

Features of the Intelligence Structure of Future Digital Technology Professionals

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ABSTRACT

At present, the problem of predictors of successful learning of programming and mastery of computer thinking is becoming especially urgent. The authors proposed to analyze the structure of the intellectual abilities of students of different education profiles to identify the intelligence features of future information technology specialists. The study involved 319 first-year students of the Ural State Pedagogical University of Yekaterinburg. To study the characteristics of computer intelligence indicators, a universal intellectual test was used. The following factors were identified in the structure of the intelligence of computer scientists:

1) probabilistic-mathematical, 2) verbal-informational, 3) visual-spatial. The mathematical intelligence of computer scientists is not associated with verbal-logical thinking because the leading factors are the ability to consistently work out the hypotheses put forward on the basis of an intuitively distinguished general property of a cognizable phenomenon. The authors also found that digital technologists quickly switch to various mental actions, relying on various forms of spatial manipulations with a cognizable object.

Keywords: *intelligence, computer thinking, intelligence structure of digital technology specialists, general intelligence, spatial abilities*

1. INTRODUCTION

We live in a digital ecosystem full of software-driven objects. In this context, it is difficult to disagree with L. Manovich [1] that the ability to process computer language becomes an inevitable skill, a new kind of literacy that allows us to fully and effectively participate in digital reality, which we are surrounded and programmed. M. Roman-Gonzalez believes that a person is literate when he can read and write in computer language [2]. The advantage of numerical thinking as a positive factor in the cognitive development of learners has been recognized long time ago [3]. In the current digital era, numerical mental operations have become required everywhere, being the basic skill of organizing communication, science, culture and business in our society [4], therefore, computer thinking is considered as a necessary skill for creating and consuming information technology products. J. Wing determined that computer thinking “includes solving problems, designing systems and understanding human behavior, relying on fundamental concepts of computer science” [5, p. 33]. In 2011, J. Wing clarified that computer thinking is the organization of thought processes aimed at formulating problems and solving them in such a way that solutions are presented in digital form. In general, computer thinking can be conceptualized as thought processes involved in the formulation of intellectual problems, the

solutions of which can be represented in the form of computational steps and algorithms.

K. Brennan and M. Reznik describe the structure of computer thinking, which includes three key dimensions:

1. “Computing concepts” (sequences, cycles, events, concurrency, conditional expressions, operators and data);
2. “Computational practice” (experiments and iterations, testing and checkout, reuse and re-mixing, abstraction and modularity);
3. “Computational perspectives” (expression, connection and interrogation) [6].

Computer thinking involves the development of thinking skills of algorithmic solutions to problem situations, a high level of intelligence (general cognitive abilities) and the ability to reason, plan and solve intellectual and practical problems [7].

A. Ambrosio, C. Javier, and F. Georges suggested, within the framework of the cognitive approach, to consider computer thinking as a synthesis of the following three ability factors from the Kettell-Horn-Carroll intelligence model [8]:

1. Fluid intelligence (Gf), defined as: the use of intentional and controlled mental operations to solve new problems that cannot be solved automatically. Thought operations include conclusions, the formation of a system of concepts, classification, generalization and hypothesis testing, identifying relationships, understanding the consequences, solving problems, extrapolating and transforming information. Inductive and deductive thinking are usually considered hallmarks of Gf [9].

2. Visual processing (Gv), defined as “the ability to generate, store, retrieve and transform visual images and sensations. Abilities are usually measured by tasks (figurative or geometric stimuli) that require the perception and transformation of visual forms or images and / or tasks that require maintaining spatial orientation relative to objects that can change or move in space [9].

3. Short-term memory (Gsm), defined as “the ability to perceive and maintain awareness of a limited number of information elements in an immediate situation (events that occurred at the last minute or so). A system with limited bandwidth, which loses information quickly through the destruction of memory traces, if a person activates other cognitive resources to update information in direct awareness [9].

P. Buffum and others believe that the development of a student learning assessment procedure is relevant in the field of computer science and related disciplines such as physics, because the need for young people to master computer technology is growing [10]. At present, there is no toolkit for differentiating computer abilities in domestic psychological and pedagogical practice. The authors made an attempt to determine the specific structure of the intellectual characteristics of future digital technology specialists.

2. RESEARCH METHODOLOGY

The study involved 319 first-year students of the Ural State Pedagogical University of Yekaterinburg. Respondents are residents of different cities and other settlements of Sverdlovsk, Chelyabinsk, Tyumen, the Republic of Bashkortostan, the city of Yekaterinburg and other regions in order to provide a representative sample for different representatives of the general population. The sample was random and stratified by gender and age. The age of the respondents ranged from 17 to 19 years, the average age was 17.8 years ($SD = .55$). Data was collected from October 2017 to December 2019. Test books were completed on a voluntary basis by respondents during two regular 45-minute sessions in the presence of a trained researcher.

