacy skill proficiency was 269.90 out of 500 points. The mean age was approximately 42 years, while the distribution of gender was fairly uniform and 37% of adults had a college or higher degree. The majority of adults (86%) were born in the United States. The patterns of mean literacy proficiency scores are represented in Figures 1-3. It should be noted that these figures do not represent the ACP effects but, rather, a snapshot or descriptive summary by age, period, and cohort given the data available for the time frame between 1994 and 2017. From examination of Figures 1 and 3, age and literacy skills appeared to be negatively correlated. Figure 2 suggests weak downward trend, if any, between 1994 and 2017. On a relevant note, 2014 and 2017 PIAAC included the oversampled, older age group (66-74 years). Yet, the patterns of means exclusive of this older age group showed similar trends.

Table 3 summarizes the findings from the HAPC-CCREMs. In these results, the statistically significant fixed quadratic effect of age indicated a non-linear relationship between age and literacy among adults. Based on the Model 2 results, literacy skills start declining around 26 to 27 years of age and this finding is consistent with prior research (Barrett & Riddell, 2019). Subsequently, literacy skills decline at an accelerated rate in accordance with age. There was evidence of period and cohort effects, with level-2 period and cohort

variances of 10.48 and 88.60, respectively, and 95% credibility intervals that did not include zero. These statistically significantly level-2 random effects indicated between-period and between-cohort variabilities, which are possible period- and cohort-related temporal sources of variation in literacy skills.

Discussion

Considering the human capital and wider benefits of adult literacy (Becker, 1993; Reder, 2020), the objective of the current study was to analyze three comparable nationally representative data sets, IALS, ALL, and PIAAC, to document potential temporal sources of variation in adult literacy skills in the U.S. Results from the HAPC-CCREM revealed significant non-linear age effects, as well as the period and cohort effects on adult literacy skills. Consistent with previous research (Barrett & Riddell, 2019; Green & Riddell, 2013), mean literacy skills start declining in the early stages of adult life. Aging is linked to general cognitive decline in later adult life and, in turn, older age may partially explain the literacy decline (Hanushek et al., 2015; Hartshorne & Germine, 2015). However, as Green and Ridell (2013) point out, the age-related literacy decline varies by initial proficiency levels, with those demonstrating higher proficiency at a younger age tending to experience greater decline, commencing even immediately after the conclusion of initial formal schooling (i.e., around the age of 25-35 years). It should be noted that those with lower literacy proficiency may not experience salient decline in accordance with age, or at least, decline is not captured by the assessment, simply due to the floor effect. Additionally, types of cognitive functions show different developmental trajectories. For example, verbal ability stays constant while numeric ability declines across adult life stages and lifestyles, such as characterized by social and physical activity habits (Hedden & Gabrieli, 2004; Mirowsky, 2011). Thus, despite the fact that the average literacy level generally starts declining around the age of 25-35 years and at a more accelerated rate in older age, the variability by the skill levels as well as relevant lifestyle factors should not be overlooked.

Also, considering the importance of formal education on literacy skills, older age may indicate the time that has passed since the last formal education --- the recency effect (Desjardins & Warnke, 2012; Kim, 2018). However, given that the adult literacy assessments used here are designed to assess adult activities/skills (e.g., work-related, civic, personal), rather than skills based on academic curricula, it does not appear likely that the age-related decline in literacy skill is fully or even largely explainable as an artifact of the assessment used. The PIAAC literacy assessment was designed to capture a wide range of adult literacy proficiency, which reflects the skillsets needed for a transition from school to work, general cognitive skills and generic work-related skills (Schleicher, 2008). At the same time, the IALS, ALL and PIAAC literacy assessments partially reflect multiple domains of cognitive skills. In addition, certain types of cognitive skills (e.g., vocabulary, crystalized intelligence) are needed for different life stages (Baltes, 1987; Desjardins & Warnke, 2012; Parkin & Java, 1999). In formal education settings, there arguably are more opportunities to use a wide range of cognitive as well as reading and writing literacy skills. Yet, following formal education in earlier life stages, adults may increasingly use a narrower range of specific cognitive skills, such as job-related skills, and in turn, basic literacy skills may decline (Murray et al., 2016). Additionally, sub-populations of adults, for example, those who are not in the labor force, may have fewer

opportunities to use specific or basic literacy skills, and lack of literacy practice/engagement may result in skill loss (Green & Riddell, 2013; Reder et al., 2020). These age-related changes in literacy proficiency should be cross-referenced with discussions on the period and cohort effects.

