Chapter #8

THE TRANSITION FROM CONCRETE TO FORMAL THINKING

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ABSTRACT
In the current study we have investigated the development of logical and mathematical reasoning among a mature sample following Piaget's theory of cognitive development. The purpose of the current study is examining if continued biological development and/or continued accumulation of life experience, learning and education can develop thinking that contributes to the transition to the formal operational thinking stage. Research was designed to test whether knowledge content (domain) affects learning by studying cognitive distribution in three domains. The study further explores the premise that schooling is the main factor that precipitates the transition to formal thinking. The research is based on two kinds of populations: The first consists of one thousand literate adults aged between 18 and 76 (M= 39). And the second of one hundred and three illiterate adults. The findings indicate that, there was not any continuation of the formal cognitive development during the entire adult life. Only about 25% of the population continues to the formal operational stage, and this is before the age of 20. learning was affected by domain specificity. In addition, about one-fifth of the illiterate population that never attended school do achieve formal thinking.

Keywords: cognitive development, formal thinking, concrete thinking, domain specificity, mathematical reasoning, genetic regulation.

1. INTRODUCTION

The current paper is based on the theory of cognitive stages by Piaget and Inhelder (Inhelder & Piaget, 1969; Piaget, 1972) which deal with the cognitive development of children in their transition from the concrete operational stage into the formal one. According to Piaget, the course of development is linear and continuous. The stages of cognitive development are universal - shared by children of all cultures and races.

Piaget also mentions high thinking schemes such as probabilistic thinking, equilibrium, proportion, isolation and control of variables, which develop with the progression of the cognitive level and maturate during the formal operation stage (Piaget & Inhelder, 1975). Hence, the ability of the student to apply those high thinking schemes, as those required for "scientific thinking," depends on the age of the student. The theory of cognitive development is considered a universal theory, which is valid for the entire population.

While Piaget focused on the cognitive development of the individual, a series of extensive studies, which were conducted around the world found that cognitive development has a universal pattern until the end of the concrete operational stage at the age of about 12. (Alon, 2003; Herbst, 2006; Habib-Allah & Babai, 2007; Naser, 2007, Green, 1983, Shayer & Adey, 1981). Only part of the whole population continues to move to the formal operational stage.

At the basis of this research lies the following question: does the section of the population who could not succeed in moving into formal thinking until the age of 17, develops this ability at an older age? If so, then this means postponing cognitive maturation to a later age. If the answer is no, then what is the role of all the learning and the experience acquired during elder life? The present study examined the distribution of cognitive levels among adult populations, as opposed to studies that examined the average of cognitive levels among youth population (12-17).

2. LITERATURE REVIEW

Piaget's theory of cognitive development defines the successive and universal developmental stages of the cognitive system. The order of the stages is fixed and extends from birth to the end of adolescence. Recently conducted studies have shown that two-thirds of the population reaches the end of the concrete operational stage and only about one-third continues to the formal and post-formal stages of development (ages 12-20).

2.1. The Transition from Concrete to Formal Thinking in the Broad Population

Shayer & Adey's (1981) study of the cognitive levels, which included 12,000 students from junior and high schools in England, found that only about 30% of students achieve the formal operational stage, while 70% of students remain at the concrete level of thinking. These findings show that not all junior and high school students reach the formal level of thinking as suggested by Piaget.

The research also found a contradiction between the requirements of the curriculum and the level of cognitive ability of students, which can explain the learning difficulties and the low proficiency among students in subjects that require abstract thinking.

Green's study (1983), that includes 3,000 students aged 11-16 in East Midlands, England, showed that most students do not acquire the formal operational stage until the age of 16. Several studies conducted in countries such as Australia, Pakistan and Israel show that less than 25% of ninth graders are at the formal level of thinking, while the vast majority of them are in the pre-formal stages of thinking (Iqbal & Shayer, 2000; Shayer & Adhami, 2007; Endler & Bond, 2001; Huppert, 2002).

2.2. Domain Specificity Content and Cognition

Various theories have emphasized the influence of specialized cognitive systems for different content domains. Carey and Spelke's 'Core Knowledge' theory (Carey & Spelke, 1996) and Fodor and Chomsky's Descriptive Modularity' theory (Fodor, 1983) are very well known in this regard.