The authors of the study proceeded from the hypothesis that the intelligence structure of future digital technology specialists has its own specifics compared to future linguists and psychologists.

To study the characteristics of computer intelligence indicators, a universal intellectual test (UIT HRC) was used, containing the following subtests:

1. Awareness "- evaluates erudition, the degree of familiarization with culture, cognitive interests, the amount of long-term memory.

2. "Hidden figures" - the flexibility of perception, the field of independence.

3. "Missing words" - understanding of the content, speed of perception of speech material.

4. "Arithmetic problems" - the ability to concentrate active attention, practical mathematical thinking.

5. "Comprehensibility" - the ability to build conclusions on the basis of life experience, common sense, logical judgments.

6. "Image Exclusion" - flexibility, unconventional thinking, insight, the ability to find perceptual-logical connections.

7. "Analogies" - a sense of language, combinatorial-logical thinking, the ability to find approximate solutions.

8. "Number series" - inductive thinking, the ability to operate with numbers, a sense of rhythm.

9. "Inference" - deductive thinking, the ability to operate with ordered information, noise immunity judgments.

10. "Geometric addition" - figurative thinking, spatial imagination, combinatorial abilities.

11. "Learning words" - the effectiveness of memory processes, the ability to concentrate, endurance to mental stress.

The combination of several subtests of the universal intellectual test (UIT HRC) forms a number of abilities that make up the structure of intelligence:

1. Verbal Intelligence

2. Graphic intelligence

3. Numerical abilities

4. Linguistic intelligence

5. Mathematical

6. Logical thinking

7. Memory Efficiency

8. Shaped design

9. Theoretical and practical knowledge

10. Probabilistic decisions

11. Concentration

An exploratory factor analysis implemented in the Statistica 12 statistical package was used to identify the features of the intelligence structure of a sample of respondents.

Respondents were divided into three groups, depending on the profile of training (which, in turn, the respondent chooses based on the idea of their abilities in the chosen field of activity): 96 respondents studying for IT specialists, 121 respondents studying at the faculty of foreign languages and 102 respondents studying for the specialty of psychologist.

Thus, the structures of the intelligence of respondents of different training profiles were analyzed.

Table 1 Factor structure of intelligence of computer scientists

indicators	Probabilistic-mathematical	Verbal-information	Visual-spatial
Verbal	0,128918	0,950959	0,263033
Graphic	0,127109	0,163506	0,949778
Numbers	0,887421	-0,199925	0,181661
Linguistic	0,775263	0,483502	-0,069442
Maths	0,887421	-0,199925	0,181661
Logical thinking	-0,169201	0,831681	0,427859
Memory Efficiency	-0,589752	0,712202	0,146696
Shaped design	0,027933	0,318623	0,892237
Theoret and pract knowledge	0,403750	0,742164	0,031898
Probabilistic decisions	0,708322	0,352894	0,231536
Concentration	0,900458	0,174541	-0,104155
Expl.Var	4,061616	3,251023	2,108233
Prp.Totl	0,369238	0,295548	0,191658

The results of factor analysis of the structure of the intelligence of computer scientists are presented in table 01. The data in the table confirm that the structure of the intelligence of computer students consists of three factors. The 1st factor with a total dispersion of 4.06 can be designated as "Probabilistic-mathematical". This factor included indicators such as numerical abilities (0.887), linguistic abilities (0.83), mathematical abilities (0.887), probabilistic solutions (0.708), and concentration (0.9004). Analyzing this factor, it can be noted that in this factor, such an indicator as concentration of attention is most pronounced.

In other words, computer scientists have a developed system of attentive abilities, which is the basic substructure for making hypothetical-deductive decisions based on in-depth information analysis. The mathematical intelligence of computer scientists is not associated with verbal-logical thinking because the leading factors are the ability to consistently work out the hypotheses put forward on the basis of an intuitively distinguished general property of a cognizable phenomenon. Categorical thinking does not improve the success of computer science in foreign languages and mathematical concepts. They will better understand concepts if they are included in the context of practical activities (for example, software development). In order to ensure efficient processing of information, computer scientists need to ensure intensive involvement in the cognitive process, thanks to the formation of after random attention and intrinsic motivation.