Explanations for period and cohort effects are limited in the literature. Social and economic conditions, as well as quality of education systems at the time of individuals' schooling, are arguably the main reasons provided for period and cohort effects (Flisi et al., 2019). Also, from a life course perspective, it is possible that the size and composition of each cohort along with the social/economic conditions may determine which resources are available to individuals and differentiate access to high quality formal education. For example, large cohorts such as the Baby Boomer cohort, which faced more severe within-group competition over economic and educational opportunities due to its larger cohort size relative to other cohorts (e.g., Millennials), or cohort members who lived through the Great Depression in their pre- and early-adult lives may have experienced reduced access to education opportunities due to limited economic resources (Elder, 2018). Also, social inequality by gender and race/ethnicity may have played a role. Indeed, our analysis showed that, after adjusting for specified sociodemographic characteristics, period- and cohort-related variability in literacy skill was reduced (see Table 3). It should be noted that the timing, components (e.g., crystalized and fluid intelligence; verbal meaning and word fluency), and patterns (i.e., simultaneous gains and losses in different cognitive skills over time) of cognitive skill changes in adult life may widely vary for different reasons across cohorts (Baltes, 1987; Hartshorne & Germine, 2015). Future research could seek to identify specific explanations of the APC effects on the literacy skills when more data and alternative research methods become available.

Several limitations should be noted in this study. We are aware that the HAPC-CCREM requires strong assumptions (e.g., the exchangeability assumption) and possible pitfalls may ensue in the statistical estimation (Bell & Jones, 2014). At the same time, HAPC-CCREM has advantages over other methods, such as decomposition of APC effects with cross-sectional data. Whereas more methodological development is needed regarding APC analysis, HAPC-CCREM is useful to quantify possible temporal sources of variation (Masters & Powers, 2020). Also, the use of cross-sectional data limited our capacity to understand the changes in literacy skills, whereas longitudinal panel data enable researchers to directly investigate changes in adult literacy and APC effects (Beller et al., 2019; Reder et al., 2020). Moreover, due to methodological concerns and data limitations including unbalanced and unequal-interval data, our analysis did not consider specific period or cohort differences. The current APC analysis guidelines caution against fitting overly-complicated APC models, and also caution users not to extrapolate APC analysis results to specific matters (Masters & Powers, 2020). Indeed, at the time of this study, APC models may only be useful for descriptive purposes (Kramer & Casper, 2015). Relatedly, our APC analytic model was relatively simple and the possibility of omitted variable bias cannot be ruled out. For example, potentially relevant individual characteristics such as childhood socioeconomic status (e.g., parents'/guardians' education) were not included in our final model although sensitivity analysis showed that our findings were consistent with the results reported in the current study. Finally, we did not include any higher-level measures above and beyond period and cohort. For example, macro-level social and economic environmental

characteristics (e.g., job demands, or the "Matthew Effect" whereby literate persons become increasingly literate) may partially explain the predictors of variation in the adult literacy trends. Again, our analysis focused on the rigorous description and documentation of three potential temporal sources of variation in adult literacy—age, period, and cohort.

Strength and Contributions

To date, limited research has been carried out using multiple versions of cross-sectional data consisting of sophisticated and comparable literacy measures of adult literacy and using APC analysis (Barrett & Riddell, 2019; Desjardins & Warnke, 2012). Using relatively under-utilized HAPC-CCREM and Bayesian estimation methods, the APC analysis with five time-points from IALS, ALL and PIAAC presented here adds unique empirical evidence to the literature. Also, investigation of systematic decomposition of APC effects remains scant in recent adult literacy research. Potential sources of adult literacy variation inform labor as well as adult education policies in the United States. Particularly, as older adults remain in the labor force longer and need to constantly learn new skills to stay employable (Cummins et al., 2015), age-related literacy skill decline is disadvantageous in the labor market and adult education settings. Findings about the APC effects provide a context in terms of different earlier life and education experiences, such as the social and economic conditions of specific cohort members (e.g., Baby Boomers). Therefore, for example, offering adult literacy education programs that are crafted to each cohort could maximize effects of adult education and training. This study included the adult population aged between 18 and 74 years of age and was based on human capital theory, along with lifelong and lifewide learning perspectives, which entail social and political participation in societies (Becker, 1993; Reder, 2020). Our findings suggests possibly unstable nature of human capital over the life course, due to the combination of individual aging-related decline and skill obsolescence in the dynamic societies (e.g., scientific and technological advancement) (e.g., Schuetze, 2007). These multilevel sources of variations in literacy proficiency over time provide insights to andragogy --- "the arts and science of helping adults learn" (Knowles et al., 1998, p. 61). That is, adults may have diverse learning preference due to the earlier life experiences in different time points. In summary, the current study documented the APC effects on literacy skills of the adult population in the United States, possibly due to the individual as well as societal level impacts.