Core Knowledge Theory believes that children are born with innate cognitive mechanisms. Those mechanisms are seen as learning traits with evolutionary and survival value that help the children acquire valuable information concerning their environment. A newborn toddler can distinguish between a living creature and a non-living one and also the ability to differentiate between human faces and inanimate objects. These are traits that children are born with, which help them survive. These mechanisms develop and change while interacting with the environment, life experience and contradictory evidence. However, the scientific community is widely divided around the very nature of the construct of intelligence. Steven Pinker (2002) in his book "blank slate" is describing the modern denial of human nature by ignoring the major role that biological principles undertake in regulating human behavior. The Bell Curve (Herrnstein & Murray, 1994) have summarized the best of the research evidence for the unitary regulation of cognition by the g factor and the central role of heredity in it. A different perspective was presented by Gardner in his Multiple intelligence "MI" model in which he suggested that a neurological infrastructure of the brain is the basis for ten separate and independent intelligences.

Fodor (1983), in The Modularity Theory of Mind, claims that cognition consists of separate components that function independently with interfaces between them or some of them. According to this perspective, cognition is not a construct of mental processes that result from a cooperative activity of the general recognition mechanisms; rather, it consists of specific independent mechanisms. The human linguistic ability itself is also modular. It is composed of various systems that function independently, still with interfaces among them. After half a century of research, the modularity of linguistic ability has gained significant confirmation. An innovative addition to Fodors construct is A Thousand Brains (Hawkins, 2021). The treatise on intelligence by Stephen J. Ceci (1996) assembled much of the contradictory research denying the very existing of g and the major role that heredity takes in regulating intelligence. To this very day the scientific community is still divided between the models of intelligence described so far.

2.3. Illiteracy and Ignorance

Illiteracy is the inability to read and write. There is a state of functional illiteracy, where a person acquires initial reading and writing skills, but they could be more effective in daily life behavior. According to UNESCO - 2013, there are nearly 906 million illiterate people worldwide. The number of illiterate people in Israel in 2011 reached 122,449 (33,827 men and 88,622 women) (UNESCO, 2013). Approximately 5% of the population in the States is illiterate, as defined by the US government. According to the British government, 7 million citizens are illiterate. In Arab countries, more than 25% of males and 50% of women were illiterate in 2000. Most of the learning in these populations is informal and concrete. Oral calculation is very common among illiterate people ensuring proper functioning. However, writing calculation is formal, usually requires an algorithm, and refers to the absolute numerical values unrelated to context (Carraher, Carraher, & Schliemann, 1985; Smagorinsky & Coppock, 1995). Nunes (2010) have found that students tested orally on the subject of 'gain and loss' received higher scores than those tested in written tests (Nunes, 2010).

Extensive studies in England show that genetic factors strongly influence mathematical functioning at age 7. In a study of 3,000 same-sex twins aged 7, which aims to examine the influence of genetic variables on performance in mathematics, reading and general intelligence (g), it was found that there was a genetic overlap between mathematics, reading and intelligence. These findings indicate that most of the genes that contribute to individual differences in mathematics are the same that affect reading and intelligence. These findings do not correspond with the results of the genetic studies, which indicate that one-third of the genetic variance in math is unrelated to reading and general intelligence (g); there are specific genes for mathematical performance (Kovas, Harlaar, Petrill, & Plomin, 2004). Some human traits are determined by the polymorphic mechanism, i.e., a single gene determines two or more phenotypes; for instance, human blood type is determined by a single gene with three alleles ABO. However, most personal behavior traits are very complex and controlled by many genes. These features, such as weight, height, skin color, IQ, etc., are polygenic (Wattad & Chen, 2023a).

Searching for specific genes that influence IQ is part of the Human Genome Project. While defects in single genes, such as the Fragile X gene, can cause mental retardation, the heritability of the general cognitive ability (g) is probably influenced by a group of genes that control this characteristic (cognition); information about the location of those genes on the chromosomes and which chromosomes are they laid on, is still missing. This group of genes is called Quantitative Trait loci (QTLs). Future identification of QTLs will allow a deeper understanding of IQ, development, and interaction between the gene and the environment (Fisher, 2006).

