**Alternative Cognitive Devices and the Lack of Development of Higher Order Thinking Skills, as Measured by the Reduction In Common Measures of Intelligence, Knowledge, and Learning**



in partial fulfillment of the requirements for
Master of Science in Education: Information Technology

The undersigned members of the Graduate Faculty of Western Oregon University
have examined the enclosed Thesis entitled:

**Alternative Cognitive Devices and the Lack of Development of Higher Order Thinking Skills, as Measured by the Reduction In Common Measures of Intelligence, Knowledge, and Learning**

Presented by: © Robert E. Mahoney

A candidate for the degree of
Master of Science in Education: Information Technology

and hereby certify that in our opinion it is worthy of acceptance in partial fulfillment of the requirements for this master's degree.

Date: ________________

Chairperson Examining/writing Committee: ______________________________ Dr. Mary Bucy

Committee member: ______________________________ Dr. David Bucy

Committee member: ______________________________ Dr. Linda Stonecipher

Director of Graduate Studies: ______________________________ Dr. Linda Stonecipher

**Alternative Cognitive Devices and the Lack of Development of Higher Order Thinking Skills, as Measured by the Reduction In Common Measures of Intelligence, Knowledge, and Learning**

# Acknowledgements

I would like to take this opportunity to recognize the invaluable assistance received from the committee chair, Dr. Mary Bucy. Her guidance and assistance in directing me to relevant resources made this undertaking infinitely easier.

Dr. David Bucy provided the impetus to examine the effects of technology as due to a lack of acquired cognition, and for this I shall be forever grateful.

Dr. Linda Stonecipher deserves credit for providing me input and tireless assistance to make this thesis a reality.

Dr. Denvy Saxowsky deserves special recognition for providing exceptional and relevant classes in information technology, and for guiding the many students through the MS Education-Information Technology major.

I would also like to acknowledge my wife, Sharlon and children, Kristin and Megan, who gave up countless family hours to allow successful completion of my thesis.

## Table of Contents

## List of Tables

## List of Figures

## Nomenclature

| | |
|---|---|
| ACD: | *Alternative Cognitive Devices*. Devices such as calculators and spell-check functions that perform a portion of the brain function that was previously performed by the user. |
| Cognition: | The mental process by which humans come to know. |
| Genotypic Intelligence: | That portion of the intelligence of a person that is a direct result of their genetic composition. |
| Phenotypic Intelligence: | That portion of the intelligence that is observable, as a result of the interaction of the genotypic intelligence with the environment. |

## Abstract


**Alternative Cognitive Devices and the Lack of Development of Higher Order Thinking Skills, as Measured by the Reduction in Common Measures of Intelligence, Knowledge, and Learning**



by ©Robert E. Mahoney, 2009
A candidate for the degree of: Master of Science in Education, Information Technology
Western Oregon University
June 13, 2009



Environmental and genetic causes are proposed mechanisms for the rise in measured IQ for each successive generation, commonly referred to as the Flynn Effect. Many developed countries, however, have seen either a reversal or slowing of the gains in IQ. This paper provides a synthesis of research in fields relating to the Flynn Effect, cognition, intelligence, and measures of knowledge, learning, and IQ. It notes that since the early to mid 1990's changes have occurred in such measures, and it provides evidence that a probable environmental factor contributing to said changes is the presence of technology, specifically, Alternative Cognitive Devices. Alternative Cognitive Devices are those that have replaced a portion of the "thinking" process on behalf of the user, such as the "spell-check" function of a computer. The paper further presents evidence that it is feasible that Alternative Cognitive Devices have changed the manner in which cognition occurs, effectively outsourcing some of the process of learning and reducing higher order thinking skills, thereby resulting in changes in the measures of intelligence, knowledge, and learning.

# Alternative Cognitive Devices and the Lack of Development of Higher Order Thinking Skills, as Measured by the Reduction In Common Measures of Intelligence, Knowledge, and Learning

## Introduction

Many view technology, learning, and cognition as inseparable components in today's educational arena. As each new technology is introduced, it is accompanied by the development of ways to integrate it into the curriculum. The introduction of movies, for example, was associated with a move to incorporate them into the curriculum as a means to bring the world into the classroom. The introduction of innovative ideas into a society typically generates questions about how the new technologies affect the general population. Television, for example, created a series of questions regarding the effect on society, the family, and attention span. Many questions, such as the effect of violence in the media (Hetsroni, 2007), still remain. Interpreting the effect of innovative technologies on the general population has, in fact, occurred throughout history. Plato questioned the introduction of writing in his work "*Phaedrus*" as he feared that the written word would diminish the knowledge that people recalled through rhetoric (Churchill, 2003). Given the rapid advances in technology in the last 20 years, it is therefore particularly appropriate to examine the effect(s) of such technological tools on society, and, in particular, on the educational process.

### ***Background***

As an instructor at a high school, I make daily observations regarding student performance. While students may receive an education comparable to or better than prior generations due to the integration of technology into the curriculum, the question arises as to whether today's students perform any better. Casual observation indicates that the current generation of students has poor verbal and math skills, as they are often unable to choose the proper homophone or solve a simple mathematical equation. Given that these observations are of high school students, the widespread misuse of homophones such as “their, they’re, and there” is alarming. Additionally, the inability of students to perform basic mathematical operations without the use of a calculator could be an indicator of a poor mathematical foundation. Such observations, however, are purely anecdotal, and could be a function of the specific demographics of where the observations were made.

Research, however, supports the observations that student achievement is not improving, and to the contrary, is diminishing. For example, SAT scores are declining, and employers report that newly graduated employees lack essential skills (Cocodia, Kim, Shin, Kim, Ee, Wee, & Howard, 2003, p. 798). A report by The National Endowment for the Arts, “*Reading At Risk: A Survey of Literary Reading in America*” notes that “literary reading in America is not only declining rapidly among all groups, but the rate of decline has accelerated, especially among the young” (Bradshaw & Nichols, 2004, p. vii). Researchers are reporting that reading from a digital display results in higher cognitive loads and lower achievement levels (Eshet-Alkalia & Geri, 2007). Others report that video game usage has been negatively associated with SAT scores and GPA (Anand, 2007).

In a recent survey, 35 % of college teachers indicated that the readiness of entering college students has declined in the last several years (Bauerlein, 2008). The print media are questioning whether technology is affecting the way we think, with articles such as “*Is Google Making Us Stupid”* (Carr, 2008). A recent article in the media from the United Kingdom reveals that these declines are not limited to the United States, with an observation that, "employers are becoming more dissatisfied with the basic skills of school leavers, despite their expertise with new technologies" (Phillips, 2007).

It can be argued, however, that it is unfair to judge students by an old standard; that they should be judged by a more contemporary standard, measuring their Information and Communications Technology (ICT) skills. Educational Testing Service (ETS) has developed a test that measures competency in the use of technology. They found that "Few test takers demonstrated key ICT literacy skills" (Educational Testing Service, 2006). For example, when asked to devise a slide to make a persuasive argument, a mere 12% of the students used only points directly related to the argument. In searching the Web for information, only 40% of the test-takers used multiple terms to narrow the search. Therefore, whether by the standard of yesterday or today, the proficiency of students in basic tests is being questioned.

Barnes (1999) concurs with the lack of technological competency noted by the ETS study by stating, "Students frequently do not know where they are, how they got there, and how to find the information they are looking for" (p. 13).

Given the technological changes over the last twenty years, the question arises as to whether alterations in the mode of learning caused by the introduction of technology have negatively influenced the manner in which cognition occurs, thereby modifying student achievement levels. The major difference between the introduction of older technologies, such as television or movies, and those that have occurred over the last two decades is that some of the latter have involved Alternative Cognitive Devices.

### *Statement of the Problem*

Alternative Cognitive Devices (ACD), such as calculators and spell-check functions, are those that perform a portion of the brain function previously performed by the user. Users no longer need to use long-term memory to recall proper spelling or mathematical data. They offer an alternative means of “thinking”, such that the users rely upon the device to perform some of the function(s) that were previously within the scope of the brain functions of the user. Alternative Cognitive Devices have changed the manner in which cognition occurs, effectively outsourcing some of the process of learning. The current study seeks to determine if such alterations in cognition have caused resultant changes in the measures of intelligence, knowledge, and learning.

The scope of this paper is to examine the manner in which the introduction of technologies with alternative cognitive functions influence cognitive development and, thereby, influence the educational process. The question arises as to whether reducing the cognitive processes required of the populace through the use of Alternative Cognitive Devices produces a resultant reduction in the development of higher order thinking skills. If such a supposition is true, the lack of development of higher order thinking skills could manifest itself in a reduction in common measures of intelligence, knowledge and learning.

IQ tests are used as a common measure of intelligence levels, as they compare the participant to a representative sample of his/her peers. IQ tests have to be re-normed periodically due to rising scores with successive generations. This rise in the measures of intelligence is termed the Flynn Effect. To determine the significance of any changes in measures of intelligence, whether negative or positive, one must first understand the

Flynn Effect. If, in fact, Alternative Cognitive Devices impair the development of higher order thinking skills this may, in turn, result in a decrease in common measures of intelligence, or a reversal of the Flynn Effect.

***Purpose of the Study***

This research seeks to examine the relevant literature to determine if technology can be proposed as a factor in any decrease or reversal of the rising trend in common measures of intelligence.

***Theoretical Bases, Organization, and Method***

The primary means of exploring the issue will be through a literature review of material from multiple areas, coupled with a synthesis. The goal of synthesis is to examine studies in allied areas, and bring them together to determine if an overarching relationship is observable, thereby perhaps establishing new theoretical approaches to examining the relevant data. For the purposes of this paper, the areas of study include the Flynn Effect, cognitive development, intelligence, and the role of Alternative Cognitive Devices. Through an extensive analysis and synthesis of the findings of the subject material, the research seeks to establish if sufficient evidence exists to indicate that ACD technologies may hinder the development of higher order thinking skills, thereby modifying measures of intelligence, knowledge, and learning.

***Limitations***

Two major limitations are present within the subject paper. First, the widespread use of Alternative Cognitive Devices such as calculators makes it difficult, if not impossible to perform an experimental study with significant validity. While students under a test situation may be restricted from using an Alternative Cognitive Device, such as a calculator, there is no way to control for the widespread use of such devices in other environments such as the home (Roberts, 1980). Other Alternative Cognitive Devices, such as spell-check or predictive spelling, are in common use in developed countries, which precludes the use of a controlled study as a means to validate the observations and analysis in the current paper.

Secondly, one of the primary data sources used for several of the tables and figures within the subject study was the National Assessment of Educational Progress, commonly referred to as NAEP or the Nation's Report Card. This data source was used because it studies both short and long-term trends in mathematics and reading, and uses a representative sample of the United States school population. The long-term data are compared to prior years as a means to validate the trends. Unfortunately, the long-term data are not gathered every year. As a result, when comparing NAEP test results to possible environmental factors, the NAEP data may have been gathered in a different year than the comparative data under study. This restricted the ability to establish a correlation coefficient, since data for matching dates were unavailable. Given this restriction, the study examines the data from a temporal standpoint by examining long-term test trends and comparing those to the changes in environmental factors over the same period.

***Definition of Terms***

As used in the current study, the term Alternative Cognitive Devices shall refer to devices that perform a portion of the brain function previously performed by the user, such as calculators and spell-check functions. While these devices cannot think, per se, they perform cognitive functions that the user was required to perform prior to their introduction into society. The term Alternative Cognitive Devices may be abbreviated as ACD.

