SOME DATA ABOUT DEVELOPMENT OF COGNITIVE ABILITIES OF PRIMARY SCHOOL PUPILS

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Summary

The paper discusses the structure and development of cognitive abilities. Various theories of structure and development of intelligence are stated.

The aim of the research is to examine the development of abilities of primary schools pupils aged 11 to 14. Subjects sample is random and it consists of 397 pupils of Zagreb primary schools which are tested by intelligence tests while attending fifth and eighth grades.

In the research we used the cybernetic model of cognitive abilities by K. Momirović, K. Bosnar and S. Horga, according to which there are three basic cognitive abilities that can be presented as functions of input, parallel and serial processors.

The results of the subjects are presented in two ways: as standard total results and as results on the first main component. In the latter, we applied differential pondering of test performance, and the scale values of particular problems in the test are calculated using inverse integral of normal distribution. All results are presented in percentiles.

The results show that the input processor is the fastest to develop, then follows the parallel processor, and the serial processor is the slowest; this confirms already existing knowledge about development of cognitive abilities.
Key words: development of cognitive abilities, structure of cognitive abilities.

1. INTRODUCTION

The structure of cognitive abilities has been the subject of many research papers. The general conclusion is that there are differences in comprehension of structure of cognitive abilities. Besides Spearman's monarchistic model of intellect structure, there are oligarchic models of Thurstone and Guilford, which differ considerably from each other, and various hierarchic models; ones suggested by Burt and Vernon are the best known among them.

Charles Spearman, British scientist and a follower of Galton, was the first to raise the question of structure of cognitive space. He developed a theory, based on his research, according to which there is a general factor present in solving all cognitive problems, i.e. general cognitive ability, and a greater number of specific factors, i.e. specific abilities, depending on specific circumstances of particular problem situation.

In later papers, influenced by other researchers' criticism and based on his own research, Spearman partly revised his theory and added specific factors (that are orthogonal by definition) to the general one, and the "specific factors" that are in correlation (these factors were later named as group factors).

Spearman interpreted the general factor as a mathematic quantity that explains correlations between various kinds of cognitive problems. He ascribed to it the title of mental energy. He also developed a method of variable inter-correlation analysis, considered to be the starting point of factor analysis.

At the same time (in the beginning of 20th century) in the U.S.A. Thorndike suggested a multi-factor theory of cognitive abilities, the so-called atomistic theory. According to this theory, every cognitive ability consists of numerous different elements or factors (not factors used in factor analysis). Any cognitive act includes a different combination of these elements. As every cognitive operation includes somewhat different element structure, cognitive space consists of numerous specific abilities.

A similar opinion is expressed by Thomson (1939) in his "sampling theory". According to this theory, every cognitive ability is determined by a special sample of units (specific parts of central nervous system), which are very numerous. The inter-connection between two theories is the stronger the greater is the similarity between the samples of units of these abilities, i.e. the greater is the number of the same units in the sample. According to "sampling theory", specific cognitive processes activate limited areas of central nervous system, and the increase of generality level of a cognitive ability proportionally activates wider areas of central nervous system.

Using multi-factor analysis, Alexander (1935) isolated three group factors of intelligence: verbal factor, practical factor and factor that is responsible for success in school. He also established the existence of general factor. Alexander's research showed that the general factor of intelligence is not sufficient for explanation of total valid variance of the cognitive variables system. Tests are divided in groups according to their similarity. The representatives of these groups are so-called group factors, which are inter-connected. A group factor is a common factor for a group of variables; with the development of factor analysis, this has been accepted as a basic definition of factor.

L. L. Thurstone's model of mental abilities (1936) represents a kind of compromise between Spearman's and Thorndike's theories. According to this model (theory), intellectual abilities cannot be explained by any general factor, nor by an infinite number of specific factor, but by a limited number of group factors, by primary mental abilities that are relatively independent.

Based on grêat amount of empirical research, Thurstone et al with high level of probability established six primary mental abilities, i.e. factors: numeric factor (N), verbal factor (V), spatial factor (S), factor of verbal fluency (W), factor of reasoning (R) and mnemic factor (M).

In some papers, instead of factor of reasoning, two factors of narrower range: factor of inductive reasoning (I) and factor of deductive reasoning (D). Some research produced also the perceptive factor (P).