Based on the findings from this study, future research should address several important areas. First, APC analysis benefits from further methodological refinement and innovation. Given the current limitations in APC analysis (Bell & Jones, 2014; Masters & Powers, 2020), improvements in the APC analytic approach are critical. Also, longitudinal panel data expand the possibility for analyses of APC effects in adult literacy research (Reder et al., 2020). Although the use of a synthetic cohort is a conventional approach in APC analysis, future research in adult literacy should consider theoretical cohorts such as the Baby Boomer, Generation X, and Millennial cohorts (e.g., Hughes & O'Rand, 2004). Furthermore, APC effects on different types of literacy skills, such as job-related, quantitative, and digital literacy should be included in future research agenda. Moreover, sub-group analyses of specific social groups, such as joint classifications of gender and race/ethnicity, are critical, particularly for countries with diverse populations. Finally, additional research is needed to clarify explanations for the temporal sources

of variations in adult literacy, and to identify the linkages with specific cohorts and historical events (e.g., major changes in education policy, economic conditions, and public health crises such as the COVID-19 pandemic), as well as examine potential interactive effects of these temporal sources of variation on adult literacy skills.

Conclusion

The current study utilized large-scale assessment data from 1994 IALS, 2003 ALL, and 2012/2014/2017 PIAAC, and generated empirical evidence of the APC effects on literacy among the adult population aged between 25 and 65 years in the United States. Results showed that literacy skills tended to decline with age at an accelerated rate. In addition, there were notable variations across the period and cohorts. The empirical findings from this study provide possibly multi-level sources --- individual aging and skill obsolescence due to the social change --- of literacy declines over time. These sources of variations in literacy proficiency reflect diverse learning preference by cohorts and as such, should be reflected in adult education programs. Given the important roles of basic skills as a part of human capital as well as well-being of the societies, closely monitoring the literacy skills trend over time and reflecting empirical evidence in adult education programs and education policy are critical. Based on the findings from this study, and the potential for subsequent availability of large-scale assessment data, future research should identify specific explanations for the APC effects on literacy over the life course to inform specific areas of adult education program and policy modifications.

References

Baltes, P. B. (1987). Theoretical propositions of life-span developmental psychology: On the dynamics between growth and decline. *Developmental Psychology*, *23*(5), 611-626. https://doi.org/https://psycnet.apa.org/doi/10.1037/0012-1649.23.5.611

Barrett, G. F., & Riddell, W. C. (2019). Ageing and skills: The case of literacy skills. *European Journal of Education*, *54*(1), 60-71. https://doi.org/https://doi.org/10.1111/ejed.12324

Becker, G. S. (1993). *Human capital: A theoretical and empirical analysis with special reference to education* (3rd ed.). The University of Chicago Press.

Bell, A., & Jones, K. (2014). Another 'futile quest'? A simulation study of Yang and Land's hierarchical age-period-cohort model. *Demographic Research*, *30*, 333-360. http://www.jstor.org/stable/26348202

Beller, J., Miething, A., Regidor, E., Lostao, L., Epping, J., & Geyer, S. (2019). Trends in grip strength: Age, period, and cohort effects on grip strength in older adults from Germany, Sweden, and Spain. *SSM - Population Health*, *9*, 100456. https://doi.org/https://doi.org/10.1016/j.ssmph.2019.100456

Benhabib, J., & Spiegel, M. M. (1994). The role of human capital in economic development evidence from aggregate cross-country data. *Journal of Monetary Economics*, *34*(2), 143-173. https://doi.org/https://doi.org/10.1016/0304-3932(94)90047-7

Coulombe, S., & Tremblay, J.-F. (2006). Literacy and growth. *Topics in Macroeconomics*, *6*(2), 1-32.

Cummins, P., Taylor, P., & Kunkel, S. (2015). Working longer, learning longer. *Public Policy & Aging Report*, *25*(4), 120-124. https://doi.org/10.1093/ppar/prv025

Desjardins, R., & Warnke, A. J. (2012). Ageing and skills: A review and analysis of skill gain and skill loss over the lifespan and over time. *OECD Education Working Papers, No. 72*. OECD Publishing. https://doi.org/10.1787/5k9csvw87ckh-en

Elder, G. H. (2018). *Children of the Great Depression*. Routledge.