The 2nd factor with a total dispersion of 3.25 can be designated as "Verbal-Information". This factor includes such indicators as verbal abilities (0.95), the ability to use

theoretical and practical knowledge (0.74), logical abilities (0.83), and memory efficiency (0.71). Analyzing this factor, it can be noted that for computer science, the verbal component of intelligence is not connected with the mathematical one, because of the ability to learn not only natural languages, but also programming languages designed for machines. When mastering computer languages, the memory that was developed in primary school age is used, which develops in parallel with logical abilities and the ability to control one's own cognitive processes. Moreover, a complex of verbal symbolizations is not mastered as a set of discrete characters, but as an integral system of specific semantic structures in a software algorithm. The group of abilities combined in this factor is expressed in the ability to formulate and solve problems, based on the fundamental concepts of computing and using the syntax logic of programming languages: main sequences, loops, iterations, conditions, functions and variables. Working memory, which allows computer scientists to maintain the desired logical relationship without the need for constant monitoring of the process of making an informational decision.

The 3rd factor with a total dispersion of 2.1 can be designated as "Visual-spatial." This factor includes such indicators as graphic abilities (0.949) and abilities for figurative design (0.892). Analyzing this factor, it can be noted that spatial abilities are an important component of the intelligence structure of future digital technology specialists, since they must process information sequentially circulating in small circles contained in each information structure to decide whether the system under test is working. Specialists of digital technologies quickly switch to various mental actions, relying on various forms of spatial manipulations with a knowable object.

Table 2 Factor structure of linguistic intelligence

indicators	Categorical thinking	Spatial	Mnemological abilities
Verbal	0,685157	0,112040	0,674088
Graphic	0,357360	0,897837	0,112548
Numbers	0,875926	0,290666	0,081656
Linguistic	0,812345	0,105055	0,367786
Maths	0,875926	0,290666	0,081656
Logical thinking	0,814613	0,198791	0,239429
Memory Efficiency	0,201853	0,146511	0,816059
Shaped design	0,129441	0,965514	0,080673
Theoret and pract knowledge	0,176015	0,066920	0,850199
Probabilistic decisions	0,735565	0,218761	0,429408
Concentration	0,864049	0,209544	0,269278
Expl.Var	4,831256	2,088117	2,325191
Prp.Totl	0,439205	0,189829	0,211381

The results of factor analysis of the linguistic intelligence structure are presented in table 02. The table data confirm that the linguistic student intelligence structure consists of three factors.

The 1st factor with a total dispersion of 4.8 can be described as “categorical thinking”. This factor includes indicators such as numerical abilities (0.87), linguistic abilities (0.81), mathematical abilities (0.87), probabilistic solutions (0.73), and concentration (0.86). Analyzing this factor, it can be noted that in this factor, such an indicator as concentration of attention is most pronounced. Categorical thinking consists of the structural elements of thought, which can be represented graphically and schematically. The language of diagrams and visual images is rather difficult to reduce to a verbal description. Intellectual categories carry a semantic load that is very difficult and sometimes impossible to convey using ordinary reasoning. A clear and schematic representation of categories is as important as their verbal description, allowing you to comprehend, cover with a single eye complex categorical relationships.

Future linguists are accustomed to categorizing the semantics of sign systems and tend to pay attention to those cognitive goals that increase the predictability of reality, expanding without violating the boundaries of the existing individual system of mental space.

The 2nd factor with a total dispersion of 2.08 can be designated as “Visual”. This factor includes such indicators as graphic abilities (0.949) and abilities for figurative design (0.892). Analyzing this factor, we can note the existence of a relationship between linguistic models and spatial judgments. There are three main ways in which spatial orientation is semantically expressed: from the point of view of the properties inherent in the objects themselves (“house facade”, “nose” “plane”), their location (“west of Uralmash”) or their location relative to the speaker’s orientation or listener (“to your left”, “to the right of the toolbar”).

The 3rd factor with a total dispersion of 2.3 can be designated as "Mnemological abilities." This factor included indicators such as verbal ability (0.67), memory efficiency (0.81), and the use of theoretical and practical knowledge (0.85). This factor contains a complex of mnemological abilities containing procedural and declarative memory. Procedural memory is a dynamic system that contains knowledge on how to perform various intellectual and practical actions. Declarative memory is a repository of a person’s existing knowledge, symbolic knowledge (subdivided into semantic and episodic memory. Declarative memory gives a person the opportunity to store associations acquired during the training process and actualize them in real activities.