A major question regarding universal education is what drives cognitive development- Schooling or genetics? All over the world, educational policies and practices assume that schooling is the key to cognitive development. If this is true, all illiterate adults who never attend school will lag in their cognitive development and not attain formal thinking. This question was put to test in this study.

3. METHOD

The research sample consisted of 1000 adults from different strata of society. The research population is heterogeneous in terms of gender, sector, education, age and occupation. The average age of the sample was 39. In addition, second sample included 103 illiterate subjects, ages 40-90. The study population is heterogeneous in terms of socioeconomic status, place of residence, and work. The questions were read and explained by the researcher by demonstrating the questions. The subjects answered the questions orally, and the answers were recorded by the researcher.

For data collection purposes, we used a quantitative-correlative layout to examine the cognitive level according to Piaget's cognitive theory and to understand the functional relationships between the cognitive level and other background variables.

We used a series of three tests developed by "Mathematics and Science Perceptions in High School" at Chelsea College, University of London, between 1973 and 1978. We received the tests directly from Prof. Shayer, with guidance and counseling regarding the transfer and the processing of the data. These tests were validated and adapted to fit the norms of the population in the U.K.

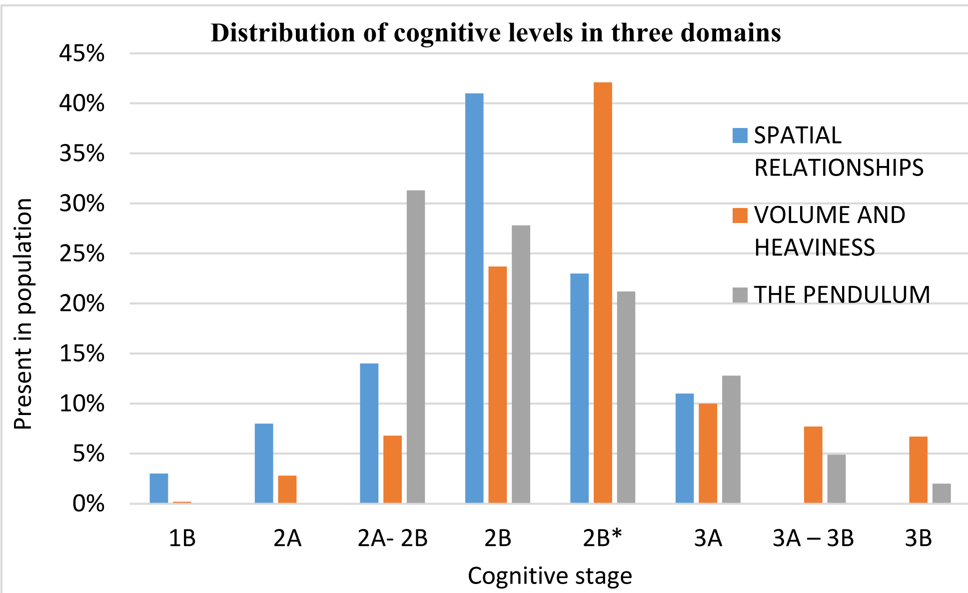
4. FINDINGS AND DISCUSSION

The findings of the current study indicate that the entire sample reaches the concrete operational stage according to Piaget's theory of cognitive development. Less than 25% of the participants continue to proceed to the formal and post-formal stages. In the domain of "spatial perception", about 11% of all subjects perform at the level of formal thinking, while the rest of the adults are in the transition phase and at the concrete stage of thinking. In the domain of "conservation", 25% of all adult participants are at the level of formal thinking and the rest (75%) are in the transition phase and at the concrete operational stage. In the domain of “isolation and controlling variables”, 19% of all subjects are at the level of formal operational stage and the rest of the participants are in the transition phase and at the concrete operational stage. On average, 18% of the sample goes through formal operational stage. Table 1 presents these results.

Table 1.
Cognitive stages in three domains.

Cognitive stage	The cognitive level	Percent pf total sample Test 1	Percent of the total sample Test 2	Percent of the total sample Test 3
	1B	3%	0.2%	
Early concrete	2A	8%	2.8%	31.3%
Mid concrete	2A- 2B	24%	6.8%	
Mature concrete	2B	41%	23.7%	27.8%
Concrete generalization	2B*	13%	42.1%	21.2%
Early formal	3A	11%	10%	12.8%
Mid formal	3A – 3B		7.7%	4.9%
Mature formal	3B		6.7%	2%
	Total	100%	100%	100%

Figure 1.
Distribution of cognitive stages in three domains.