## Review of Relevant Literature

### *The Flynn Effect*

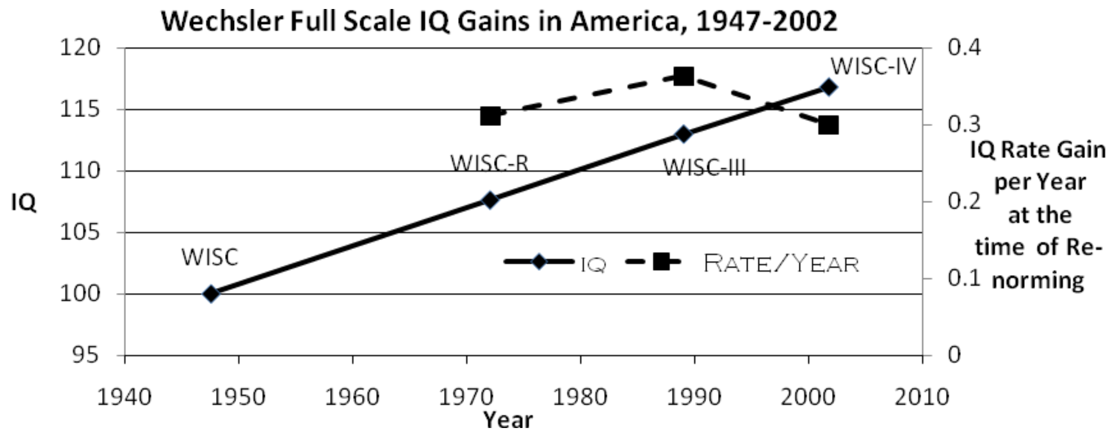
James R. Flynn was a pioneer in performing extensive research on the rise in IQ tests norms, measured between successive generations. The average score on IQ tests is traditionally set at a value of 100. Since "test performance improves from one generation to the next" (Sundet, Barlaug, & Torjussen, 2004, p. 350), new norms must be established periodically. Someone scoring 100 on an IQ test would be at the $50^{th}$ percentile, indicating that their performance was average (Flynn, 2007). Assessing a test participant as being average, however, is accurate only when one compares that score against a representative sample of the population. An IQ score can best be considered as a rank order (Lichten, 2004) since it is a measure of the individual relative to the given population. When norms were reset so that a score of 100 represented the average IQ of a representative population, test participants were noted to score better on the older normed test. The main premise of the Flynn Effect, therefore, is that measured IQ exhibits gains that have occurred over time. Since obsolete vocabulary should cause subsequent generations to encounter additional difficulty on the older tests, any finding that successive generations perform better on the obsolete test norms is not expected (Flynn, 1984, p. 46).

In examining the data, however, Flynn noted that the subjects did better on the older normed tests than the newer tests, regardless of the order in which they were given. Flynn studied the rise in IQ scores through a historical examination of data, as well as through the results of individual participants. When examining individual data, Flynn used as many studies as possible, but excluded those wherein test practice effects may have been an issue due to a close time interval between subsequent tests (Flynn, 1984, p. 31). One method of testing the validity of the observed rise in IQ norms was to examine data on tests given approximately one year apart to the same subjects, using the older normed test and a newer normed test. The one-year interval allowed a sufficient time period to eliminate test practice effects, yet still provided a short enough time interval that measures in intelligence would not change significantly due to maturation.

Flynn's findings in examining historical data and using the method noted above showed that later generations perform better on the measures of intelligence than earlier generations. Conversely, "going from past to present, standardization samples had set higher and higher standards of performance, standards a subject found more difficult to meet" (Flynn, 1987). This trend was subsequently termed the Flynn Effect by Herrnstein and Murray (1994).

Flynn's examination of this phenomenon noted that while the net gains differ from country to country, they are slightly more than 3 percentage points over a decade (Flynn, 1984, 1999; Flynn &Weiss, 2007), until approximately 1990. One of the most commonly used measures of intelligence in the United States is the Wechsler test. Originally developed in 1947, it has been re-normed several times (Flynn, 2007). The original test, the Wechsler Intelligence Scale for Children is commonly referred to as the WISC. The first re-norming, conducted in 1971, is labeled the WISC-R, with the R standing for "revised". The test was again re-normed in 1989 (WISC III) and 2001 (WISC IV). Examination of the WISC data, using 1947 as a baseline, reveals a gain in the measures of intelligence as depicted in the chart on the following page.

*Figure 1. Wechsler IQ test Gains at the time of re-norming, data derived from "What is Intelligence" (Flynn, 2007)*




While the graph shows persistent gains with each re-norming of the test, the rate of gain, as depicted by the broken line has slowed since 1990. The observed IQ gains are greatest in the area of fluid intelligence, tests that measure one's inherent cognitive ability rather than their acquired knowledge. As such, culturally reduced IQ tests, such as Raven's Progressive Matrices, tend to show the greatest gains (Flynn, 1998a, p. 26). Raven's Progressive Matrices consists of a series of images in a matrix. The images show a pattern, such as the progressive rotation of some component, the addition of lines, or the alteration of the shape. One of the images in the matrix is missing and the test subject attempts to complete the missing portion, based upon the alterations in the prior images of the matrix. Given that Raven's Progressive Matrices do not rely upon language as a measure of IQ, it is considered a culturally reduced test, and a better test of one's inherent cognitive ability (fluid intelligence) rather than their acquired knowledge (crystallized intelligence). Research also shows that the rise in test scores extends to numerical knowledge. Bocéréan, Fischer, and Flieller (2003) conducted a long-term comparison of 3 to 5 ½-year-olds, and found that when cohorts from 1921 were compared to those from

2001, those in successive generations generally performed better on number evaluation tasks than those from earlier generations.

The presence of the Flynn Effect, however, poses a significant paradox. If one accepts the premise that IQ gains of approximately 3% occur every decade, then the implication is that our ancestors must have been mentally impaired. If one extrapolates backward and instead assumes a 3% loss in IQ for each prior generation, ancestors should have a lower IQ. If one extends this line of reasoning back several generations, the ancestors could be considered mentally impaired as their IQ would be below the threshold for intellectual disability (Flynn, 2007, p. 10). Clearly, our ancestors were not mentally impaired as they were able to function successfully in society. The explanation lies in the type of material that is the subject of IQ tests. Tests such as Wechsler Similarities, one of the subtests of the Wechsler IQ test series and Raven's Progressive Matrices rely on the ability to categorize information in a manner consistent with "post-scientific operational thinking" (Flynn, 2007). Flynn provides an example, by noting that Americans in 1900 would be more likely to say that dogs are for hunting rabbits, as opposed to categorizing them as mammals. Categorization is a by-product of post-industrial scientific thinking, which often uses abstraction, rather than concrete referents. Knowledge, as viewed from the perspective of someone in 1900, was not trivial, but was based upon what was essential to live productively. The rise in IQ scores over time does not indicate that our ancestors were mentally impaired; rather it represents "the liberation of the human mind" (Flynn 2007) over time. The rise in IQ norms is a symbol of the post-industrial switch from concrete referents to the abstract. Our daily routines and schooling are a reflection of a switch to an abstract manner of thinking that differs greatly from that of our ancestors. Schooler (1998) described the relationship between the person and the environment as being one in which the "environment rewards cognitive effort" (p. 74), and as such, individuals should be inclined to improve their intellectual capacity. Conversely, one can argue that the gains in intelligence are valid indicators of a true rise in intellectual operations of the population, caused by the environmental complexity.

***Societal Significance of Changes in the Flynn Effect***. The Flynn Effect and any changes in its rate have considerable legal, ethical and funding ramifications. For example, those that are mentally impaired are not considered able to properly understand the intent or implications of a wrongful act, and therefore are not subject to the same sanctions as other citizens. *The Flynn Effect and U.S. Policies, The Impact of Rising IQ Scores on American Society Via Mental Retardation Diagnoses* (Kanaya, Scullin, & Ceci, 2003) notes that decisions regarding capital cases often revolve around whether the defendant is significantly mentally impaired (generally considered to be an IQ under 70). Yet, the assessment of an IQ of 70 is largely a function of what norm is in use at the time the subject is tested. In other words, someone could be put to death, because of a conviction, when, in reality, they could be considered mentally impaired if the proper norm had been used. The study notes, "…fluctuations in IQ scores as a result of aging norms being replaced by new harder norms could have unexpectedly large public policy implications" (p. 780). Flynn addresses this issue in much of his literature, even entitling a chapter "IQ Gains Can Kill", in his book, "*What is Intelligence*" (Flynn, 2007). In fact, the Fourth Circuit Court of Appeals of the United States notes in *Walker vs. True* (2005) that the Flynn Effect needs to be considered when making a determination of mental retardation, based upon IQ tests.

The Flynn Effect has other far-ranging ramifications, including which students qualify for special education services and the related funding. In fact, during the period from 1947 to 1999, the percent of the population classified as “mentally retarded” fluctuated from 1:23 to 1:213. This fluctuation was largely a result of the timing of when the participants were given the test, relative to any re-norming (Flynn, 2007).

Applicants for Social Security benefits in the United States are also affected by the re-norming of IQ tests. Those applicants who receive benefits based upon a mental impairment are judged according to tests that may or may not be accurate for their generation, depending upon when the test is normed. Because the Flynn Effect and any changes or reversals in it have substantial consequences for many aspects of society, it is therefore particularly relevant to examine if Alternative Cognitive Devices are modifying the thinking processes of the general population, and thereby are modifying the rate of IQ gain.

***Commonly Cited Reasons for the Flynn Effect.*** Various reasons are frequently postulated for the apparent gain in the measures of intelligence, as calculated by a rise in IQ norms. Intelligence is largely influenced by genetics and the environment (Singh, 1996). The genetic component, however, is insufficient to account for the degree of observed change between successive generations (Dickens & Flynn, 2001; Flynn, 1987, 2007; Nettlebeck & Wilson, 2004; Rowe & Rodgers, 2002). Therefore, extensive research has been conducted examining probable environmental causes.

During the time interval initially studied by Flynn, 1932-1978, there was a concurrent growth in the body height of people (Malina, Bouchard, & Bar-Or, 2004, p. 671). Increased nutrition is one of the reasons often posited for this growth in body size.

Increased nutrition in later born individuals would result in increased brain size and this, in turn, could result in increased cognitive abilities (Storfer, 1999, p. 186). Mingroni (2007) provides an excellent summary of other common explanations that have been proposed for the Flynn Effect, including improvements in medical care and education, changes in test-taking attitudes (Brand, 1990), test practice effects, and the role of smaller families (Zajonc & Mullaly, 1997). Increased cognitive stimulation due to period-related environmental influences, such as television and other media, have also been suggested (Rönnlund & Nilsson, 2008). As noted previously, Flynn proposes that a shift to a post-industrial society has caused a resultant change from concrete to abstract reasoning among the population.

While increased nutrition initially appears as a viable cause of the Flynn Effect, it is not as probable when one carefully examines the issue. Flynn (2007) argues that while there were substantial gains in nutrition levels in the United States in the 20th century, he is skeptical that it has significantly contributed to IQ gains since 1950. He makes a convincing argument that most of the nutritional changes since 1950 have involved prenatal care. Changes in prenatal care and nutrition would not significantly affect IQ gains, as there would be corresponding increases in mentally impaired children born that subsequently survive due to such positive advances in society. Additionally, the prevalence of "junk food" in contemporary society brings into question whether today's diet is superior to that of 1950.

In a chapter of "*The Rising Curve, Long Term Gains in IQ and Related Measures*", Martorell (1998) notes that most of the nutritional deficits that would impair cognition have vanished in the United States and Northern Europe. He further observes that the nutritional components that would affect cognition, such as iodine deficiency and anemia were overcome in the period from 1850 to 1960. Therefore, any additional rises in the measures of IQ are not likely to be attributable to nutrition.

An even more powerful reason to reject the nutrition hypothesis involves those who were subject to the Dutch Famine of 1942, caused by the hoarding of food supplies by German troops during World War II. "Yet, they do not even show up as a blip in the pattern of Dutch IQ gains" (Flynn, 2007).