Many factor analyses have shown that primary mental abilities are not orthogonal (independent), and this is the basic assumption of Thurstone's model. Since the inter-correlations of primary mental abilities were positive and often considerably high, Thurstone accepted the possibility of existence of the general cognitive factor in the space of second order, so his model could be treated as a hierarchic model as well.

Model suggested by John Guilford (1956) classifies cognitive abilities into three categories. The first way of classification is made according to operations or sorts of processes that occur at solving cognitive problems. This way of classification enables to distinguish five groups of intellectual activities: factors of cognition, memory, convergent thinking, divergent thinking and evaluation. The second way of classification is based on contents, which can be figurative, symbolic, semantic and social. When an operation is applied to some contents, six kinds of products are possible: units, classes, relations, systems, transformations and implications. Since there are five operations, four contents and six products, total number of cognitive abilities according to this model is 120 special abilities. Although the author did not succeed in empirical verification of all 120 cognitive abilities, he maintains that their number is even greater and that the structure of cognitive space is extremely complex.

The best known hierarchic models have been suggested by Burt (1949) and Vernon (1950). Burt's model is known under the title of successive dichotomies model. The first dichotomy consists of dividing the general factor of thinking into general cognitive and general practical factors. Among the practical abilities Burt includes psycho-motorial abilities and ones related to spatial orientation and manipulation of mechanical objects. Toward the bottom of the hierarchy, general cognitive and general practical factors branch to narrower abilities. The model envisages a five level hierarchy of abilities. In Vernon's hierarchical model, general cognitive factor is at the top of the hierarchy, in the space of the fourth order. In the space of the third order this factor is divided to two factors: verbal-educational factor and spatial-mechanic factor. In the space of the second order the educational factor is divided to: verbal comprehension, verbal fluency and numerical factor, and spatial-mechanic factor is divided to spatial visualization and mechanic information. In the space of the first order there are many specific cognitive abilities.

Raymond B. Cattell published in 1941 his theory of two basic types of intelligence: fluid (gf) and crystallized (gc) intelligence. During the sixties, Cattell and Horn were performing extensive research and established that these are two distinct general factors of intelligence. Factor of fluid intelligence is to the greater extent influenced by genetic factors, and the factor of crystallized intelligence is influenced by them to a much lesser extent. Fluid intelligence is closely connected to metabolic and biological processes; it is so-called natural intelligence. Crystallized intelligence is considerably influenced by social surroundings, especially by the process of education.

Reuchlin and Valin (1953) suggested a simple model of cognitive abilities, according to which there are three basic cognitive abilities: perceptive reasoning, eduction of relations and symbolic reasoning. Perceptive reasoning enables to receive and decode the information, as well as to solve simple problems of perceptive nature. Eduction of relations is the ability to establish the relations between objects and phenomena, i.e. between elements within a given structure. Symbolic reasoning is the ability to operate with symbols on an abstract level. Since the correlations between these abilities were substantial and positive, a possibility of existence of a general factor was also predicted. In our country, this model has been frequently verified and its credibility has been confirmed, concerning both the three basic cognitive abilities and the general cognitive factor.

This model is the basis for the cybernetic model of cognitive processes by K. Momirović, K. Bosnar and S. Horge (1982), that is used in examining the development of cognitive abilities in this research.

Among the best known recent theories of cognitive abilities are Gardner's and Sternberg's theories.

Howard Gardner (1983) suggested the theory of multiple intelligence. According to this theory, there are seven types of intelligence: linguistic, logical-mathematical, spatial, musical, physical-kinaesthetic, inter-personal and intra-personal. Linguistic intelligence is essential in activities of reading, writing, speaking and listening. Left hemisphere is important for this type of intelligence. Logical-mathematical intelligence is applied in solving abstract logical and mathematical problems. Spatial intelligence is important in visualization of relations of objects in space. Right hemisphere of the brain is essential for this ability. Musical intelligence is expressed in composing, singing, playing an instrument, and in understanding music itself. Although the localization is not completely clear, the right hemisphere is more important. Physical-kinaesthetic intelligence is essential for performing complex motorial structures, for example, in sports and dance. Motorial cortex is essential; every hemisphere controls the opposite side of the body. The right-handed have their motorial controlled primarily by the left brain hemisphere. Inter-personal intelligence is essential for relations and communication with other people. Persons having a high level of this intelligence are very good at perceiving differences between people, their moods, temper, motives, intentions and so on. Intra-personal intelligence consists of understanding oneself. It relates to the person's sensibility for its own mood, capabilities, properties, motives. It clearly follows that one general ability does not exist. This theory has some similarities with Thurstone's theory of primary mental abilities.

