PERIÓDICO TCHÊ QUÍMICA
ARTIGO ORIGINAL

ANÁLISE DE HABILIDADES COGNITIVAS PARA APRENDIZAGEM DE CIÊNCIA, TECNOLOGIA, ENGENHARIA E MATEMÁTICA: DOIS PONTOS DE VISTA, DUAS OPINIÕES

ANALYSIS OF COGNITIVE ABILITIES FOR STEM LEARNING: TWO VIEWPOINTS, TWO OPINION

АНАЛИЗ КОГНИТИВНЫХ НАВЫКОВ ПРИ ОБУЧЕНИИ STEM: ДВЕ ПОЗИЦИИ, ДВА ВЗГЛЯДА

NIKULOVA Galina[1*]; BOBROVA Lubov[2]

[1 2] Lipetsk State Pedagogical University, Lipetsk, Russia

[1] Department of Informatics, Information Technology, and Information Security

[2] Department of Mathematics and Physics

** Corresponding author*
e-mail: niklipp@mail.ru

Received 12 December 2020; received in revised form 20 February 2021; accepted 07 March 2021

RESUMO

Introdução: A abordagem da educação com foco na cognição é um dos fatores fundamentais para preparar a geração mais jovem para dominar ainda mais o espaço educacional e informativo. **Objetivo:** o objetivo é determinar os tipos de dificuldades cognitivas em alunos de disciplinas *STEM* (ciências, tecnologia, engenharia e matemática) na escola, para determinar uma conexão entre as habilidades e habilidades cognitivas e determinar sua importância para ambos os lados do processo educacional - os professores e os alunos. **Métodos:** O método básico do estudo é pesquisar os respondentes, usando o questionário criado pelo autor do estudo, em seguida, analisar e processar estatisticamente os resultados. O estudo incluiu três etapas: identificação de dificuldades significativas dos alunos em realizar atividades educacionais dentro de uma disciplina específica, identificação das habilidades e habilidades cognitivas mais exigidas, busca de conexões e determinação da correspondência de habilidades e habilidades cognitivas. **Resultados e Discussão:** Foram identificados os tipos de estudos que mais apresentaram dificuldades aos alunos e a interligação entre as competências cognitivas. Diferenças foram reveladas ao comparar as respostas dos dois grupos de respondentes sobre a complexidade e a importância das ações educativas no estudo da física e da matemática e o tipo de atitude dos alunos em relação ao nível reprodutivo da educação ou aos algoritmos de ações mais claros e memoráveis. As competências mais significativas para o sucesso do processo educacional foram extrapoladas. A análise de correlação em pares de capacidade cognitiva / habilidade cognitiva possibilitou corrigir as ideias iniciais sobre a relação. **Conclusões:** Os dados coletados permitiram estabelecer a complexidade das atividades educacionais e as habilidades e habilidades cognitivas aplicadas à disciplina. A sistematização dos resultados do estudo das opiniões subjetivas de alunos e professores sobre a importância das competências cognitivas para o *STEM* possibilita transformar propositalmente o processo educacional, levando em consideração as necessidades de seus participantes e da sociedade..

Palavras-chave *habilidade cognitiva, dificuldades de aprendizagem, processo de aprendizagem, escola, cognição STEM*