The Brand Hypothesis (Brand, 1987) proposes that society has become more permissive and that this has modified the test-taking attitudes of participants on timed tests. Whereas earlier generations were scrupulously detail-oriented, later generations are more likely to be more liberal and willing to guess when an answer is unknown. Evidence, however, has disproven this suggested causal relationship (Flynn, 1998). Culture-free tests, such as Raven's Progressive Matrices, do not involve issues of "right or wrong by guessing but by mastering or not mastering rules that govern the orderliness of the matrix" (p. 43). Success in Raven's Progressive Matrices involves selecting the next logical step in the matrix through examination and analysis, and is not likely to be influenced by someone's willingness to guess.

Improvements in medical care are likely to follow the same line of reasoning as that suggested for nutrition. There is likely to be a concomitant rise in mentally impaired individuals surviving due to better care that could offset any gains due to medical care. This could create a relative state of equilibrium in the IQ of the general population.

Smaller families, improved familiarity with test-taking and cognitive stimulation due to environmental influences, such as television, fall under a broader umbrella of societal changes due to technology. Initially smaller families do not appear to be caused by technological change, until one considers the likely effects of contraception, including the birth control pill. Flynn (2007) touches on the contribution of societal-technological changes when discussing IQ gains in noting, “Formal education played a proximal causal role but a full appreciation of the causes involves grasping the total impact of the industrial revolution” (p. 176).

Patricia Greenfield (1998) also identifies technology as one of three components that she terms ecocultural changes that are interwoven to account for much of the gain in IQ scores. The other two components are urbanization and formal education. Yet, the latter two components are also subject to and therefore modified by technological advances.

Given the apparent significance of the technological revolution to measures of intelligence, any variations in the rate of change may be traceable to the prevalent technology surrounding the time of the change.

Despite the apparent significance, few have studied the effect of technology on the modification or reduction of measures of intelligence. Many authors have stated that technology is detrimental to the proper intellectual development of students, leading to social isolation (Postman, 1993) and the lack of an experiential framework (Healy, 1990, 1998). Yet, while such studies discuss technology as being detrimental to students, they lack any hard data on which to base their assertions.

The introduction of technology has resulted in unintended side effects, such as the reduction in reading for pleasure (Greenfield, 1998) which could serve to modify the learning patterns of students, and thereby also modify measures of intelligence that are affected by environmental influences.

Like Healy's observations regarding the lack of an experiential framework, Weizenbaum's *Computer Power and Human Reason: From Judgment to Calculation* (1977) makes a powerful statement that technologies provide a detachment from direct experience. He further elaborates on this by providing the clock as an example of a technology that serves to regulate man's measure of time while actually disassociating him from the direct experiences of the sun rising or the crowing of a rooster. Many technologies, while assisting man, remove the experiences by which we acquire knowledge. Weizenbaum's book, written in 1977 at the forefront of the current technological revolution, provides a relevant warning, that a teacher "must teach the limitations of his tools as well as their power" (p. 277). Postman compares technology to a Faustian bargain, noting, "For every advantage a new technology offers, there is a corresponding disadvantage" (Postman, 1995, p. 192).

Bearing the above in mind, an examination of technology and its role in the process of cognition is appropriate.

***Technology, Cognition and Knowledge***

The link between technology and cognition is pervasive. The manner in which we learn, or fail to learn, is regulated by the prevalent technology. Prior to the widespread use of print medium, for example, people learned from an oral tradition. Stories were passed from generation to generation through the spoken word. With the advent of the printing press, it became possible for thoughts and ideas to become widely distributed. The primary means of learning switched from an oral tradition to a review of written material, whether reading primers or the great classics. With the technological move from an oral tradition to the written word, many of the stories of those who did not know how to write were lost. The shift created by the technology changed not only the manner in which information was passed on and learned, it also changed the nature of what was passed to the succeeding generation(s). Given the close alliance between the predominant technology of any given era and the manner in which learning occurs, the relationship between current technologies and cognition is a crucial area to examine.

The link between technology and cognition, however, does not always have favorable consequences. Bauerlein (2008) suggests, “the abundant material progress in an adolescent’s life hasn’t merely bypassed or disengaged him or her from intellectual progress, but has, perhaps, hindered it” (p. 36). If this is truly the case, then an understanding of the manner in which technology and cognition are integrated is required.

The rapid technological changes of recent years have required rethinking about the manner in which cognition occurs. Distributed cognition and activity theory provide a contemporary means by which to examine the effects of technology, as both concepts view technological innovations as societal tools. “A portion of the cognitive power used by an individual resides in artifacts or tools created by the larger society” (Gilbert, 1999). Given this perspective, the tool, person, and society share reciprocal roles in interacting with each other to form the basis of cognition. Within this framework, written discourse, mathematical notation, and even computers are viewed as cognitive tools (p. 252). An examination of mathematical notation can demonstrate the societal influence on cognition. In order to be effective, algebraic symbols need to be universally recognized, so that others may interpret your results. Symbolic representation of a math problem does not rest solely within the brain of the person performing the calculation. It is not simply a matter of coming to a realization through cognitive processes, rather, the symbolic math representation is a technological tool used as a means to cognition *within the societal context*.

Viewed in this manner, technological tools can be seen to have ramifications for both the individual and the society. Positive benefits can occur when the tool is used as a society intends, as this results in a reduction of ambiguity and a concurrent understanding shared by the individual and the society.

It should be noted, however, that societal tools can have negative consequences for both the individual and the society. Gilbert (1999) notes that the computer, a societal tool, can have negative outcomes, as students may fail to develop reflective skills, develop useless skills, and become over-reliant on the "authority" of the computer. Of particular concern is that the use of computers can have the unintended consequence of reducing human abilities (p. 254). This line of thinking is mirrored by Salomon (1998), who notes, "there is a danger of intellectual shallowness" (p. 8). Salomon lists other "distal effects" of technology, including the danger of information overload, thinking in non-associative fragmentary ways, and a devaluation of information.

Dr. Gary Small, author of *iBrain, Surviving the Technological Alteration of the Modern Mind*, discusses how the brain is actually modified by the use of technologies. He notes that individuals develop new neural networks in response to the various stimuli received by the brain. As such, the brain provides an "organizational framework" or series of shortcuts to help it sort additional incoming data. Dr. Small provides an example that serves to both illuminate the purpose of neural networks and inadvertently provides a warning about the dangers of technology interfering with cognition. According to Small (2008), “Young children who have learned their times tables by heart no longer use the more cumbersome neural pathway of figuring out the math problem by counting on their fingers or multiplying on paper” (p. 6). The inadvertent warning involves those students that fail to learn their multiplication tables who would then lack the development of the noted neural pathways. If the technology of the calculator has made such a task appear to be obsolete from the perspective of the student, then it is feasible that such neural networks may not be established. Students lacking the declarative knowledge of multiplication facts would be hard pressed to implement the appropriate procedure for mentally multiplying two numbers.

Declarative knowledge is that which someone learns and “knows”, while procedural knowledge is knowing how to do something (Shavelson, Ruiz-Primo, & Wiley 2005; tenBerge, 1999). Failing to learn multiplication tables due to reliance on the calculator performing the cognitive function would ultimately reduce the declarative knowledge of the product of two numbers. It is likely, however, to increase the declarative knowledge of the functions of the calculator. Therefore, when students need to access neural pathways for multiplication of two numbers, they are non-existent, or modified into pathways that do not represent multiplication facts, but rather pathways that represent the functions of the calculator.

Anderson, Matessa, and Lebiere (1997) make strong arguments that procedural knowledge relies upon declarative knowledge. While there may be examples of patients with anterograde amnesia that can learn a procedural process without being able to recall the underlying declarative knowledge (tenBerge, 1999), in most instances "procedural knowledge basically specifies how to bring declarative knowledge to bear in problem solving" (Anderson, 1997). In defining his Adaptive Character of Thought-Rational (ACT-R) process, Anderson (1996) makes it clear that the rules established in procedural knowledge can only be applied when the underlying declarative knowledge is present (p. 356).

Therefore, the question arises as to how the procedural knowledge can function when the related declarative knowledge is not fully developed or available because of over reliance on the "thinking" components of the prevalent technology. If a technology user fails to develop neural networks for the declarative knowledge of multiplication tables, then one is hard pressed to explain how the procedural knowledge of how to mentally multiply can be as effective without the use of the assistive technology.

Given that technologies can have unintended negative consequences on cognition, a brief examination of the genotypic and phenotypic components of intelligence, and the role that they play in the Flynn Effect and cognition, is required.

***Phenotypic and Genotypic Intelligence***

Lynn and Harvey (2008) examined the Flynn Effect from the perspective of genotypic and phenotypic intelligence. They propose that genotypic intelligence, that portion which is attributable to genetic causes, has been declining. In contrast, phenotypic intelligence, or that intelligence which is manifested and thereby measurable, has been rising. The phenotypic intelligence is caused by a combination of genetics and the overlay of environmental factors.

In order to understand the significance of each component of intelligence, when examining the Flynn Effect, one needs to also explore the issue of differential birth rates and IQ. As early as 1927, Lentz noted a negative association between intelligence and the number of siblings. Those with higher intelligence, as measured by standardized IQ tests, had fewer children than those with lower IQs. He described it as “an inverse relationship between size of family and IQ” (Lentz, 1927). More recent studies (Lynn & Harvey, 2008; Lynn, 1998b; Herrnstein & Murray, 1994) have shown that this pattern persists. In fact, the study by Herrnstein and Murray determined that women in the United States with an IQ of 111 have an average birth rate of 1.6 children, while those with an IQ of 81 had 2.6 children. Flynn (2007) notes that those with higher educational levels of achievement have fewer children than those with less education. When discussing these issues, some persons make an erroneous assumption that lower intelligence causes a person to reproduce more frequently, when in reality the likely cause of the differential birth rates is a societal imbalance to services such as contraceptives. Martin (1995) suggests that women with higher education traditionally have more reproductive choices. Given that the numbers do indicate a differential birth rate, however, the implications are that intelligence in the general population should be decreasing, since intelligence is partially hereditary (Jensen, 1998; Plomin & Spinath, 2004). Neisser (1998) states that the heritability for IQ is between 0.40 and 0.80, as measured by test scores among white Americans (1.00 means that genes account for all of the heritability, and a value of zero means that there is no genetic component). It is hypothesized (Lynn, 1996; Herrnstein & Murray, 1994; Lentz, 1927; Lynn & Harvey, 2008) that the larger pool of lower intelligence in the population should, over time, causes a decline in the intelligence levels of the general populace. The Flynn Effect, however, stands in stark contrast to those expectations, *unless* one considers the contribution by genotypic and phenotypic intelligence.

Lynn and Harvey (2008) propose that genotypic intelligence is actually decreasing, as expected, due to the negative association with the number of siblings and IQ, and that this is masked by the rise in measures of intelligence attributable to environmental improvements (the Flynn Effect). They further propose that when the impact of the environmental conditions is exhausted, phenotypic intelligence will decline, thereby allowing the genotypic decline to manifest itself. Any changes in the rate of the Flynn Effect could therefore be an indicator of the genotypic decline noted above. If the environment were such that it no longer supports a rise in the phenotypic intelligence, then the genotypic decline would become prevalent.

If the current technologies no longer support a rise in phenotypic intelligence, then there should be a change in the rate of the Flynn Effect, or even a decline in the measures of intelligence. Even if someone is not an advocate of the genotypic intelligence hypothesis, any reversal or change in the rate of the Flynn Effect is significant due to the societal ramifications for areas such as law, education and technology.

### ***Cessation or Reversal of the Flynn Effect***

The significance of the Flynn Effect to the present study is that the increase in IQ norms for each subsequent generation held true until very recently. Research has noted that the Flynn Effect has halted and/or reversed in certain areas. Teasdale and Owen (2005) examined the intelligence tests of 500,000 Danish conscripts from 1959 to 2004.