Robert Sternberg (1984) suggested triarchic theory of intelligence, by which he tries to explain the relations between intelligence and person's interior world, between intelligence and external world of a person, and between intelligence and experience. The first part is concerned with problem solving strategies, the second — with question of adaptation to external surroundings, and the third part — with solving problems on various experience levels in one's life. It follows that this theory is oriented to explaining cognitive processes, their function in adaptation to external surroundings, and to analysis of relations between cognitive processes and experience, where experience is defined as interaction between problem solving strategies on particular levels of development and effects of adaptation to external surroundings. This theory has some similarities with Piaget's theory, which is also concerned with processes that go on during problem solving.

Starting from Reuchlin's and Valin's model, Luria's theory (1966) and cybernetic model of Das, Kirby and Jarman, (1975), Momirović, Bosnar and Horga (1982) suggested a cybernetic model of cognitive processes, which is a two-level hierarchic model. According to this model, on the first level there are three cognitive processors: the input processor, the parallel processor and the serial processor. On the second level there is a central processor. The input processor decodes and structuralizes information from external surroundings. At the same time, the parallel processor processes a greater number of information flows and simultaneously searches short-term and long-term memories. The serial processor processes and analyzes information in succession and in the same manner searches short-term and long-term memories. Central processor controls and co-ordinates the work of these processors.

The input processor corresponds to the Reuchlin's and Valin's factor of perceptive reasoning, Thurstone's perceptive factor, Alexander's practical factor and Horn's and Stankov's factor of general visual and general auditive function. Parallel processor corresponds to Reuchlin's and Valin's relation eduction factor, Spearman's factor of eduction of relations and correlates and Cattell's and Horn's factor of fluid intelligence. Serial processor corresponds to Reuchlin's and Valin's symbolic reasoning factor, Vernon's verbal-education factor, Cattell's and Horn's crystallized intelligence factor and Thurstone's verbal and numerical factors. Central processor corresponds to Spearman's general cognitive factor and Eysenck's, Burt's and Vernon's factors of general intelligence.

According to Piaget (1964), there are four basic developmental stages: senso-motorial, pre-operative, concrete-operative, and the period of formal operations. Senso-motorial period lasts from birth to the age of two. Within this period Piaget distinguishes several phases, during which particular senso-motorial abilities and beginnings of cognitive processes are being developed. Pre-operative period, between age two and seven, is a period of speech development and intuitive intelligence. Between age seven and twelve, cognitive processes proceed on a concrete level. After age twelve, there is a period of abstract intelligence, problem solving based on principles of formal logic and understanding notions outside their concrete meaning as well. To Piaget, two basic cognitive processes are assimilation and accommodation. The former consists of embedding the new information (problem) into already existent cognitive structure (scheme). When a problem cannot be solved in this way, then emerges the latter process, which consists of embedding the new information into a new cognitive structure. These two processes proceed at the same time and they are the basis for problem solving and learning. Piaget's theory is a clinical theory, and it originated by detailed study of cognitive processes of a few subjects.

The curve of development of general intelligence (general cognitive factor) shows a tendency of fast increase until puberty, then it slows down and turns to a plateau somewhere between age eighteen and twenty. After this period, general intelligence stays at the reached level until age forty, when a slight decrease starts, and accelerates after age sixty. But, one must emphasize that there are considerable individual differences. In individuals of above average intelligence, the development of cognitive abilities lasts longer, and the decay starts later. Besides, there are considerable differences in development of particular cognitive abilities.