Evans, W. N., Schwab, R. M., & Wagner, K. L. (2019). The Great Recession and public education. *Education Finance and Policy*, *14*(2), 298-326. https://doi.org/10.1162/edfp_a_00245

Flisi, S., Goglio, V., Meroni, E. C., & Vera-Toscano, E. (2019). Cohort patterns in adult literacy skills: How are new generations doing? *Journal of Policy Modeling*, *41*(1), 52-65. https://doi.org/https://doi.org/10.1016/j.jpolmod.2018.10.002

Goodman, M., Finnegan, R., Mohadjer, L., Krenzke, T., & Hogan, J. (2013). *Literacy, numeracy, and problem solving in technology-rich environments among U.S. adults: Results from the Program for the International Assessment of Adult Competencies 2012: First look*. National Center for Education Statistics. https://nces.ed.gov/pubs2014/2014008.pdf

Green, D. A., & Riddell, W. C. (2013). Ageing and literacy skills: Evidence from Canada, Norway and the United States. *Labour Economics*, *22*, 16-29. https://doi.org/https://doi.org/10.1016/j.labeco.2012.08.011

Hanushek, E. A., Schwerdt, G., Wiederhold, S., & Woessmann, L. (2013). *Returns to skills around the world: Evidence from PIAAC* (Working Paper Issue 19762). National Bureau of Economic Research. https://www.nber.org/papers/w19762.pdf

Hanushek, E. A., Schwerdt, G., Wiederhold, S., & Woessmann, L. (2015). Returns to skills around the world: Evidence from PIAAC. *European Economic Review*, *73*, 103-130. https://doi.org/https://doi.org/10.1016/j.euroecorev.2014.10.006

Hartshorne, J. K., & Germine, L. T. (2015). When does cognitive functioning peak? The asynchronous rise and fall of different cognitive abilities across the life span. *Psychological Science*, *26*(4), 433-443. https://doi.org/10.1177/0956797614567339

Hedden, T., & Gabrieli, J. D. E. (2004). Insights into the ageing mind: A view from cognitive neuroscience. *Nature Reviews Neuroscience*, *5*(2), 87-96. https://doi.org/10.1038/nrn1323

Hox, J. J. (2010). *Multilevel analysis: Techniques and applications* (2nd ed.). Routledge.

Hughes, M. E., & O'Rand, A. M. (2004). *The American people: Census 2000: The lives and times of the Baby Boomers*. Russell Sage Foundation.

International Association for the Evaluation of Educational Achievement. (2016). *Help manual for the IDB analyzer (SAS macros)*. http://www.iea.nl/data

Kalleberg, A. L., & Von Wachter, T. M. (2017). The U.S. labor market during and after the Great Recession: Continuities and transformations. *The Russell Sage Foundation Journal of the Social Sciences*, *3*(3), 1-19. https://doi.org/10.7758/rsf.2017.3.3.01

Kim, S. (2018). Literacy skills gaps: A cross-level analysis on international and intergenerational variations. *International Review of Education*, *64*(1), 85-110. https://doi.org/10.1007/s11159-018-9703-4

Knowles, M., Holton, E. F., & Swanson, R. A. (1998). *The adult learner: The definitive classic in adult education and human resource development* (5th ed.). Gulf Publishing Company.

Kramer, M. R., & Casper, M. (2015). Kramer and Casper respond to "A-P-C … It's easy as 1-2-3!". *American Journal of Epidemiology*, *182*(4), 318-319. https://doi.org/10.1093/aje/kwv049

Masters, R., & Powers, D. (2020). Clarifying assumptions in age-period-cohort analyses and validating results. *PLoS One*, *15*(10), 1-21. https://doi.org/https://doi.org/10.1371/journal.pone.0238871

Mather, M., Jacobsen, L. A., & Pollard, K. M. (2015). Aging in the United States. *Population Bulletin*, *70*(2), 1-21. https://www.prb.org/wp-content/uploads/2019/07/population-bulletin-2015-70-2-aging-us.pdf

Mirowsky, J. (2011). Cognitive decline and the default American lifestyle. *The Journals of Gerontology: Series B*, *66B*(Supplement 1), i50-i58. https://doi.org/10.1093/geronb/gbq070

Murray, T. S., Binkley, M., & Shillington, R. (2016). *Reconstructing the evolution of the American supply of cognitive skills: A synthetic cohort analysis*. American Institutes for Research. https://static1.squarespace.com/static/51bb74b8e4b013957oddf020/t/5788f14c725e2502e4eb5340/1468592461152/Murray_Binkley_Shillington_PIAAC.pdf

National Center for Education Statistics. (2015). *Data files*. https://nces.ed.gov/surveys/piaac/datafiles.asp

National Center for Education Statistics. (n.d.). *History of international adult literacy assessments*. https://nces.ed.gov/surveys/piaac/history.asp

Organization for Economic Co-operation and Development. (2000). *Literacy in the information age: Final report of the International Adult Literacy Survey*. https://www.oecd.org/education/skills-beyond-school/41529765.pdf

Organization for Economic Co-operation and Development. (2011). *PIAAC conceptual framework of the Background Questionnaire main survey*. http://www.oecd.org/skills/piaac/PIAAC(2011_11)MS_BQ_ConceptualFramework_1%20Dec%202011.pdf

Organization for Economic Co-operation and Development. (2013). *OECD skills outlook 2013: First results from the Survey of Adult Skills*. http://www.oecd.org/about/publishing/Corrigendum-OECD-skills-outlook-2013.pdf

Organization for Economic Co-operation and Development. (2016). *Skills matter: Further results from the survey of adult skills* (OECD Skills Studies, Issue. O. Publishing. https://www.oecd.org/skills/piaac/Skills_Matter_Further_Results_from_the_Survey_of_Adult_Skills.pdf

Organization for Economic Co-operation and Development. (2019). *The survey of adult skills : Reader's companion* (3rd ed.). https://doi.org/https://doi.org/10.1787/f70238c7-en.