They noted that the decades from 1959-1969 and 1969-1979 saw 3 percentage point gains. This rate of gain slowed to 2 percentage points in the decade from 1979 to 1989, and then slowed to the point of no gain by 2000. The Danish conscript data are derived by comparing scores against the mean and standard deviation of a 1959 baseline. The test that was administered to the men is called the Borge Priens Prove (BPP), and it consists of a verbal component, a geometric component, a subtest involving number sequences, and a matrix subtest similar to the Raven's Progressive Matrices (p. 838). Sundet, Barlaug and Torjussen (2004) had similar findings when examining the IQ records of conscripts from Norway from the mid 1950s to 2002. Sundet, et al. noted a decreasing rate of gain in measures of intelligence, which came to a stop in the mid 1990s. Emmanuelsson, Reuterberg and Svensson (1993) performed a comparative study of groups of Swedish 13-year-olds tested from 1960 to 1990, and noted that verbal test scores rose until 1980, whereupon they reversed. Additional studies in Britain and Australia (Shayer, Ginsburg & Coe, 2007; Shayer, 2008; Cotton, Kiely, Crewther, Thomson, Laycock, & Crewther, 2005), have shown that the Flynn Effect is either ceasing or slowing in other economically developed countries.

Yet, the decline of the Flynn Effect is not as great in the lower socio-economic groups, including countries that are not as economically developed. Teasdale and Owen (2005) noted that those in the developing countries are still subject to the Flynn Effect. Research in rural areas of Kenya (Daley, Whaley, Sigman, Espinoa & Neumann, 2003) shows that the Flynn Effect has not slowed. Those in developing countries, where the Flynn Effect still has significant gains, do not have access to the same level of technology as residents of developed countries. This overlaps the same population identified by

Czaja, Charness, Fisk, Hertzog, Nair, Rogers, et al. (2006), who noted, "the use of computers and the Internet is lower among older adults, minorities, disabled people, and those with less income and education".

Given that populations with less exposure to technology have not seen the same reversal in the Flynn Effect that has been experienced by developed countries, it is feasible that technology may act as an environmental factor altering the rate of gain in developed countries.

The recent declines or reversals in the Flynn Effect for developed countries may indicate that the environmental factors within those countries have reached a stage wherein they fail to support improvement in the phenotypic intelligence, thereby allowing the genotypic intelligence to manifest itself.

While many environmental factors have been proposed as contributing to the development of intelligence, a pervasive environmental factor in the last 60 years has been the introduction of technology. Aspects of technology underlie many of the suggested environmental factors, whether improvements in medicine or greater cognitive development due to the visual-spatial presentation of information in the media. It is therefore reasonable to examine the role of technology in being a factor in the reversal of the Flynn Effect in some developed countries. One of the more prevalent changes in technology that is likely to influence phenotypic intelligence is the development of Alternative Cognitive Devices (ACD).These are devices that assist the user in the thinking process, such as calculators, spell-checkers, and computers. The question arises, however, if the use of such devices results in a lack of development of the cognitive processes of individuals, thereby limiting the ability of the user to develop higher order thinking skills.

***Decline in Other Measures of Intelligence, Knowledge, or Learning***

Other measures of intelligence, such as SAT scores, show the same downward trend as IQ scores. Patricia Greenfield and her colleagues report the decline of verbal SAT scores are the result of modern technology, such as the television, telephone, and e-mail (Greenfield, 1998). SAT scores, however, are not as valid to use as measures of population intelligence or knowledge, because the pool of students is self-selected and does not represent the general population (Neisser, 1998, p. 19). David Grissmer (2000) attributes the decline in SAT scores as being the result of a change in the pool of students taking the test. Whereas the test used to be taken by an elite set of students, it is now estimated that over 40% of high school students take the SAT. The inclusion of students with lower cognitive abilities in the pool of students would serve to lower the overall scores, when comparing score trends over time, according to research conducted by D.A. Rock (1987). Rock attributes the bulk of the change in SAT scores, however, to changes in student behavior and school processes, such as taking less laboratory and foreign language courses.

Greenfield (1998) finds that the rise in forms of communication, such as e-mail and the telephone, has resulted in a decrease in other forms of communication, such as letter writing. The context in which verbal expression occurs has changed from the decontextualized language used in literary works to the contextualized language used with television, telephone, and e-mail. According to Greenfield, such a change explains the decrease in Verbal SAT scores (p. 117).

Hauser (1998) explains that SAT scores lack validity as social indicators because the test takers are self-selected and said selection varies disproportionately over time. He also notes that changes in college admissions policies, geographic origin, sex, and minority status of the test-takers are not uniform, and therefore comparisons over a time interval are not appropriate.

Additionally, in recent years, the addition of the writing component to the SAT has required that participants take additional time to complete the test. This can lead to possible fatigue effects that would modify the comparative significance of the scores. Given the possible confounding variables noted above, the SAT score is not necessarily an indicator of inherent population intelligence or knowledge, but rather it is an indicator of the current societal-educational environment.

Yet another possible affirmation of the decrease in cognitive abilities involves the decline in textbook difficulty. Hayes, Wolfer and Wolfe (1996) note that the mean level of reading difficulty of today's $6^{th}$-$8^{th}$ grade readers is simpler than a $5^{th}$ grade reader before World War II. Sentence structures within textbooks have been simplified, shortening them to an average length of fourteen words, from twenty words prior to 1945. Hayes, et al. suggest that there may be a correlation between the change in textbook difficulty and the reduction in SAT scores, but they further note that there exists inadequate data to establish a causal relationship.

SAT scores may lack validity as indicators in the rate of change in the measures of intelligence, knowledge, and learning. Information on textbook difficulty lacks significant numerical data to measure changes in the noted areas. Therefore, an analysis of other measures was conducted, specifically the math and verbal abilities of students, as measured by the National Assessment of Educational Progress (NAEP).

**Analysis**

The evaluation of long-term trends in measures of intelligence, knowledge or learning was performed by examining IQ scores and other measures. As noted in Figure 1 of this paper, the rate of gain in IQ scores has decreased in the United States since the mid-1990s. Elbert Russell (2007) examined the effect of this change in the rate and predicts that the Flynn Effect will plateau or cease in the United States by the year 2024. IQ tests, however, are not normed to the full population, as they traditionally exclude those with head trauma, drug or alcohol dependence, or other conditions that would otherwise contribute to a reduction in the measured IQ of the populace. According to Russell, if IQ tests were normed to include the above population, it may indicate that the Flynn Effect has already come to a halt in the United States. Comparable changes or reversals in the Flynn Effect have also been noted in other countries, as noted in the prior section. An evaluation was performed to see if similar changes or reversals were present in areas other than IQ test norms, such as measures of knowledge or learning.

The National Center for Education Statistics (NCES), Institute of Education Sciences provides a regular evaluation of high school students in the United States in the area of reading and mathematics. Conducted by the United States Department of Education, the report is known as the National Assessment of Educational Progress (NAEP), but is commonly called the Nation’s Report Card. One of the evaluations performed by NAEP is called Long-term trends. Similar data are used year to year to assess long-term trends that would not be affected by changes in curriculum. The data gathered therein were evaluated as a portion of this analysis.

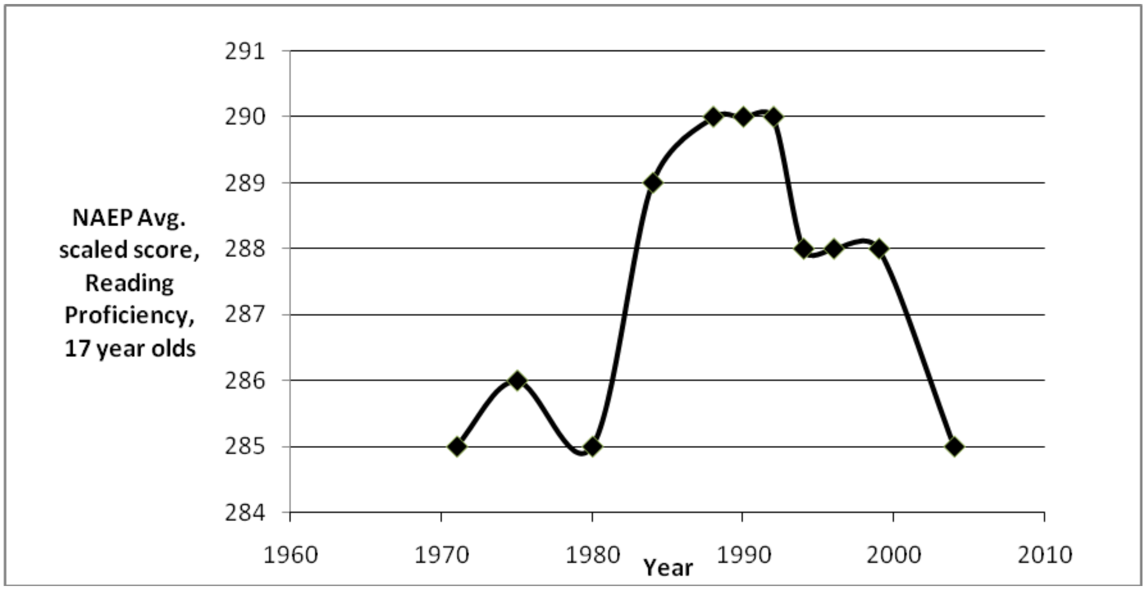
The following data regarding reading proficiency of 17-year-olds were obtained by using the NAEP Data Explorer. (http://nces.ed.gov/nationsreportcard/naepdata/):

*Table 1. Average National Assessment of Educational Progress (NAEP) Scaled Scores for long-term trend reading, age 17, by year and race*

| Year | White Reading Score | Black Reading Score | Hispanic Reading Score | Other Reading Score | All Students |
|---|---|---|---|---|---|
| 2004 | 289 | 262 | 267 | 291 | **283** |
| 2004 | 293 | 264 | 264 | 286 | **285** |
| 1999 | 295 | 264 | 271 | 290 | **288** |
| 1996 | 295 | 266 | 265 | 281 | **288** |
| 1994 | 296 | 266 | 263 | 287 | **288** |
| 1992 | 297 | 261 | 271 | 287 | **290** |
| 1990 | 297 | 267 | 275 | 290 | **290** |
| 1988 | 295 | 274 | 271 | 290 | **290** |
| 1984 | 295 | 264 | 268 | 284 | **289** |
| 1980 | 293 | 243 | 261 | 280 | **285** |
| 1975 | 293 | 241 | 252 | 274 | **286** |
| 1971 | | | | | **285** |

A quick examination of the last column of the above table indicates that the average scaled score for reading for all students peaked in 1992, and has been declining since that time. Plotted graphically, the NAEP data show the downturn in reading scores for 17-year-olds since approximately 1992.

***Figure 2. Average National Assessment of Educational Progress (NAEP) Scaled Scores for long-term trend reading, age 17, by year***




This data correspond with the observations of the National Assessment of Adult Literacy (2003), which examined, among other things, the literacy of graduating college students. In 1992, 40% of college graduates reached proficiency in reading prose, as opposed to only 31 % in 2003. The same report noted that 37% of 1992 college graduates were proficient in reading documents, as opposed to only 25% in 2003. Given the above data, the question arises as to why the reading levels should have peaked in 1992 and decreased since that time.