The distribution of levels of thinking among adult population (Figure 1) is like that among junior and high school students, as reported in population studies conducted in Israel and abroad. The distribution remains stable even at adulthood. According to the data of the current study, more than 75% of the subjects are at the transition stage and at different stages of the concrete operational level in the three fields of content. In other words, the addition of up to 50 years of education and life experience **did not lead to further cognitive development processes** and did not promote most of the population towards the formal operational stage. This means that the main control over cognitive development is found in the individual's hereditary components.

It can be concluded that cognitive development is stabilized at the end of junior-high school and through high school. Age, life experience, and academic studies do not contribute significantly to the transition to the formal operational stage. This finding may be an obstacle to achieving the goals of Cognitive Acceleration Projects and Programs. According to our findings, the ability of thinking did not develop during the school years beyond the concrete stage, and the education system failed to contribute significantly to raising the level of thinking for about two-thirds of the population.

The personal data of the interviewees are not involved in determining the level of thinking. This finding reinforces the universal significance of the hereditary factor. Apparently, the individual's ability of thinking is not significantly influenced by the environment, culture, age and sex. The main difference in cognitive development is interpersonal variance. Formal learning and education can be a mediating factor in the learning process and can significantly contribute to students' coping with the difficulties encountered during learning, yet they cannot develop mechanisms that facilitate the transition into the formal operational stage. The practical conclusion is to consider placing an emphasis on adapting teaching environments to the concrete capacity of thinking alongside the attempts to produce cognitive acceleration.

The prevailing perception in educational theory is that teaching and learning are what enable and create cognitive development. Several projects were designed to promote students' general thinking skills in order to overcome their cognitive disabilities, such as programs for cognitive acceleration, and various teaching and learning methods (explicit teaching, inquiry, constructivist learning and so on). Despite all the efforts, the evaluation studies present a hard picture of the distribution of student achievements. The average number of students reaching proficiency in STEM remains low, and the variance in achievements in all science subjects is very high. According to the findings of the current study and previous studies (Shayer & Adey 1981), the cognitive development is held among more than 70% of the population at the concrete operational stage at the age of 12-13, and only a small portion moves to the formal operational stage. This can explain the difficulty many students experience when dealing with abstract topics. This possibility attributes a significant part of the students' difficulties to the biological-developmental factor and not to the environmental factor. A study that focused on the question of whether cognitive abilities continue to develop throughout adulthood indicates similar results (Wattad & Chen, 2023b).

The findings of the current study are in line with the findings of previous studies conducted in Israel and around the world. Those studies examined the cognitive level in adolescence in which the percentage of students who existed in the formal operational stage was less than 30% (Alon, 2003; Habib-Allah & Babai, 2007; 2006; Naser, 2007; Shayer & Adey, 1981). These studies do not fit Piaget's (1971) theory of cognitive development, which assumes that the entire population was supposed to be in the formal operational stage. Analysis of findings from the international Pisa research indicates that, about two thirds of the world population belong to quality groups one two and three that represent the low achieving section of the proficiency scale (Chen & Wattad, 2023).

The fact that only a small percentage of the population attain the formal operational stage can explain the difficulties most of the student population has when dealing with subjects that require abstract thinking such as mathematics, physics and chemistry. it seems that such a problem can exists regarding abstract concepts in the humanities and social sciences. This finding also indicates a discrepancy between students' cognitive abilities and the requirements of the curriculum. Teachers who instruct their students to acquire research and problem-solving skills must be aware of the distribution of their students' thinking levels.

The main conclusion of these results is that the process of cognitive development is driven primarily by an innate factor.

The findings of the current study led us to suggest the possibility that there are two genetic control systems that control the development of cognitive thinking. The first is the SPC (Sensorimotor, Preoperational and Concrete). These capacities are universal and are genetically controlled by a Quantitative Trail Loci (QTL1). The second system, FPF (Formal and Post Formal). It is found in only a quarter of the population and is controlled by a separated control system QTL2. The existence of such control system needs further study at the molecular biology level.