Paccagnella, M. (2016). *Literacy and numeracy proficiency in IALS, ALL and PIAAC*. OECD Publishing. https://www.oecd-ilibrary.org/content/paper/5jlpq7qglx5g-en

Parkin, A. J., & Java, R. I. (1999). Deterioration of frontal lobe function in normal aging: Influences of fluid intelligence versus perceptual speed. *Neuropsychology*, *13*(4), 539-545. https://doi.org/10.1037/0894-4105.13.4.539

Raudenbush, S. W., & Bryk, A. S. (2002). *Hierarchical linear models: Applications and data analysis methods* (2nd ed.). Sage Publications.

Reder, S. (2020). A lifelong and life-wide framework for adult literacy education. *Adult Literacy Education*, *2*(1), 48-53.

Reder, S., Gauly, B., & Lechner, C. (2020). Practice makes perfect: Practice engagement theory and the development of adult literacy and numeracy proficiency. *International Review of Education*, *66*, 1-22.

Saal, L. K., Yamashita, T., Shaw, D. M., & Perry, K. H. (2020). An exploration of U.S. adults' information processing skills and political efficacy. *Journal of Adult and Continuing Education*, *26*(2), 178-202. https://doi.org/10.1177/1477971419852750

Schleicher, A. (2008). PIAAC: A new strategy for assessing adult competencies. *International Review of Education*, *54*(5), 627-650. https://doi.org/10.1007/s11159-008-9105-0

Schuetze, H. G. (2007). Individual learning accounts and other models of financing lifelong learning. *International Journal of Lifelong Education*, *26*(1), 5-23. https://doi.org/10.1080/02601370601151349

Smith, T. W., Marsden, P., Hout, M., & Kim, J. (1972-2014). *General Social Survey* NORC at the University of Chicago. https://gss.norc.org/

Yamashita, T., & Kunkel, S. R. (2015). An international comparison of the association among literacy, education, and health across the United States, Canada, Switzerland, Italy, Norway, and Bermuda: Implications for health disparities. *Journal of Health Communication*, *20*(4), 406-415. https://doi.org/10.1080/10810730.2014.977469

Yang, Y. (2006). Bayesian inference for hierarchical age-period-cohort models of repeated cross-section survey data. *Sociological Methodology*, *36*(1), 39-74. https://doi.org/https://doi.org/10.1111/j.1467-9531.2006.00174.x

Yang, Y., & Land, K. C. (2006). A mixed models approach to the age-period-cohort analysis of repeated cross-section surveys, with an application to data on trends in verbal test scores. *Sociological Methodology*, *36*(1), 75-97. https://doi.org/https://doi.org/10.1111/j.1467-9531.2006.00175.x

Yang, Y., & Land, K. C. (2008). Age–period–cohort analysis of repeated cross-section surveys: Fixed or random effects? *Sociological Methods & Research*, *36*(3), 297-326. https://doi.org/10.1177/0049124106292360

TABLE 1: Cross-Classified Samples by Periods and Cohorts

Period (Survey year)	Synthetic cohort (5-year)														Column Total
	1930	1935	1940	1945	1950	1955	1960	1965	1970	1975	1980	1985	1990	1995	
1994 (ILAS)	230	260	280	300	320	360	330	290	200	110	0	0	0	0	2670
2003 (ALL)	0	90	240	300	320	380	360	400	370	351	400	60	0	0	3260
2012 (PIAAC)	0	0	0	390	470	520	520	470	500	480	520	490	340	0	4690
2014 (PIAAC)	0	70	380	300	60	90	100	120	120	250	520	480	620	140	3240
2017 (PIAAC)	0	0	80	200	280	360	350	280	300	300	350	310	290	240	3360
Row Total	230	420	980	1490	1440	1700	1660	1550	1490	1490	1790	1340	1260	380	17220

Note: Per the U.S. Department of Education, Institute of Education Sciences restricted use data guideline, the figures were rounded to the nearest 10.