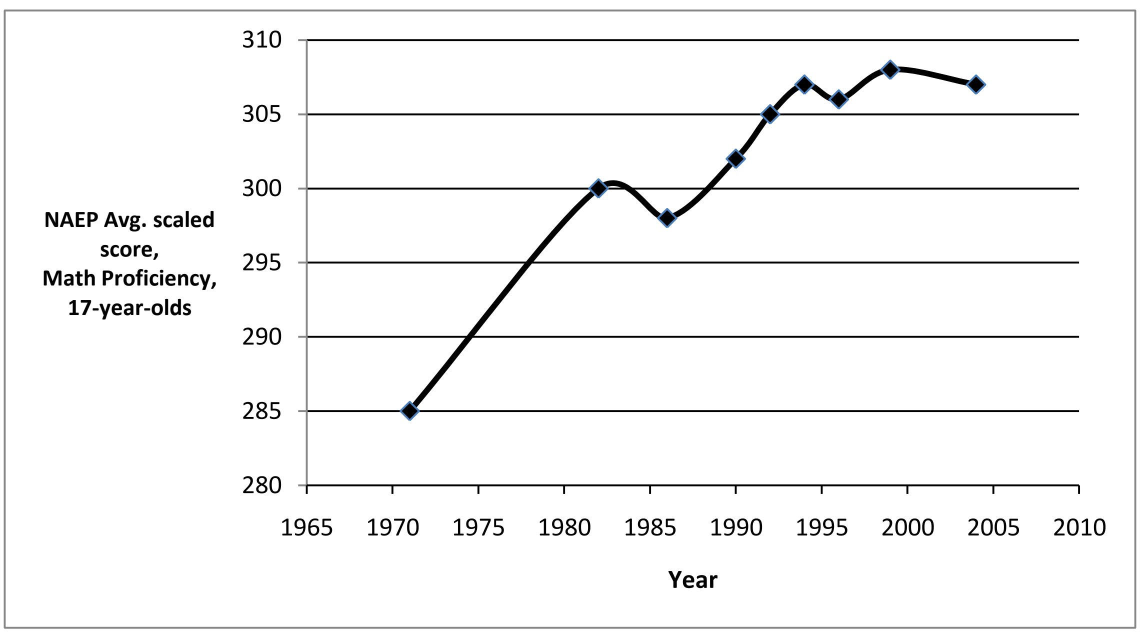
A similar analysis was conducted on the math proficiency of 17-year-olds by examining NAEP long-term trends in mathematics. The following data regarding mathematics proficiency of 17-year-olds were obtained by using the NAEP Data Explorer. (http://nces.ed.gov/nationsreportcard/naepdata/):

*Table 2. Average National Assessment of Educational Progress (NAEP) Scaled Scores for long-term trend mathematics, age 17, by year and race.*

| Year | White Math Score | Black Math Score | Hispanic Math Score | Other Math Score | All Students Math Score |
|---|---|---|---|---|---|
| 2004 | 313 | 285 | 289 | 320 | **307** |
| 1999 | 315 | 283 | 293 | 320 | **308** |
| 1996 | 313 | 286 | 292 | 312 | **306** |
| 1994 | 312 | 286 | 291 | 313 | **307** |
| 1992 | 312 | 286 | 292 | 317 | **305** |
| 1990 | 309 | 289 | 284 | 312 | **302** |
| 1986 | 308 | 279 | 283 | 305 | **298** |
| 1982 | 304 | 272 | 277 | 309 | **300** |
| 1971 | | | | | **285** |

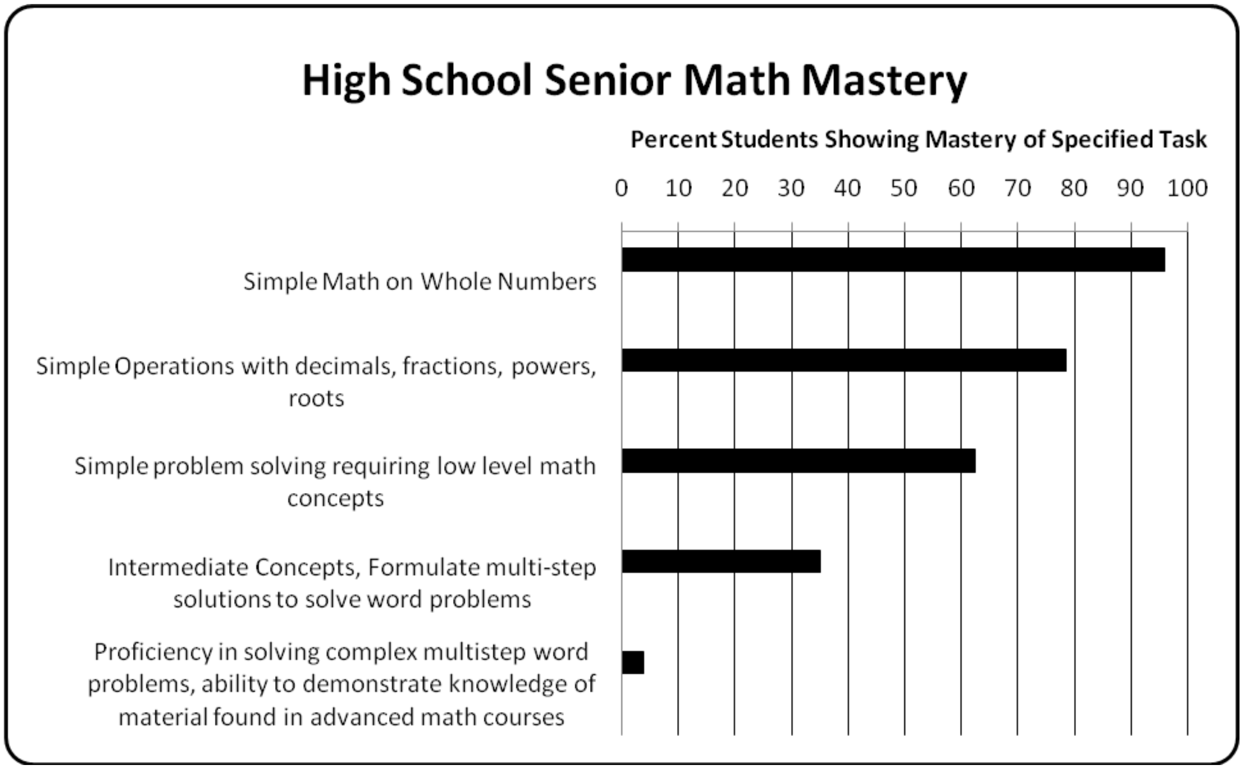
Plotted graphically, the NAEP data show stagnation of the gains in mathematics scores for 17-year-olds since approximately 1992.

*Figure 3. Average National Assessment of Educational Progress (NAEP) Scaled Scores for long-term trend mathematics, age 17, by year*




Examination of the data in the above table show that while the math scores have not experienced the same downturn that the verbal scores have experienced, they have also not changed much since 1992. What is surprising, however, is that since the mid-1990s the scores have been relatively stable, and have not reflected the prior dramatic upward change, given that students currently have extensive technology at hand. There has not been a significant change in the data, despite having access to a variety of technological tools, such as graphing calculators and computer software, that can depict 2 and 3-dimensional representations. The significance of the lack of improvement is further reflected in the National Center for Education Statistics study entitled "A Profile of the High School Senior in 2004: A First Look" (2005). While the study indicates that over 75% of the surveyed high school seniors had completed Algebra 2, trigonometry, pre-calculus or calculus, it also showed that over 21% of those students failed to demonstrate mastery of operations that only require Algebra 1 content, such as simple operations with decimals, fractions, powers, and roots. It further showed that almost 65% of the students could not formulate multi-step solutions to solve word problems, despite having been enrolled in courses that support that type of work. The following graph depicts the mastery of specific skills by high school seniors.

***Figure 4. Percent of Students demonstrating mastery of specific mathematics knowledge and skills, High School Seniors (based upon data from the National Center for Education Statistics study entitled "A Profile of the High School Senior in 2004: A First Look."***




Yet another indicator of the lack of proficiency in mathematics is shown in Schoenfeld's article, "*When Good Teaching Leads to Bad Results: The Disasters of 'Well-Taught' Mathematics Courses*" (1988). He provides an example of a response to a question from an NAEP test in which the students are asked how many 36-passenger buses would be required to transport 1128 soldiers. Only 23% of the students provided the correct answer of 32 buses. Other students provided answers such as 31, remainder 12. This kind of reasoning by the students shows a lack of a conceptual understanding of the underlying material and a lack of mastery.

Therefore, in examining the math data from NAEP, that showed little improvement in scores since 1992, one must also be cognizant that the majority of students do not attain proficiency in the courses that they have completed. They fail to master the material and lack a conceptual understanding. While the NAEP numbers for math may remain relatively stable since 1992, compared to those for reading, they do not necessarily represent proficiency by the students.

## Discussion

Given that developed countries show an apparent reversal or stagnation in measured intelligence, knowledge, and learning in recent years, environmental changes within that period are the logical starting point to attempt to isolate any precipitating factors. Genetic changes would fail to account for the degree of observed changes. This report proposes that at least a portion of the environmental factors that are involved include the presence of Alternative Cognitive Devices.

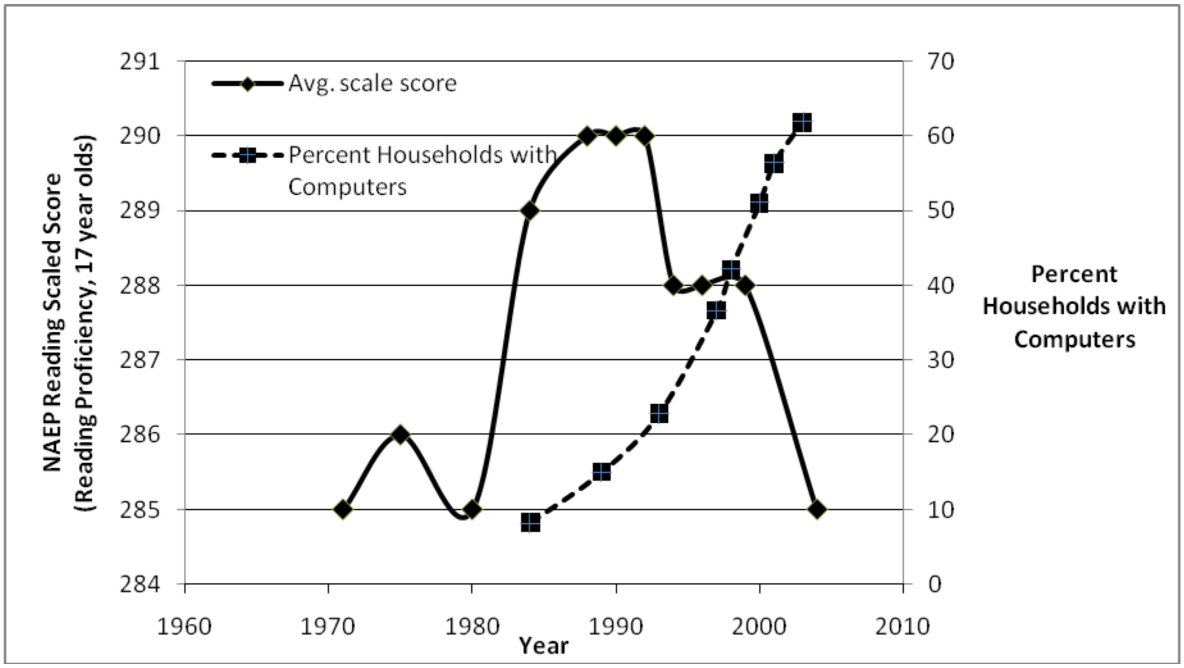
The rapid explosion in technology in the last two decades has been largely led by the computer. While more recent innovations, such as predictive spelling in cell phones, may also be considered Alternative Cognitive Devices, there exist inadequate data over a substantive time to consider the effects of such recent innovations if one wants to consider long-term trends. Therefore, in order to conduct a preliminary analysis of long-term trends, the logical location is to study the presence of the computer. Initially, due to cost considerations, the computer was largely a device used by business. As costs decreased, however, home use of the computer became commonplace. The United States Census has collected data regarding home computer use since 1989, when only 8.2% of households had a computer. The presence of a computer within the household is an excellent indicator of the growth in the use patterns of the personal computer within the lives of the citizenry. Since educational funding allowed for introduction of computers into the classroom at a rate that was generally faster than the adoption rate for home use, the use of computers in the home provides a conservative estimate of the usage of the computer by the general population. United States Census data (2005) indicate that by 2003, over 61% of households had a computer, and among those households, over 69% of children aged 15 to 17 years old, used said computer for word processing.

Additionally, among teachers that assigned students to perform work on computers in 1999, 61% assigned students tasks that required the technologies of word processing or spreadsheets (U.S. Census Bureau, 2005).