4.1. Domain Specificity Dependence

The findings of the current research second the 'Modularity of the Mind' theory. This theory claims that cognition consists of separate components that function independently. Fodor argues that 'module' is the innate cognitive ability with the unique expertise to process a particular data type within a specific processing system (Fodor, 1983). According to this approach, cognition is not constructed of mental processes which are the result of a joint operation of the general recognition mechanisms, but rather it is constructed of specific independent mechanisms. The findings of the research indicate a significant variance in the distribution of the levels of thinking among the three content domains. Namely, the thinking ability of the participants depends on the content. According to the 'Modularity Theory,' while performing the test, the participants activated different internal modules depending on the content of the task. Although the second and the third tests dealt with a content domain that relates to science in two different subjects, there were gaps in the results and the achievements of the participants in both tests. These findings also support the research findings of Wattad and Chen, who examine the influence of content area on adult cognitive abilities (Wattad & Chen, 2023a).

These findings negate the concept of one general intelligence factor that serves all content domains. This view argues that a positive relationship exists between all the intelligence tests a person have and that one cognitive factor underlies the process of solving many problems.

Core Knowledge is another theory that emphasizes the existence of basic knowledge systems that specialize in different domains. This theory believes that children are born with innate cognitive mechanisms which help them survive. Human beings have been awarded many systems for representing and reasoning (Carey & Spelke, 1996; Spelke, 2003).

4.2. Proposal for a Genetic Model of the Regulation of Cognitive Development

Assuming that the hereditary factor is the main driving force of cognitive development, we propose the following model of inheritance-cognition relationships as an important component in the cognitive development processes. This model combines our findings with the relevant findings of behavioral genetics (Krapohl et al., 2014).

We propose that there are two genetic control systems that control the development of cognitive thinking. The first one is the SPC (Sensorimotor, Preoperational and Concrete) - a control system responsible for the emergence of cognitive abilities in the first three stages of the individual's development.

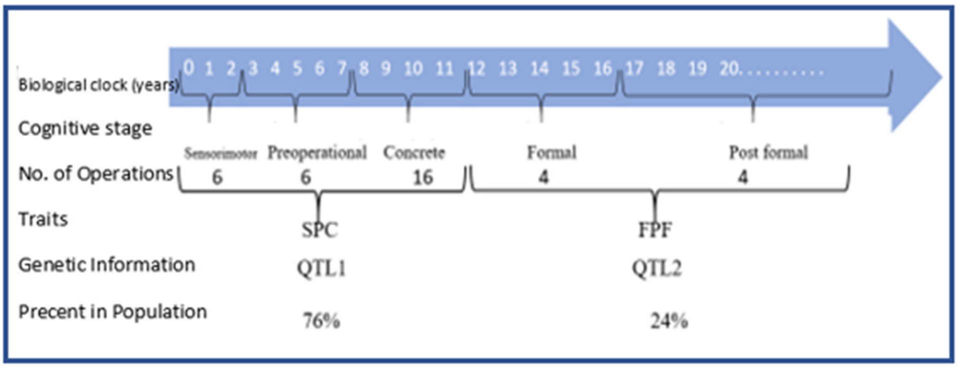
This system is universal. The entire research population has reached the concrete stage of thinking and has acquired the cognitive abilities from previous stages. These features and capabilities appear in a regular order of time,

The second system is FPF (Formal and Post Formal). This control system is responsible for the development of more complex, formal and post-formal thinking abilities. This control system is found in only about a quarter of the population. In other words, formal and post-formal cognitive abilities are not universal.

This study deals with the development of cognitive abilities, which are called "Traits". Most of the behavioral features are complex (love, talk, think ...) and are controlled by a polygenic system (many genes that control one feature). Studies in molecular genetics indicate that there is a group of genes that control properties that are situated in unknown chromosomes. This group is called QTL (Quantitative Trait Loci). This is a variable that includes a genetic information unit without defining a specific gene or its location on the chromosomes.