The differences are obvious even on the level of two basic types of intelligence according to Cattell and Horn — fluid and crystallized intelligence. The curve of fluid intelligence reaches its summit about age 18, and after that there is a fall, slight until age 25, then a little steeper between age 25 and 35, and after age 35 this fall slows down. As opposite from fluid intelligence, crystallized intelligence reaches its peak after age 30, with the tendency to stay at maximum level even after age 40. But, one must emphasize that about 95% of crystallized intelligence develops until age 18; that means that the rise of the curve after age 18 is minimal. Both curves are characterized by relatively steep rise until age 18. They differ at the point of slowing down: the rise of crystallized intelligence slows down at age 18, and the rise of fluid intelligence slows down at age 15. The development of crystallized intelligence exists even after age 18, because it is influenced by process of education, which continues after age 18. It may be argued that the crystallized intelligence is, in a sense, a reflection of education during the whole life-span. Cattell and Horn maintain that one of the basic reasons for decay of fluid intelligence is the decline of cognitive speed, which accelerates after age 18.

Thurstone reported data for seven primary mental abilities. According to development curves, it follows that around 80% of particular abilities develops at the following ages: perceptive ability — 12 years, spatial ability — 14 years, reasoning ability —- 14 years, memory ability — 16 years, numerical ability — 16 years, verbal ability — 18 years and verbal fluency — after age 20. In these data it is evident that there are considerable differences in speed of development of particular cognitive abilities. It is also evident that those abilities that cannot be influenced by education processes and experience in general later come to maturity, i.e. their development takes more time. As a rule, the faster the development of particular ability, the influence of genetic factors is stronger.

The more gifted a person is, the development of cognitive abilities takes more time, and when a plateau is reached, the decay is slower. In a person of below average intelligence, the development of cognitive abilities end earlier, depending on the degree of intellectual retardation. Besides, the decay of intelligence in these persons starts earlier and proceeds the faster the lower is the intellectual level achieved.

2. THE AIM OF THE RESEARCH

The aim of the research is to verify the hypothesis of unequal speed of development of particular cognitive abilities. It is known that perceptive abilities are the fastest to develop, and verbal are the slowest. Cognitive abilities are tested two times by the same tests, on a sample of primary school pupils, aged 11 to 14. Tests are construed according to the cybernetic model of cognitive abilities by K. Momirović, K. Bosnar and S. Horge (1982) that envisages three basic cognitive processors: input, parallel and serial processor. The functions of these processors correspond to: perceptive reasoning, eduction of relations and correlates and symbolic reasoning, respectively.

3. THE METHOD

Sample of subjects is selected as random sample, and consists of 397 pupils of Zagreb primary schools, of both sexes, tested by cognitive tests when they were 11 and 14.

Three cognitive tests were applied. The IP test for examining the efficiency of input processor consists of 24 problems, and is construed by K. Momirović, K. Bosnar and F. Prot. The PP test examines the efficiency of parallel processor, and the SP test examines the efficiency of serial processor. Both tests contain 20 problems, and are construed by M. Mejovšek.

The results of the subjects were determined in two ways. The first was the standard manner, the so-called brutto result (B), the total of all correctly solved problems, where every correctly solved problem had a value of one point. For these results we calculated the arithmetic mean and standard deviation. Results were determined also as component scores (K) (results on the first main component of problem inter-correlation matrix). In the second manner we used differential pondering of test performance; the scale values for particular problems were determined using inverse integral of normal distribution. Both results are shown in percentiles.

Due to technical reasons, in the first manner of evaluation of the results (B), incorrectly solved problem was valued as 1.0, and correctly solved problem was valued as 2.0.

4. THE RESULTS

Table 1. IP test results (percentiles)

Percentiles	B11	B14	K11	K14
1	28.36	36.91	-10.24	-11.94
3	33.99	43.02	- 6.43	- 2.96
5	35.90	43.98	- 4.72	- 1.58
10	38.95	45.10	- 2.76	- .65
20	40.89	46.01	- 1.04	.00
30	42.75	46.86	- .26	.26
40	43.06	46.95	.28	.32
50	44.11	47.04	.71	.38
60	45.05	47.80	1.09	.44
70	45.98	47.85	1.40	.50
80	46.20	47.90	1.59	.56
90	47.18	47.95	1.94	.62
95	47.71	47.98	2.03	.65
97	47.83	47.99	2.07	.67
99	47.94	48.00	2.10	.68

M11=43.42 s11=3.77 M14=46.85 s14=1.85

Table 2. PP test results (percentiles)