The data regarding word processing are significant, as the level of word processing usage reflects one of the primary uses of the computer as an Alternative Cognitive Device. Rather than learning the correct spelling of various words, many students prefer to use the spell-check function. Unfortunately, spell-check, as it exists today, fails to detect homophone misuse.

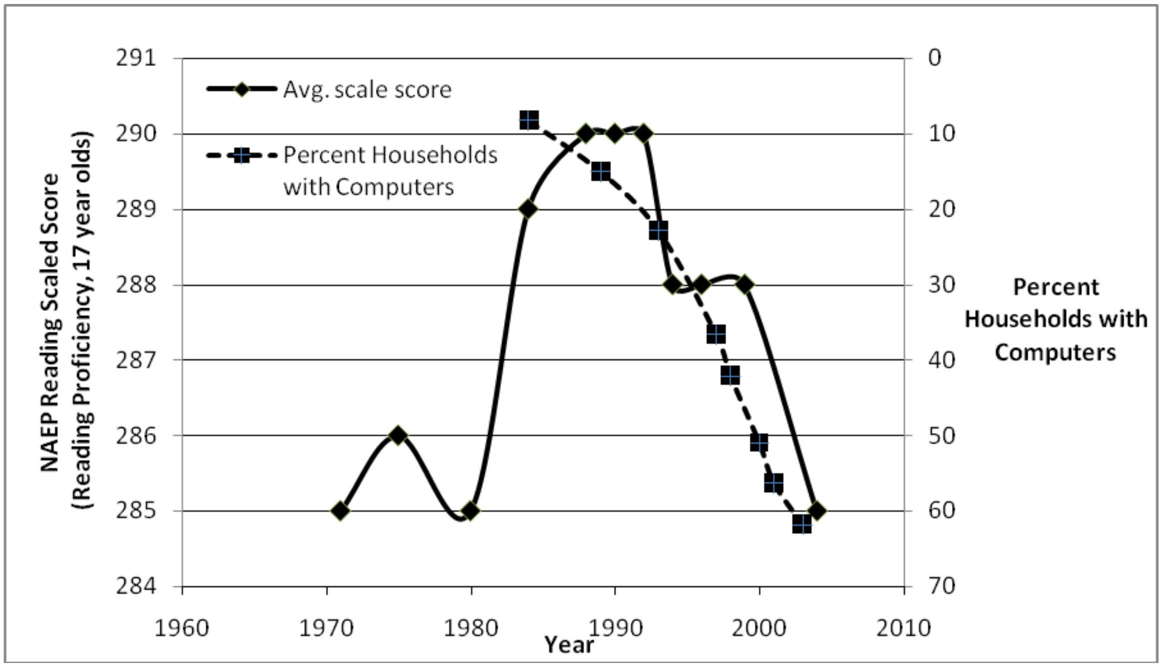
It could be argued that the computer, in particular, the spell-check function of word processing, is an indicator of the overall technological progress of a society using Alternative Cognitive Devices. Using the above data, I compared the use of computers in the household (U.S. Census, 2005) to the NAEP reading scores of students over the same time period.

***Figure 5. Average National Assessment of Educational Progress (NAEP) Scaled Scores for long-term trend reading, age 17, and Percent Households with Computers, by year.***




Examining the graph above, one can see that as the households with computers rose, the reading proficiency of 17-year-olds fell. By inverting the axis for the households with computers, the relationship is made even clearer, as depicted on the following page:

***Figure 6. Average National Assessment of Educational Progress (NAEP) Scaled Scores for long-term trend reading, age 17, and Percent Households with Computers (Inverted Axis), by year.***




While the charted trends in home computer use and reading scores do not necessarily establish a causal link, the overall temporal trend is worth noting. The rapid increase in home computer use matches a concurrent downward trend in reading proficiency. It appears plausible that some of the environmental factors affecting the downturn in measures of intelligence, knowledge, and learning are attributable to the prevalence of the computer in society. As Mark Bauerlein (2008) notes, “the enhancements and prosperities, claimed to turn young Americans into astute global citizens and liberated consumers sometimes actually conspire against intellectual growth”(p. 36). Barnes also noted that replacing print-based media with computer media could create a “major social literacy gap” (Barnes, 1999, p. 14). It appears as if it is possible that developed countries are currently at that juncture.

Computer users who rely on the spell-check function and fail to learn the difference between “their”, “there” and “they’re” also fail to establish the requisite knowledge to communicate properly. Failure to learn the proper use of words has a long-term effect in that it exacerbates communication errors. When one is unable to distinguish proper word usage due to over-reliance on the computer, the problem is subsequently multiplied when the person uses other ACDs such as the predictive spelling functions that are common in cell phones. Salomon discusses such effects when he distinguishes between effects ‘with’ the computer and effects ‘of’ the computer. The effects ‘with’ the computer can be either positive or negative and reflect the user’s interaction with the technology. Effects ‘of’ the computer deal with the “cognitive residue” (Salomon, 1990). Salomon specifically discusses the cognitive residue in terms of the benefits afforded by the technology. It can be equally argued that such residue from interaction with the computer can also lead to negative ramifications.

The negative residue left by ACD use, specifically the spell-check function of the word processor, is typified by a quote from a 20-year-old on a USA Today blog (Bauerlein, 2008):

> Today’s young people don’t suffer from illiteracy; they just suffer from e-literacy. We can’t spell and we don’t know synonyms because there’s less need to know. What smart person would devote hours to learning words that can be accessed at the click of a button? Spell-check can spell. Shift +F7 produces synonyms. What is wrong with relying on something that is perfectly reliable? (p. 66)

Failure to learn the proper use of words, however, can result in someone selecting the wrong word, as the spell-check function fails to detect the problem. A review of a portion of a poem on the Internet illustrates an extreme example, in which many of the words of the poem are not used correctly, yet they would not be detected by the spell-check function, as each word is a proper word, just used incorrectly.

CANDIDATE FOR A PULLET SURPRISE
By Jerrold H. Zar (1992)

I have a spelling checker,
It came with my PC.
It plane lee marks four my revue
Miss steaks aye can knot sea.

Eye ran this poem threw it,
Your sure reel glad two no.
Its vary polished in it's weigh.
My checker tolled me sew.

While the above poem may represent an exaggeration, the temporal alignment of the increase in home computer use and the concurrent reduction in measured verbal abilities call into question whether the Alternative Cognitive Devices are modifying the measures of knowledge, learning, or intelligence.

In order to establish a more definitive link between Alternative Cognitive Devices and the changes in the rate of gain of learning, knowledge or intelligence, another example of ACD use in society was studied, specifically, the widespread use of calculators in both the classroom and in the general public. Richard Lynn (1998a) argues effectively that a common test of fluid intelligence, Raven's Progressive Matrices, requires understanding the principles of mathematics. In order to determine the logical next step in the matrix, one needs to apply principles of addition, subtraction, and sequences. Accordingly, decreasing math scores would serve to mirror the decrease in the rate of gain in IQ scores observed in developed countries. If a population failed to learn the foundational principles of mathematics due to over-reliance on calculators, it should be reflected in a change in both the rate of gain in IQ scores, and in long-term mathematics trends. Such a change was noted, even in the media, with an observation that" arithmetic skills began to slide distinctly backward" after the mid-1990s (Schneider, 2006).

While many studies have determined that calculators provide more opportunities for students to practice due to the rapidity of calculation (Pomerantz & Waits, 1997), few have studied if calculators aid in the conceptual understanding of mathematics. Cassity (1997) examined such an issue and noted that students who used a graphing calculator did not develop the level of conceptual understanding that those without graphing calculators developed. Conceptual understanding, from the perspective of mathematics instruction, can be viewed as the development of a schema that goes beyond the basic math facts. The schema uses said facts for facilitating retrieval of related material to solve a problem. Roberts (1980) also notes that while calculators assist in computation, the conceptual benefits are minimal. Roberts indicates that students with calculators can do more problems per given time, and yet he also found that this increase in the number of problems did not significantly aid in the students' conceptual understanding.

Loveless (2004) examined NAEP mathematics data and observed that nine-year-olds perform poorly when not allowed a calculator. The table below, derived from Loveless' research into the NAEP data merits examination:

***Table 3. Percent of Matched Questions Correct, selected items from National Assessment of Educational Progress (NAEP) 1999 Mathematics Test, Age 9, based upon Calculator Usage/Non-Usage***

| MATH SKILL | Allowed Calculators (Percent Correct) | Not Allowed Calculators (Percent Correct) |
|---|---|---|
| Addition | 87.0 | 78.4 |
| Subtraction | 89.2 | 59.7 |
| Multiplication | 87.9 | 42.5 |
| Division | 77.1 | 48.3 |

Examination of the data can lead to the faulty conclusion that calculators must be of great assistance in mathematics, as the percent of students answering correctly is considerably higher for the group with calculators than the scores for those students not using calculators. Rather, one must note that if calculators are allowed on tests that measure computational proficiency of fourth graders, said usage would only show the computational proficiency *with an assistive device*. In examining the data, the lower proficiency scores of the students not using calculators suggests that students failed to develop the underlying foundational math, due to the presence of an Alternative Cognitive Device. Loveless notes that "Believing that a nine-year-old can compute when he or she cannot do so without a calculator is tantamount to believing that a nine-year-old can ride a bike when he or she cannot do so without training wheels"(p. 23).

The above observation is consistent with the research of McNamara (1995), who found that when students had to generate answers, rather than reading them from a calculator display, they had improved retention of the mechanism of multiplication. The research, conducted on second grade children, proposes that the students who had to generate answers developed more effective cognitive procedures than the calculator-enabled students did.

Wilson & Naiman (2004) performed an informal study of college students at Johns Hopkins University and found that students who were encouraged to use calculators in K-12 had lower grades in their college math classes than their counterparts.

A portion of the problem lies in the stance taken by the National Council of Teachers of Mathematics (NCTM), which advocated in a position paper in 1987 that teachers should make use of calculators in classrooms at all grade levels, as long as basic skills were taught. The position was reiterated in the 1989 NCTM *Curriculum and Evaluation Standards for School Mathematics*. The position was modified in the 2000 NCTM standards in the belief that technology should "not be used as a replacement for basic understandings” (NCTM, 2000). In 2005, NCTM finally changed its position on calculators in the classroom and now indicates that there needs to be a balance between knowledge, skills, and tools (NCTM, 2005 & 2008).

Unfortunately, in their zeal to adopt the latest technology to facilitate conceptual understanding, many educators forget that an underlying mastery of foundational material needs to be present. As John Dewey (1916) stated so eloquently, “…skill obtained apart from thinking is not connected with any sense of the purposes for which it is to be used” (p. 152).

## Conclusions

Technology is a pervasive part of the society of developed countries. Each innovation has the potential to modify the ways in which people interact with their environment and with each other. Technological changes can affect both the individual and the society in both positive and negative ways. Few would consider innovations such as the Salk vaccine for poliomyelitis to have negative consequences. Technology can have unintended negative consequences, and therefore the introduction of innovative ideas needs to consider the ramifications, especially when considering the effect on the educational environment. Research using the Internet, for example, is less effective if students fail to learn the underlying methods of research so that they can use their time in a productive manner.

Data suggesting that the implementation of Alternative Cognitive Devices modifies measures of intelligence, knowledge, and learning, correlate well with the observations of Fuchs and Woessmann (2006). They studied data from the Programme for International Student Assessment (PISA), an assessment test for 15-year-olds and concluded that, after controlling for factors such as family and school, there is a strong negative correlation between math and reading performance and computer availability at home.