Data source: U.S. Department of Education, National Center for Education Statistics, and Statistics Canada, 1994 International Adult Literacy Survey; 2003 International Adult Literacy and Life Skills Survey; 2012/2014/2017 Program for International Assessment of Adult Competencies, 2012/2014/2017 Restricted Use File Data.

TABLE 2: Weighted Descriptive Summary of the Pooled Samples from IALS, ALL and PIAAC

Measures	N = 17,220[a] Mean (Standard Error) or Percentage
Literacy proficiency (0-500 points)[b]	269.90 (1.32)
Age (years)	41.68 (14.07)
Gender (Female)	51%
Educational attainment (college or higher)	37%
Race and ethnicity	
White	69%
Black	12%
Hispanic	13%
Other	6%
Nativity (U.S. born)	86%

a. Unweighted sample size of the final analytic sample

b. See Figures 1-3 for the mean literacy proficiency by age, period and cohort.

IALS = International Adult Literacy Survey in 1994; ALL = Adult Literacy and Life Skills Study in 2003; PIAAC = Program for the International Assessment of Adult Competencies in 2012, 2014, and 2017

Values represented the weighted mean values between 1994 and 2017.

Note: Original sampling weights and replicate weights in each survey were applied in the IDB Analyzer application (IEA, 2016).

The weighted descriptive summary was rounded per the data security guidelines provided by the National Center for Education Statistics.

Data source: U.S. Department of Education, National Center for Education Statistics, and Statistics Canada, 1994 International Adult Literacy Survey; 2003 International Adult Literacy and Life Skills Survey; 2012/2014/2017 Program for International Assessment of Adult Competencies, 2012/2014/2017 Restricted Use File Data.

The restricted file data use was approved by the Institutes of Education Sciences (IES) Data Security Office.

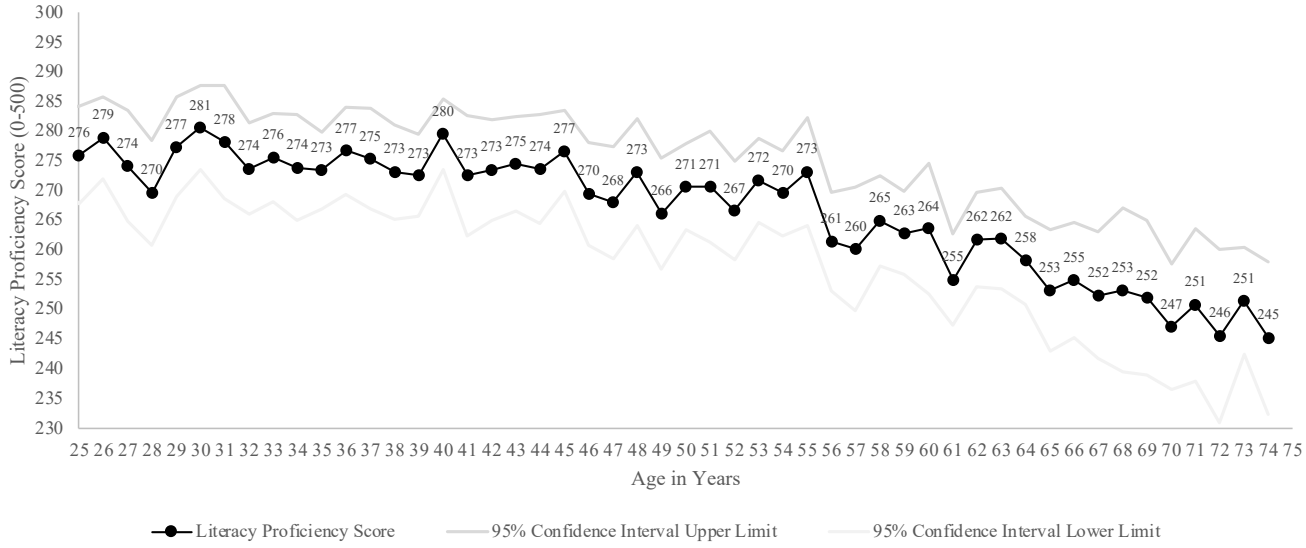
TABLE 3: Estimated Coefficients from the Hierarchical Age-Period-Cohort Cross-Classified Random Effects Models