Percentiles	B11	B14	K11	K14
1	21.94	25.04	- 5.65	- 8.61
3	23.89	27.83	- 5.06	- 6.44
5	25.01	28.92	- 4.48	- 4.94
10	26.07	31.14	- 3.67	- 2.99
20	28.06	34.01	- 1.65	- .71
30	30.03	35.11	- .88	- .02
40	31.81	35.86	- .15	.48
50	32.99	36.00	.55	.86
60	33.87	36.93	1.11	1.06
70	34.98	37.04	1.61	1.31
80	35.77	37.96	1.97	1.49
90	36.01	38.11	2.46	1.61
95	37.06	38.18	2.63	1.66
97	37.13	38.77	2.84	1.69
99	37.89	38.92	2.91	1.71

M11=32.08 s11=3.91 M14=35.40 s14=2.96

In examining the results in the tables, one should consider that the test of input processor efficiency contains 24 problems, and the test of parallel processor efficiency, as well as the test of serial processor efficiency, consist of 20 problems each.

The tables show that the subjects

achieved the highest results in the IP test, then in the PP test, and the poorest results they achieved in the SP test.

Table 3. SP test results (percentiles)

Percentiles	B11	B14	K11	K14
1	22.13	24.75	- 2.14	- 4.07
3	22.88	25.97	- 1.88	- 3.96
5	23.78	26.15	- 1.76	- 3.14
10	23.97	27.71	- 1.51	- 2.27
20	24.96	29.03	- 1.20	- 1.47
30	25.89	29.95	- .91	- .88
40	26.80	31.11	- .59	- .36
50	25.94	31.92	- .34	.06
60	27.82	32.19	- .06	.46
70	27.96	33.08	.33	1.02
80	28.90	33.99	.85	1.50
90	29.89	35.89	1.97	2.55
95	30.86	37.03	3.00	2.71
97	32.75	37.25	3.74	2.97
99	33.89	38.88	7.19	3.55

M11=27.28 s11=2.32 M14=31.64 s14=3.13

Although one could, based on results, suppose that the time for solving the IP test was too long, and that the problems in the SP test were too difficult (about the metric characteristics of the tests, see Mejovšek, 1993), still remains the fact that these differences are so great that they cannot be explained only in terms of validity of the tests. It is evident that there are also differences in the development of particular cognitive abilities. The results can be explained as being in harmony with data about development of cognitive abilities, as described by Thurstone for primary mental abilities and Cattell and Horn for the factors of fluid and crystallized intelligence.

The input processor matures first, then the parallel processor, and the latest to achieve maturity is the serial processor, which is, philogenetically, the youngest processor. The input processor is by its function the simplest and under greatest influence of genetic factors. The surroundings has the strongest influence on the serial processor, and this influence can last for a relatively long period of time. In comparison with the other two processors, the greatest deal of knowledge and experience is embedded in the functioning of the serial processor. According to Thurstone's results, 80% of the perceptive factor, that corresponds to the input processor efficiency, develops until age 12. At age 19, this ability is almost completely developed. Spatial ability and reasoning ability, according to Thurstone, at age 12 reach about 80% of its total development potential, and at age 19, they reach more than 90% of total development potential. These primary mental abilities by their functions are congruent to the parallel processor efficiency. Those primary mental abilities that correspond to the serial processor functions — numerical ability, verbal ability and verbal fluency — are the last to develop. This is especially valid for verbal factor and verbal fluency factor. These abilities reach their maximum in later years.

The results of this research also confirm that cognitive abilities do not develop at the equal pace. According to accepted cybernetical model with three cognitive processors, it is clear that they could be sorted according to the pace of reaching maturity and that this rang is determined by the relations between genetic and social factors. The education process can to the greatest extent influence the development of serial processor, to the lesser extent it can influence the development of the parallel processor, and to the least extent it can influence the development of the input processor. The development of the input processor can be influenced in the shortest time; longer time is needed to influence the development of the parallel processor, and the longest is needed to influence the development of the serial processor. The serial processor efficiency was tested using a test of synonyms in which there were synonyms on the concrete level and on the abstract level. Pupils at age 11 can solve very few such problems. Performance at age 14 is better, which is logical, but even at this developmental level, the abstract synonyms present a considerable problem for the subjects.

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