The temporal association between the development of the Alternative Cognitive Devices such as the computer and the resultant reduction in measures of verbal and mathematical reasoning should not be ignored. Given that technologies such as the Internet rewrite the neural networks, it is critical that those in education consider the effect of implementing technological changes. Students graduating from our schools should represent the summit of educational achievement, given the access that they have to vast repositories of information and numerous technological aids. Yet, it is clear that the data represent the reverse; students in developed countries are not achieving at levels consistent with the changes and employers are reporting that those entering the job market do not have the required skills. It is therefore prudent to examine if the technological changes are the very essence of the problem. If technological changes act as an environmental factor with negative consequences, then the genotypic intelligence would manifest itself, which would result in the observed decline in measures of intelligence, knowledge, and learning.

Even if one is not a proponent of the genotypic intelligence hypothesis espoused by Richard Lynn, technology needs to be considered as a significant environmental factor in the reduction of measures of intelligence, knowledge, and learning. The role that technology plays in cognition cannot be ignored, as it is feasible that reliance on technology results in a lack of declarative knowledge, or an over-reliance upon the answers provided by the technology. As Bauerlein states when discussing the poor NAEP results of America's youth, "Whatever their other virtues, these minds know far too little, and they read and write and calculate and reflect way too poorly…The Web grows and the young adult mind stalls" (p. 108).

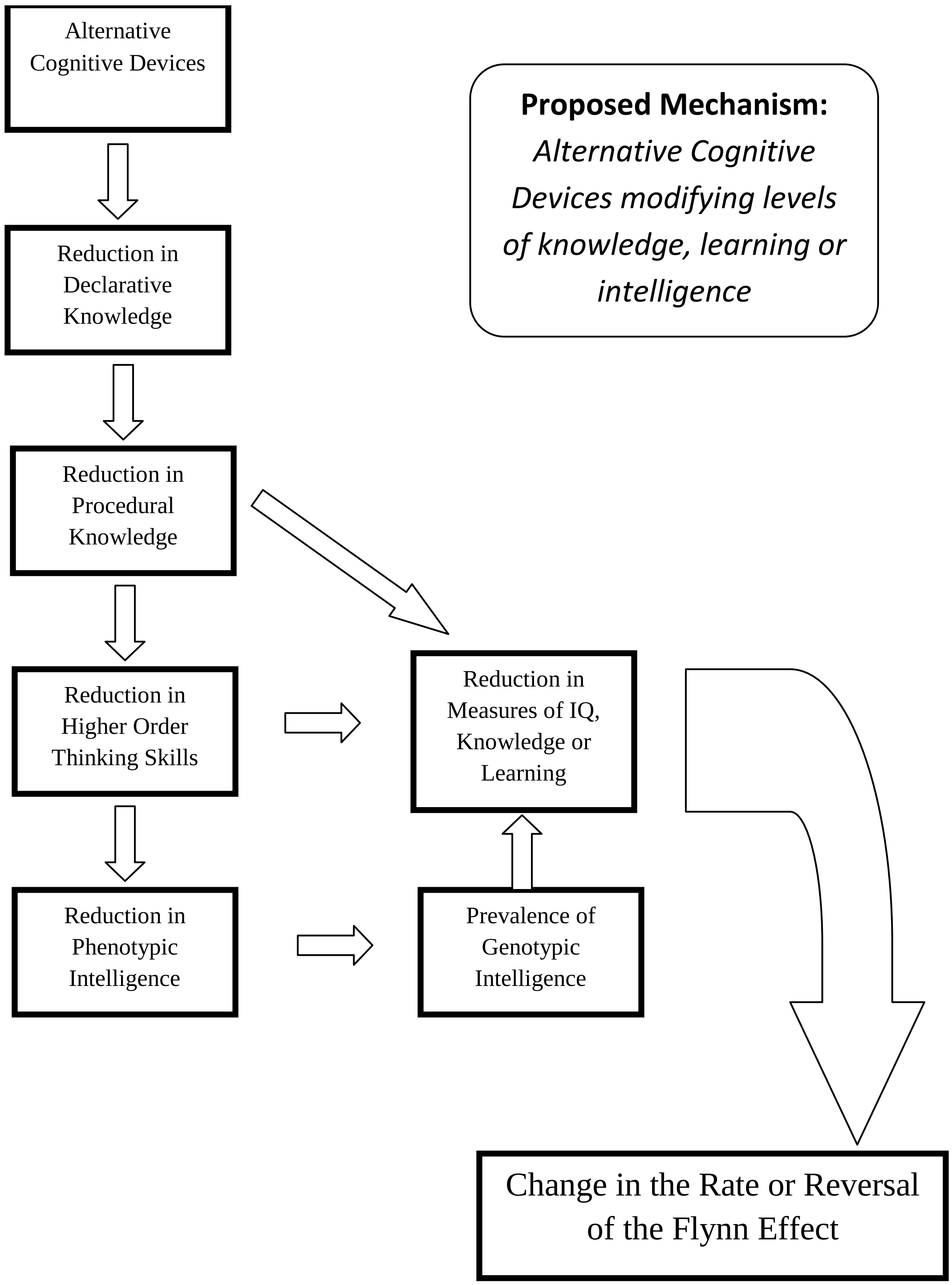
The findings of this paper, however, are not meant to suggest that technology has no value. Rather, it is to indicate that technological changes can be of benefit when implemented properly, with consideration of the effects thereof. A word processor, for example, is superior in most ways to a typewriter, but it is not a substitute for learning the proper meaning of words, nor for learning how to write properly. Calculators are superior to their predecessor, the slide rule, but are not a substitute for learning proper mathematical reasoning, and the reasonableness of an answer. When high school Algebra students reach for a calculator to determine the answer to 2 divided by 2, or 120 divided by 12 (personal observations), it is clear that the calculator has interfered with the students' abilities to develop appropriate mathematical reasoning.

The prevalence of technology in our lives, however, led to one of the major restrictions in the current study. It is difficult, if not impossible, to implement a controlled study that would eliminate use of the calculator, and/or use of the computer, to definitively determine if Alternative Cognitive Devices are a causal factor in the reduction of measures of intelligence, knowledge, or learning. Even if classroom restrictions in the use of a calculator or computer were implemented, the almost universal use of such devices in other environments, such as the home, would serve to confound and invalidate most studies. Yet, the temporal association between Alternative Cognitive Devices and changes in the measures of intelligence, knowledge, and learning merits further investigation.

Technological change is not something that should be frowned upon, rather it should be embraced, and more importantly, it should be studied. Implementing technological change merely because it exists is foolhardy. The key to including technology in education is to ensure that students have an understanding of the underlying material, and to introduce technologies that act as Alternative Cognitive Devices at the developmentally appropriate time.

A diagram exploring the manner in which alternative cognitive devices could modify levels of knowledge, learning, or intelligence is proposed below:

***Figure 7. Proposed Mechanism: Alternative Cognitive Devices modifying levels of knowledge, learning or intelligence***



# References

## References


Anand, V. (2007). A study of time management: The correlation between video game usage and academic performance markers. [Electronic version]. *CyberPsychology & Behavior, 10*(4), 552-559.

Anderson, J. (1996). ACT: A simple theory of complex cognition. [Electronic version]. *American Psychologist*, *51*(4), 355-365.

Anderson, J., Matessa, M., & Lebiere, C. (1997). ACT-R: A theory of higher-level cognition and its relation to visual attention. [Electronic version]. *Human-Computer Interaction*, *12*(4), 439.

Barnes, S. (1999). Education and technology: A cultural Faustian bargain. [Electronic version]. *Bulletin of Science, Technology & Society*, *19*(1), 11-16.

Bauerlein, M. (2008). *The dumbest generation: How the digital age stupefies young Americans and jeopardizes our future (or, Don't trust anyone under 30)*. New York: Tarcher. Washington, D.C.

Bocéréan, C., Fischer, J., & Flieller, A. (2003). Long-term comparison (1921-2001) of numerical knowledge in three to five-and-a-half-year-old children. [Electronic version]. *European Journal of Psychology of Education - EJPE, 18*(4), 405-424.

Bradshaw, T., & Nichols, B. (2004). *Reading at risk: A survey of literary reading in America*. [Electronic version]. United States, National Endowment for the Arts.

Brand, C.R. (1987). Bryter still and Bryter? [Electronic version]. *Nature, 328*(6126*),* 110.

Brand, C. R. (1990). A 'gross' underestimate of a 'massive' IQ rise? A rejoinder to Flynn. [Electronic version]. *Irish Journal of Psychology, 11*(1), 52-56.

Carr, N. (2008). Is Google making us stupid? [Electronic version]. *Atlantic Monthly, 302*(1), 56-63.

Cassity, C. (1997). Learning with technology: Research on graphing calculators. *In Proceedings of selected research and development presentations at the 1997 National Convention of the Association for Educational Communications and Technology*. (ERIC Document Reproduction Service No. ED409880) Retrieved May 10, 2009, from ERIC database.

Churchill, J. (2003). What Socrates said to Phaedrus: Reflections on technology and education. [Electronic version]. *Midwest Quarterly*, *44*(2), 211.

Cocodia, E. A., Kim, J., Shin, H., Kim, J., Ee, J., Wee, M. S., & Howard, R. W. (2003). Evidence that rising population intelligence is impacting in formal education. [Electronic version]. *Personality & Individual Differences*, *35*(4), 797-810.

Cotton, S.M., Kiely, P.M., Crewther, D.P., Thomson, Br., Laycock, R., Crewther, S.G. (2005). A normative and reliability study for the Raven's Progressive Matrices for primary school aged children from Victoria, Australia. [Electronic version]. *Personality & Individual Differences*, *39*(3), 647-659.

Czaja, S., Charness, N., Fisk, A., Hertzog, C., Nair, S., Rogers, W., et al. (2006). Factors predicting the use of technology: Findings from the center for research and education on aging and technology enhancement (CREATE). [Electronic version]. *Psychology and Aging, 21*(2), 333-352.

Daley, T.C., Whaley, S.E., Sigman, M.D., Espinosa, M.P. Neumann, C. (2003). IQ on the rise: the Flynn Effect in rural Kenyan children. [Electronic version]. *Psychological Science: A Journal Of The American Psychological Society / APS*, *14*(3), 215-219.

Dewey, J. (1916). Thinking in Education. In *Democracy and education, An introduction to the philosophy of education* (pp. 152-163). New York: The Free Press.

Dickens, W. T., & Flynn, J. R. (2001). Heritability estimates versus large environmental effects: The IQ paradox resolved. [Electronic version]. *Psychological Review*, *108*(2), 346.

Educational Testing Service (2006). 2006 ICT Literacy Assessment Preliminary Findings. Retrieved May 10, 2009 from http://www.ets.org/Media/Products/ICT_Literacy/pdf/ 2006_Preliminary_Findings.pdf.

Emanuelsson, I., Reuterberg, S. E., & Svensson, A. (1993). Changing differences in intelligence? Comparisons between groups of thirteen-year-olds tested from 1960-1990. [Electronic version]. *Scandinavian Journal of Educational Research*, *37*(4), 259-277.

Eshet-Alkalai, Y., Geri, N. (2007) Does critical thinking affect the message? The influence of text representation on critical thinking. [Electronic version]. *Human Systems Management*, *26*(4), 269-279.

Flynn, J. R. (1984). The mean IQ of Americans: Massive gains 1932 to 1978. [Electronic version]. *Psychological Bulletin*, *95*(1), 29-51.

Flynn, J. R. (1987). Massive IQ gains in 14 nations: What IQ tests really measure. [Electronic version]. *Psychological Bulletin*, *101*(2), 171-191.

Flynn, J.R. (1998) IQ gains over time: Toward finding the causes. In U. Neisser (ed.), *The Rising curve: Long-term gains in IQ and related measures* (pp. 25-66). Washington, DC: American Psychological Association.

Flynn, J. R. (1999). Searching for Justice: The discovery of IQ gains over time. [Electronic version]. *American Psychologist*, *54*(1), 5-20.

Flynn, J. R. (2007). *What Is Intelligence?: Beyond the Flynn Effect*. New York: Cambridge

Flynn, J. R., & Weiss, L. G. (2007). American IQ gains from 1932 to 2002: The WISC subtests and educational progress. [Electronic version]. *International Journal of Testing*, *7*(2), 209-224.