	Model 1 (Null) Estimate (95% credibility interval)[a]	Model 2 (Base) Estimate (95% credibility interval)[a]	Model 3 (Full) Estimate (95% credibility interval)[a]
LEVEL 1 fixed effects			
Age (years, 10-year increment)		-3.51 (-4.72, -1.14)	-6.33 (-7.06, -5.69)
Age^2		-1.14 (-1.61, -0.68)	-0.57 (-0.95, -0.20)
Gender (Female)			2.44 (1.13, 3.73)
Educational attainment (college or higher)			44.87 (41.51, 44.26)
Race and ethnicity			
White			Reference
Black			-32.53 (-34.43, -30.65)
Hispanic			-29.34 (-34.43, -30.65)
Other			-11.83 (-14.63, -9.11)
Nativity (U.S. born)			28.97 (26.79, 31.17)
LEVEL 2 random effects			
Period	92.60 (18.29, 1614.47)	88.60 (16.88, 1340.31)	13.60 (2.31, 217.39)
Cohort	91.47 (39.42, 257.64)	10.48 (3.25, 35.64)	2.03 (0.21, 9.27)
Residual variance	2717.48 (2660.11, 2777.11)	2712.98 (2656.84, 2770.17)	1854.30 (1815.77, 1894.20)
ICC (and DEFF)			
Period	0.03 (41.56)	0.03 (39.93)	0.01 (9.96)
Cohort	0.03 (113.25)	0.01 (14.26)	0.01 (4.77)
Model fit indices			
Deviance information criterion (DIC)	187453.49	187428.18	178493.60
Posterior predictive probability (PPP)	0.36	0.34	0.39
95% confidence interval for $\Delta\chi^2$	-9.38, 16.66	-10.85, 18.37	-14.00, 21.14

Notes: a. The median and 95% credibility interval from the posterior distribution. ICC = intraclass correlation coefficient. DEFF = design effect.

Data source: U.S. Department of Education, National Center for Education Statistics, and Statistics Canada, 1994 International Adult Literacy Survey; 2003 International Adult Literacy and Life Skills Survey; 2012/2014/2017 Program for International Assessment of Adult Competencies, 2012/2014/2017 Restricted Use File Data.

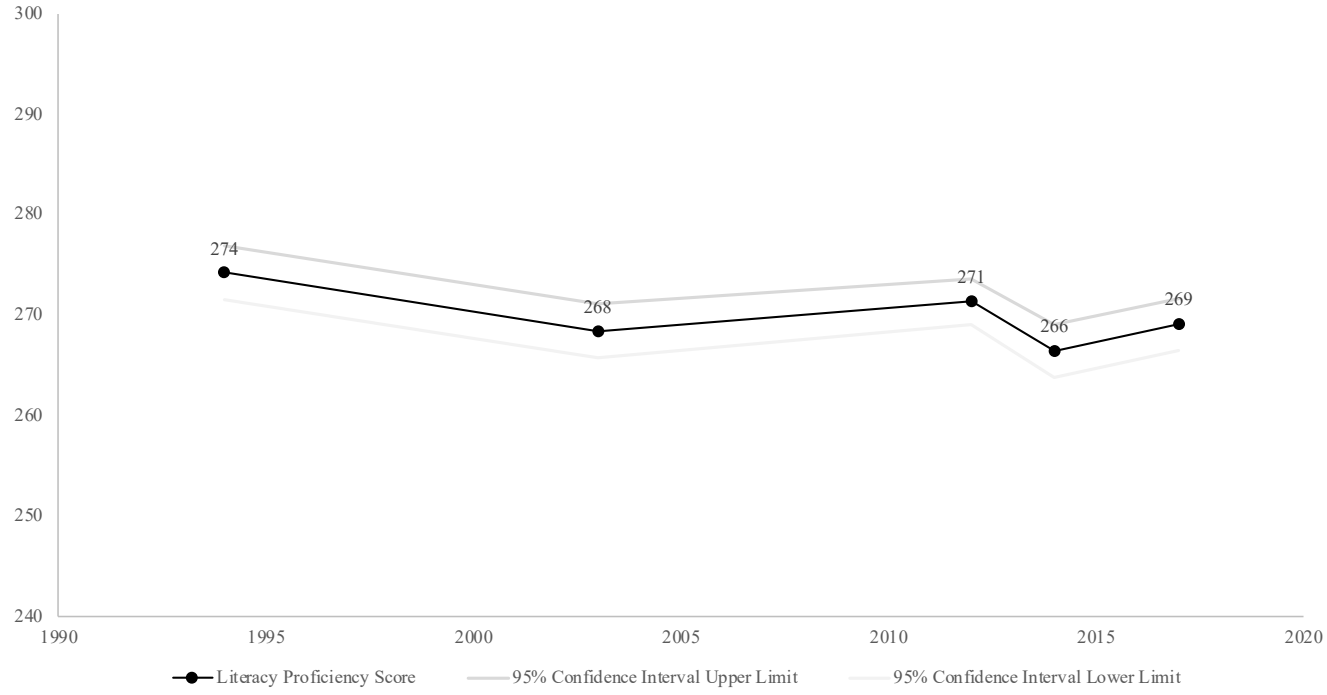
FIGURE 1: Comparisons of Weighted Mean Literacy Proficiency Scores across Age



Note: Values represent the mean literacy proficiency scores between 1994 and 2017.