Table 3 Factor structure of psychologists' intelligence

indicators	logical-mathematical	spatial	Collaborative intelligence
Verbal	0,283072	0,151563	0,920471
Graphic	0,185246	0,940127	0,218747
Numbers	0,947514	0,158528	0,184621
Linguistic	0,268157	-0,040683	0,836745
Maths	0,947514	0,158528	0,184621
Logical thinking	0,758350	0,146325	0,221357
Memory Efficiency	0,121414	0,093744	0,836718
Shaped design	0,108604	0,952885	0,043281
Theoret and pract knowledge	0,115229	0,434656	0,739236
Probabilistic decisions	0,229405	0,455403	0,747751
Concentration	0,658054	0,016524	0,631274
Expl.Var	3,082491	2,293507	3,918505
Prp.Totl	0,280226	0,208501	0,356228

The 1st factor with a total dispersion of 3.08 can be designated as “logical-mathematical”. This factor included indicators such as numerical abilities (0.94), linguistic abilities (0.758), logical abilities (0.758), mathematical abilities (0.94) and concentration (0.658). Psychologists with a logical-mathematical style of thinking use reasoning and the logical ordering of learned information. They are able to build hypothetical-deductive reasoning in order to answer practical questions, classify and systematize problems.

The 2nd factor with a total dispersion of 2.29 can be designated as “Spatial”. This factor includes such indicators as graphic abilities (0.94) and abilities for

figurative design (0.92). Analyzing this factor, we can note the ability to visualize a problem situation is an important factor in the professional development of a psychologist.

The 3rd factor with a total dispersion of 3.91 can be designated as “Collaborative Intelligence”. This factor includes such indicators as verbal abilities (0.92), linguistic abilities (0.83), probabilistic solutions (0.74), memory efficiency (0.83), the use of theoretical and practical knowledge (0.85). Collaborative intelligence is used in practical interpersonal interaction in order to achieve mutual results. This factor is expressed in the ability to form positive relationships when interacting with people.

3. DISCUSSION OF RESULTS

Thus, as a result of our research, it turned out that the intelligence structure of a digital technology specialist has significant differences from the intelligence structure of humanities. It should be noted that the results of an empirical experiment do not fully correspond to the theoretical model by A. Ambrosio, C. Javier and F. Georges. It is worth noting the rather great importance of spatial abilities. This confirms the data obtained by other researchers.

For example, a research team from Clemson University (South Carolina, USA) offers a kinesthetic approach to

4. CONCLUSION

The authors basing on experimentally obtained data came to the following conclusions:

1. The intelligence structure of computer scientists is different from the intelligence structure of linguists and psychologists. Perhaps this is due to differences in the strategy for the acquisition and use of knowledge by representatives of different professions.
2. The following factors were identified in the structure of the intelligence of future information technology specialists: 1) probabilistic-mathematical, 2) verbal-informational, 3) visual-spatial.

learning (“embodied learning”) as a means of shaping computer thinking [11]. These authors formed alternative actions for programming sequences of movement choreography in a cyberspace. A group of scientists from the University of Colorado investigated the formation of computer thinking in high school students. They worked with students on programming video games in Agent Sheets 2. M. Roman-Gonzalez concludes that the competence of a programmer is dictated by the seven components of computer thinking: abstraction and division of a problem into separate tasks; parallelism; logical thinking; synchronization; flow control; user interactivity and data representation. Therefore, for future specialists in digital technologies, students need to understand various computing concepts, depending on whether they are expressed in scripts, in a visual (block) or text programming language.

G. Jones and D. Burnett investigated the relationship between spatial skills and programming success in schoolchildren, finding a slight positive correlation between spatial visualization ability and programming.

G. Jones and D. Burnett explain the success of programming with higher IQ components than spatial capabilities. They found that participants with high spatial abilities completed orientation exercises in the code base faster than those with lower spatial abilities. A follow-up study of 49 students revealed a positive correlation between mental ability for mental rotation of shapes and programming. R. Mayer [12] found in a study of 57 college students that success in programming is due primarily to general intellectual abilities, especially the ability to logical reasoning and spatial abilities. N. Fisher, L. Cox and L. Zhao [3] studied 30 students who mastered the Java language and found that programmers use equally risky strategies for understanding programs and spatial cognition. In addition, they argued that similar cognitive skills are used for spatial cognition and program design.

D. Webb conducted a study of 35 students aged 11 to 14 years and found that spatial ability was the best predictor of knowledge of basic commands. The combination of spatial ability and field independence best predict success in creating images generated using three-dimensional computer graphics.

3. The leading factor in the structure of the intelligence of computer scientists is probabilistic-mathematical intelligence. Probably, the computational abilities of computer scientists are related to the ability to mathematical combinatorics and probabilistic methods of calculation.

4. The problem of intellectual prerequisites for success in mastering computer technology is very promising and requires further development.

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