Fuchs, T. & Woessmann, L. (2004). Computers and student learning: Bivariate and multivariate evidence on the availability and use of computers at home and at school. [Electronic version]. *CESifo Working Paper Series CESifo Working Paper Number 1321*, CESifo GmbH.

Gilbert, L. S. (1999). Where Is My Brain? Distributed cognition, activity theory, and cognitive tools. [Electronic version]. *Proceedings of selected research and development papers presented at the National Convention of the Association for Educational Communications and Technology [AECT] 21st, Houston, TX, February 10-14, 1999*.

Greenfield, P.M. (1998). The cultural evolution of IQ. In U. Neisser (ed.), *The rising curve: Long-term gains in IQ and related measures* (pp. 81-123). Washington, DC: American Psychological Association.

Grissmer, D. W. (2000). The continuing use and misuse of SAT scores. [Electronic version]. *Psychology, Public Policy, and Law*, *6*(1), 223-232.

Hauser, R.M. (1998) Trends in black-white test-score differentials: I. Uses and misuses of NAEP/SAT Data. (1998). In U. Neisser (ed.), *The Rising curve: Long-term gains in IQ and related measures* (pp. 219-249). Washington, DC: American Psychological Association.

Hayes, D. P., Wolfer, L. T., & Wolfe, M. F. (1996). Schoolbook simplification and its relation to the decline in SAT-Verbal scores. [Electronic version]. *American Educational Research Journal, 33*(2), 489-508.

Healy, J. M. (1990). *Endangered minds: Why children don't think and what we can do about it*. New York, NY: Simon & Schuster.

Healy, J.M. (1998). *Failure to connect, How computers affect our children's minds- and what we can do about it*. New York. Simon & Schuster.

Herrnstein, R. J., & Murray, C. (1994). *The bell curve: Intelligence and class in American life.* New York: Free Press.

Hetsroni, A. (2007). Four decades of violent content on prime-time network programming: A longitudinal meta-analytic review. [Electronic version]. *Journal of Communication*, *57*(4), 759-784.

Jensen, A. R. (1998). *The g factor: The science of mental ability*. Westport, CN: Praeger.

Kanaya, T., Scullin, M.H., & Ceci, S.J. (2003). The Flynn Effect and U.S.
policies: The impact of rising IQ scores on American society via mental retardation diagnoses. [Electronic version]. *American Psychologist, 58*(10), 778-790.

Kovacs, K. (2007). Modern technology and the secular increase in IQ. [Electronic version]. *Communication in the 21st Century, Mobile Studies: Paradigms and Perspectives* (pp. 59-69). Vienna.

Lentz, T. (1927). Relation of IQ to size of family. [Electronic version]. *The Journal of Educational Psychology, 18*(7), 486-496.

Lichten, W. (2004). On the law of intelligence. [Electronic version]. *Developmental Review*, *24*(3), 252-288.

Loveless, T. (2004). Computation skills, calculators, and achievement gaps: An analysis of NAEP items. Draft Copy, used with permission [Electronic version]. Brown Center on Education Policy.

Lynn, R., & Harvey, J. (2008). The decline of the world's IQ. [Electronic version]. *Intelligence*, *36*(2), 112-120.

Lynn, R. (1998a). In support of the nutrition theory. In U. Neisser (ed.), *The Rising curve: Long-term gains in IQ and related measures* (pp. 335-364). Washington, DC: American Psychological Association.

Lynn, R. (1998b). The decline of genotypic intelligence. In U. Neisser (ed.), *The Rising curve: Long-term gains in IQ and related measures* (pp. 335-364). Washington, DC: American Psychological Association.

Malina, R. M., Bouchard, C., & Bar-Or, O. (2004). *Growth, maturation, and physical activity*. Champaign, Illinois: Human Kinetics.

Martin, T. (1995). Women's education and fertility: Results from 26 demographic and health surveys. [Electronic version]. *Studies in Family Planning*, *26*(4), 187.

Martorell, R. (1998). Nutrition and the worldwide rise in IQ scores. In U. Neisser (ed.), *The Rising curve: Long-term gains in IQ and related measures* (pp. 183-206). Washington, DC: American Psychological Association.

McNamara, D. S. (1995). Effects of prior knowledge on the generation advantage: Calculators versus calculation to learn. [Electronic version]. *Journal of Educational Psychology*, *87*(2), 307-318.

Mingroni, M. A. (2007). Resolving the IQ paradox: Heterosis as a cause of the Flynn Effect and other trends. [Electronic version]. *Psychological Review*, *114*(3), 806-829.

National Council of Teachers of Mathematics (1987). *A position statement on calculators in the classroom*, [Electronic Version] Reston, VA. NCTM.

National Council of Teachers of Mathematics (1989). *Curriculum and evaluation standards for school mathematics.* [Electronic Version] Reston, VA. NCTM.

National Council of Teachers of Mathematics (2000). *Curriculum and evaluation standards for school mathematics.* Reston, VA. NCTM.

National Council of Teachers of Mathematics (2005). *Computation, Calculators and Common Sense, A position of the National Council of Teachers of Mathematics*. [Electronic Version] Reston, VA. NCTM.

National Council of Teachers of Mathematics (2008). *The role of technology in the teaching and Learning of Mathematics,A position of the National Council of Teachers of Mathematics*. [Electronic Version] Reston, VA. NCTM.

Neisser, U. (Ed.). (1998). *The rising curve: Long-term gains in IQ and related measures*. New York: American Psychological Association.

Nettelbeck, T., & Wilson, C. (2004). The Flynn effect: Smarter not faster. [Electronic version]. *Intelligence*, *32*(1), 85-93.

Phillips, L. (2007, September 06). School's out for skills. [Electronic version]. *People Management*,*13*(18),14.

Plomin, R., & Spinath, F. M. (2004). Intelligence: Genetics, genes, and genomics. [Electronic version]. *Journal of Personality & Social Psychology*, *86*(1), 112-129.

Pomerantz, H, & Waits, B. (1997). The role of calculators in math education. [Electronic version]. Urban systemic initiative/Comprehensive partnership for mathematics and science achievement Superintendent's forum, Dallas Texas. Retrieved May 10, 2009 from http://education.ti.com/sites/US/downloads/pdf/therole.pdf.

Postman, N. (1995). *The End of education : Redefining the value of school*. New York, NY: Alfred A. Knopf.

Postman, N. (1993). *Technopoly: The surrender of culture to technology*. New York, NY: Vintage.

Roberts, D. M. (1980). The Impact of electronic calculators on educational performance. [Electronic version]. *Review of Educational Research*, *50*(1), 71-89.

Rock, D. A. (1987). The Score decline from 1972-1980: What went wrong? [Electronic version]. *Youth & Society*, *18*(3), 239-254.

Rönnlund, M., & Nilsson, L. (2008). The magnitude, generality, and determinants of Flynn Effects on forms of declarative memory and visuospatial ability: Time-sequential analyses of data from a Swedish cohort study. [Electronic version]. *Intelligence*, *36*(3), 192-209.

Rowe, D. C., & Rodgers, J. L. (2002). Expanding variance and the case of historical changes in IQ means: A Critique of Dickens and Flynn (2001). [Electronic version]. *Psychological Review*, *109*(4), 759-763.

Russell, E. W. (2007). Commentary: The Flynn Effect revisited. [Electronic version]. *Applied Neuropsychology*, *14*(4), 262-266.

Salomon, G. (1998, Winter98). Technology's promises and dangers in a psychological and educational context. [Electronic version]. *Theory Into Practice*, *37*(1), 4.

Salomon, G. (1990, February). Cognitive effects with and of computer technology. [Electronic version]. *Communication Research*, *17*(1), 26-44.

Schneider, D. (2006). Smart as we can get? [Electronic version]. *American Scientist*, *94*(4), 311-312.

Schoenfeld, A. (1988). When good teaching leads to bad results: The disasters of 'well-taught' mathematics courses. [Electronic version]. *Educational Psychologist*, *23*(2), 145

Scooler, C. (1998) Environmental complexity and the Flynn Effect. In U. Neisser (ed.), *The Rising curve: Long-term gains in IQ and related measures* (pp. 25-66). Washington, DC: American Psychological Association.

Shavelson, R., Ruiz-Primo, M., & Wiley, E. (2005). Windows into the mind. [Electronic version]. *Higher Education*, *49*(4), 413-430

Shayer , M., Coe, R., & Ginsburg, D. (2007). 30 years on – A large anti-'Flynn Effect'? the Piagetian test volume and heaviness norms 1975-2003.[Electronic version]. *British Journal of Educational Psychology*, *77*(1), 25-41

Shayer , M. (2008). Intelligence for education: As described by Piaget and measured by psychometrics. [Electronic version]. *British Journal of Educational Psychology*, *78*(1), 1-29.

Singh, B. (1996). The genetic-environmental influences on individual cognitive functioning or IQ. [Electronic version]. *Educational Studies (03055698)*, *22*(1), 41-56.

Small, G, & Vorgan, G. (2008). *iBrain*, *Surviving the technological alteration of the modern mind*. New York. Collins Living, An imprint of Harper Collins Publishers.

Storfer, M. (1999). Myopia, intelligence, and the expanding human neocortex: Behavioral influences and evolutionary implications. [Electronic version]. *International Journal of Neuroscience*, *98*(3/4), 153-276.

Sundet, J. M., Barlaug, D. G., & Torjussen, T. M. (2004). The end of the Flynn Effect?: A study of secular trends in mean intelligence test scores of Norwegian conscripts during half a century. [Electronic version]. *Intelligence*, *32*(4), 349-362.

Teasdale, T. W., & Owen, D. R. (2005). A long-term rise and recent decline in intelligence test performance: The Flynn Effect in reverse. [Electronic version]. *Personality & Individual Differences*, *39*(4), 837-843.

Teasdale, T. W., & Owen, D. R. (2000). Forty-year secular trends in cognitive abilities. [Electronic version]. *Intelligence*, *28*(2), 115-120.

tenBerge, T., & van Hezewijk, R. (1999). Procedural and declarative knowledge: An evolutionary perspective. [Electronic version]. *Theory & Psychology*, *9*(5), 605-624.

U.S. Census Bureau, U.S. Department of Commerce (2005). *Computer and Internet use in the United States:2003* [Electronic version].

U.S. Department of Education, National Center for Education Statistics (2005). Institute of Education Sciences (IES). *A profile of the American high school senior in 2004: A frist look – Initial results from the first follow-up of the Educational Longitudinal Study of 2003 (ELS: 2002)*, Washington, D.C.

U.S. Department of Education, National Center for Education Statistics (2003). Institute of Education Sciences (IES) *National Assessment of Adult Literacy*. Washington, D.C.. Retrieved April 19, 2009 from http://nces.ed.gov/NAAL/PDF/2006470.PDF.

U.S. Department of Education, National Center for Education Statistics (2004). Institute of Education Sciences (IES) *National Assessment of Educational Progress (NAEP)*. Washington, D.C., Retrieved April 19, 2009 from http://nces.ed.gov/nationsreportcard/ naepdata/ on April 19, 2009.

*Walker v True*, 399 F.3d 315 (4th Cir 2005), *after remand*, [Electronic version]. 401F.3d 574 (4th Cir. 2005).

Weizenbaum, J. (1977). *Computer power and human reason: From judgment to calculation*. Boston: W. H. Freeman & Company.

Wilson, W., & Naiman, D. (2004). K-12 calculator usage and college grades. *Educational Studies in Mathematics*, *56*(1). 119-122.

Zajonc, R. B., & Mullally, P. R. (1997). Birth order: Reconciling conflicting effects. [Electronic version]. *American Psychologist*, *52*(7), 685-699.

Zar, J. H. (1992). Candidate for a pullet surprise. In *NIU - Department of Biological Sciences*. Retrieved March 19, 2007 from http://www.bios.niu.edu/zar/zar.shtml.