Data source: U.S. Department of Education, National Center for Education Statistics, and Statistics Canada, 1994 International Adult Literacy Survey; 2003 International Adult Literacy and Life Skills Survey; 2012/2014/2017 Program for International Assessment of Adult Competencies, 2012/2014/2017 Restricted Use File Data. Mean values reflect weighted statistics using supplied sampling weights.

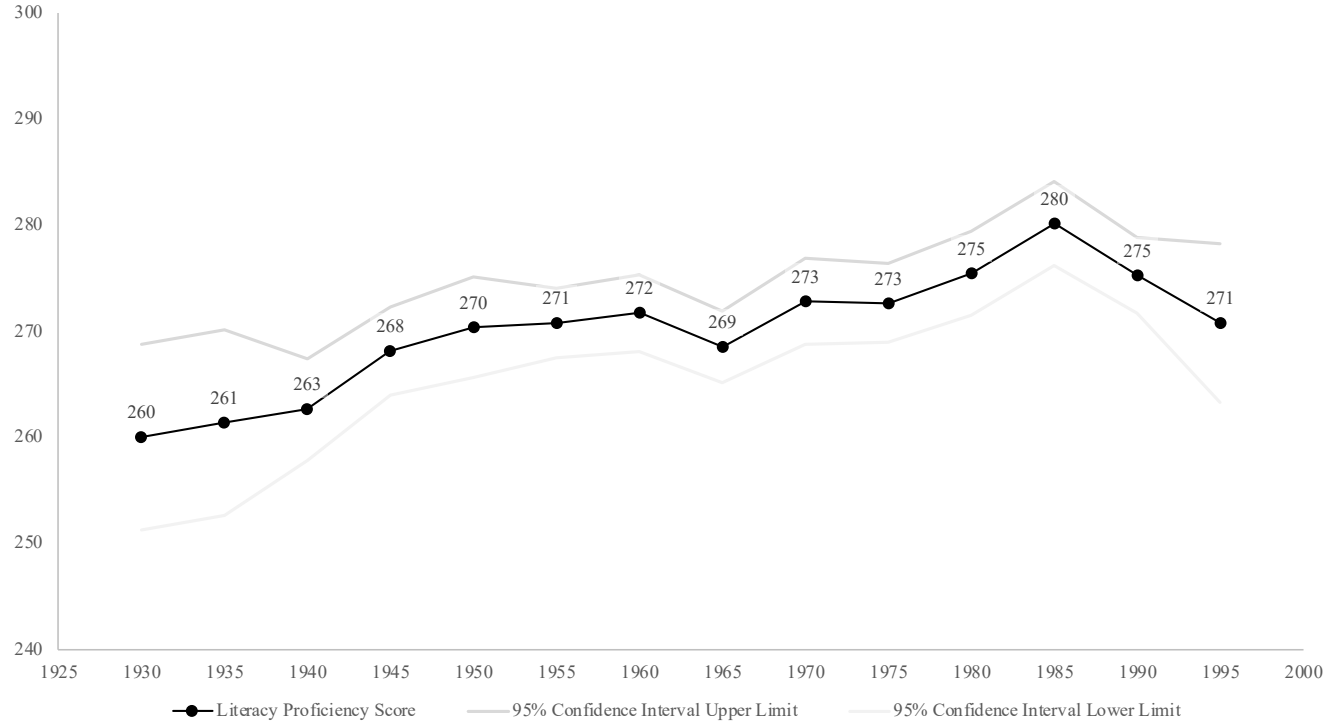
FIGURE 2: Trends of Weighted Mean Literacy Proficiency Scores between 1994 and 2017



Note: Values represent the mean literacy proficiency scores between 1994 and 2017.

Data source: U.S. Department of Education, National Center for Education Statistics, and Statistics Canada, 1994 International Adult Literacy Survey; 2003 International Adult Literacy and Life Skills Survey; 2012/2014/2017 Program for International Assessment of Adult Competencies, 2012/2014/2017 Restricted Use File Data. Mean values reflect weighted statistics using supplied sampling weights.

FIGURE 3: Comparisons of Weighted Mean Literacy Proficiency Score across 5-Year Synthetic Birth Cohorts



Note: Values represent the mean literacy proficiency scores between 1994 and 2017.

Data source: U.S. Department of Education, National Center for Education Statistics, and Statistics Canada, 1994 International Adult Literacy Survey; 2003 International Adult Literacy and Life Skills Survey; 2012/2014/2017 Program for International Assessment of Adult Competencies, 2012/2014/2017 Restricted Use File Data. Mean values reflect weighted statistics using supplied sampling weights.