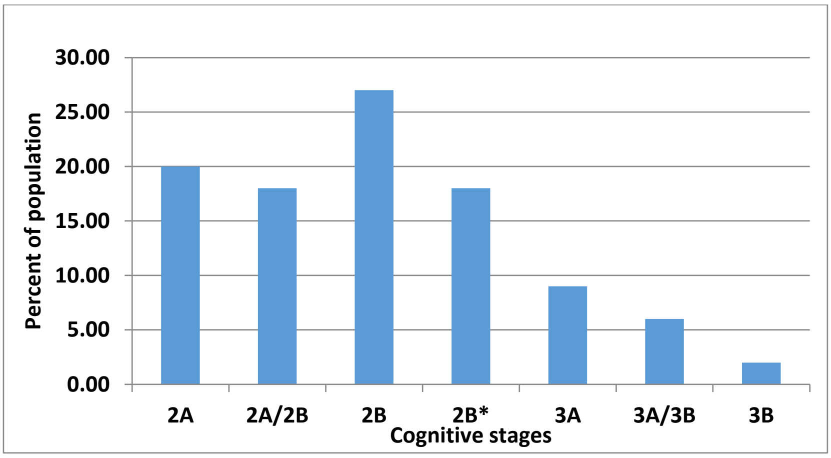
From the findings of the current study and broad population studies, all people undergo three cognitive stages up to the age of 11-12 (SPC). The stages are universal. Each stage is different from the rest and is controlled by a polygenic control system. According to Piaget, during the first three stages of development, the individual acquires up to 28 cognitive traits. Our theoretical assumption is that these traits are inherited by QTL1. Only a quarter of the population develops the features of abstract thinking FPF, which is controlled by a separate control system QTL2. In other words, the QTL2 genetic system is found only in a relatively small part of the population (see the following figure 2).

Figure 2.
A theoretical model of genetic control over cognitive development.



4.3. Literate and Illiterate Population

Figure 3.
Distribution of levels of thinking among the illiterate population.



The distribution of the cognitive levels of the illiterate participants in the test (Figures 3, 4) shows that everyone reaches the stage of concrete thinking, 18% reach the stage of transition from concrete thinking into formal, but 17% do undergo the formal thinking stage. The findings that a significant part of the population reaches the formal thinking stage (3A, 3A/3B, 3B), even though they never went to school, suggest that an innate regulation mainly drives cognitive development.

Figure 4.
Comparison between the distribution of cognitive levels of literate and illiterate groups.

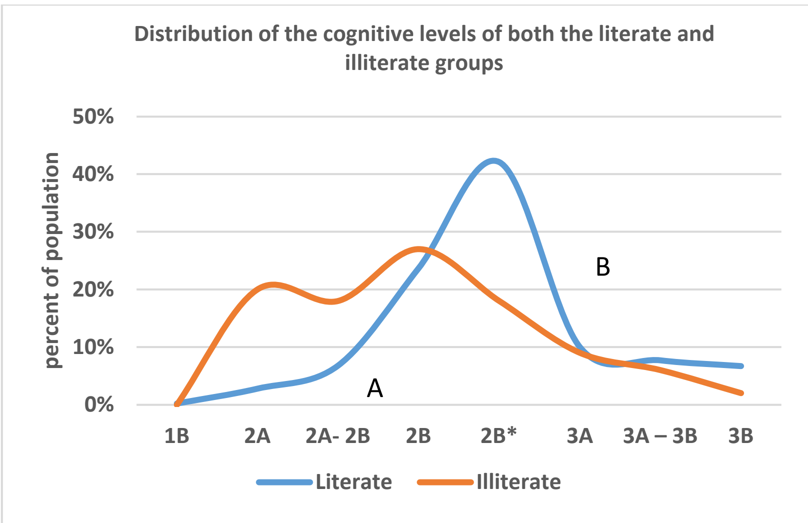


Figure 4 compares the distribution of the cognitive levels of the literate and illiterate groups. When comparing the distribution of cognitive levels between the two study groups, the experimental group (N = 103 illiterate) and control group (N = 1000 literate), it was found that the percentage of the subjects who developed formal thinking was 17% for the illiterate population and 24% for the literate. In other words, the percentage of the illiterate subjects who moved to the formal thinking stage is close to that of the literate, especially at levels 3A and 3A-3B; the small difference left was at level 3B. It can be argued that the people who continued to formal thinking at school contained the genetic component, the hereditary basis for formal cognitive tools that enabled them to move to formal reasoning. School and formal education helped these capabilities to develop phenotypically. These findings do not support the approach of the socio-cultural research, which claims that all humans are born with the same cognitive capacities and social environment, and the internalization of cultural tools brings to the development of high mental functions (Luria, 1979; Ong, 1982; Vygotsky & Cole, 1978).

Another important difference is that 18% of the illiterate participants are in a transition stage, while most of them are still in the early sub-stages of concrete thinking, as opposed to a high percentage (42%) of the literate participants in the transition stage from the concrete to the formal. This finding can be explained by the effect of school on the development of cognitive abilities. The school seems to significantly contribute to transferring most of the students to the end of the concrete and transition phases. There are sub-stages and different performance levels within the concrete stage. It seems that the school catalyzes the students' full potential and capabilities to help them reach their highest level of thinking. In other words, the school contributes to promoting thinking within the concrete stage framework; however, its effect is unable to push development beyond biological constraints.

Acquiring formal operations by a significant portion of the illiterate participants indicates the strong influence of the genetic factor on cognitive development. The current study's findings are consistent with results from twin studies that examined the correlation between the levels of intelligence and genetic relationship (Kovas et al., 2004). A study examining the genetic influence on academic achievement at the age of 16 found that 58% of the variance, in general, was influenced by heredity. This data proves that individual differences in educational achievements do not result from the quality of teaching or the teachers. Most of the variance can be attributed to genetics (Krapohl et al., 2014). We can attribute the development of formal operations among illiterate people to hereditary factors; their lack of literacy and integration in formal education did not prevent them from developing and moving to formal reasoning.

5. FUTURE RESEARCH DIRECTION

- Developing appropriate pedagogy for concrete learners.
- Experimenting digital media to enhance abstract thinking;
- Adapting the curricula to individual cognitive stages;
- Using molecular biology to pursue the genetic model of cognitive regulation.

6. CONCLUSION

The findings that only a small percentage of the population develops to the formal operational stage can explain the difficulties the majority of the population has when dealing with subjects that require abstract thinking such as mathematics, physics and chemistry. This finding also indicates a discrepancy between students' cognitive abilities and the requirements of the curriculum. Teachers who Teach their students to acquire research and problem-solving skills must be aware of the distribution of their students' thinking levels. Piaget stressed that the level of conflict or the size of the gap between the child's existing cognitive structure and the new information or the learning task should not be too large, and if so, the child cannot cope with the conflict at all.

There are many studies that attempted to teach people ‘thinking’. A series of intervention programs for development of thinking and cognitive acceleration have been developed. Yet, the idea that people can significantly improve their thinking capacities for a long term remains controversial.

Based on our research, we suggest distinguishing between cognitive development and cognitive growth. Cognitive development is universally regulated intrinsically by the genome (Innately) and thus cannot be "accelerated". However, cognitive growth is the product of learning and continues over time. It is the kind of knowledge acquired that is constrained by the developmental stage and the specific modules that were differentiated. If our findings are correct, it requires a whole reform in education strategies.

The modularity of the brain is an innate hereditary system. The environment is limited in affecting it, nor can we change it. It exists within the cognitive structures of the individual an effective metaphor for the products of the cognitive development can be described a s a toolbox (operations), which is used to solve different problems. Up to the concrete stage, 36 toolboxes or operations were developed, which are responsible for solving problems such as classification, retention, ordering, connection, etc. At the formal reasoning stage, a group of operations called INRC is added to the toolbox, enabling abstract logical thinking and making combinations of operations for solving infinite problems**.**

'Modularity Theory,' the core knowledge and the metaphor of the "toolbox," indicates the effect of the learned content domain on the participants' way of performance and, later on, the distribution of the thinking levels within the population. A fact that exists within the scientific community is that scientists at the level of formal and post-formal stage level lead and specialize in specific content domains and not in all domains of knowledge. Nobel Prize is awarded according to the domain of expertise: physics, chemistry, physiology, medicine and literature. In other words, even those who reach higher levels of thinking have a special ability in a defined content domain and not all the domains**.**

The main conclusion of these results is that the process of cognitive development is largely driven by an innate factor, or, in other words, a hereditary factor. If it was the environmental factor, it would not be possible to explain how illiterate people who never attended school have reached formal thinking stage.

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