ABSTRACT

Background: Cognition-focused approach to education is one of the foundational factors for preparing the younger generation to further mastering the educational and informational space. **Aim:** The purpose is to determine the types of cognitive difficulties in students of STEM disciplines (science, technology, engineering, and mathematics) in school, to determine a connection between cognitive abilities and skills, and to determine their significance for both sides of the educational process – the teachers, and the students. **Methods:** The basic method of the study is polling the respondents, using the questionnaire created by the study's author, then analyzing and statistically processing the results. The study included three stages: identifying significant difficulties of students in performing educational activities within a specific discipline, identifying the most demanded cognitive abilities and skills, searching for connections, and determining the correspondence of cognitive abilities and skills. **Results and Discussion:** Types of studies that presented the most difficulties to students were identified and the interconnection between the cognitive competencies. Differences were revealed when comparing the answers of both groups of respondents about the complexity and importance of educational actions in the study of physics and mathematics and the attitude type of schoolchildren to the reproductive level of education or the clearest and memorable algorithms of actions. Competencies most significant to the success of the educational process were extrapolated. Correlation analysis in pairs of cognitive ability/cognitive skill made it possible to correct the initial ideas about their relationship. **Conclusions:** The data collected allowed establishing the complexity of the educational activities and significant cognitive subject-applied abilities and skills. Systematizing the results of studying the subjective opinions of students and teachers about the importance of cognitive competencies for STEM makes it possible to purposefully transform the educational process, taking into account the needs of its participants and society.

Keywords: *cognitive ability, learning difficulties, learning process, school, STEM cognition*

ABSTRACT

Предпосылки: Подход к образованию, ориентированный на познание, является одним из основополагающих факторов, позволяющих добиться успеха в подготовке подрастающего поколения к дальнейшему освоению образовательного и информационного пространства. **Цель:** определить типы когнитивных трудностей у обучающихся STEM дисциплинам (наука, технология, инженерия и математика) в школе, определить связь между когнитивными способностями и навыками и определить их значимость для обеих сторон образовательного процесса – учителей и учеников. **Методы.** Основной метод исследования – это опрос респондентов с использованием анкеты, созданной автором исследования, с последующим анализом и статистической обработкой результатов. Исследование включало 3 этапа: выявление существенных трудностей студентов при выполнении учебной деятельности в рамках конкретной дисциплины, выявление наиболее востребованных когнитивных способностей и навыков, поиск связей и определение соответствия когнитивных способностей и навыков. **Результаты и обсуждение:** Были определены типы исследований, которые представляли наибольшие трудности для студентов, а также взаимосвязь между когнитивными компетенциями. Различия выявлены при сравнении ответов обеих групп респондентов о сложности и важности учебных действий при изучении физико-математических наук и о типе отношения школьников к репродуктивному уровню образования или к наиболее четким и запоминающимся алгоритмам действий. Были экстраполированы компетенции, наиболее важные для успеха учебного процесса. Корреляционный анализ в парах когнитивные способности / когнитивные навыки позволил скорректировать первоначальные представления об их отношениях. **Выводы:** собранные данные позволили установить сложность учебной деятельности и значимые познавательные предметно-прикладные способности. Систематизация результатов изучения субъективных мнений студентов и преподавателей о важности когнитивных компетенций для STEM позволяет целенаправленно трансформировать образовательный процесс с учетом потребностей его участников и общества.

Ключевые слова: *когнитивные способности, трудности обучения, учебный процесс, школа, STEM познание*

1. INTRODUCTION:

All our lives are intertwined with cognition and education, and the individual success of each person, by far, is ensured by the presence and possession of cognitive abilities and skills. Thinking skills, aptitude for learning, ability to understand and comprehensively resolve issues are the basic, foundational skills of the 21st Century (Jang, 2016; UNESCO, 2017). The refined diagnostics of problems ensures the chances for educational success as part of the specific environment of the educational process implementation. This study focuses on the determination of opinions of both sides of the educational process, challenges for students, and the importance of procedures, activities, and individual qualities of students to the success of the educational process.

The cognition-focused approach to planning and implementation of the educational process implies the formation and development of cognitive skills and abilities of the students for each discipline or set of disciplines being studied

(Booth *et al.*, 2017; Coyle, 2019; Santoso *et al.*, 2017; DTEUH, 2015). The authors of cognition-focused methodologies in educational environment development for physics and algebra, such as R. Teodorescu and other scientists (Teodorescu *et al.*, 2014; Gierl *et al.*, 2005; Yilmaz, 2011), assert that new educational qualities are oriented at the necessity for the student to actively participate in cognitive processing of the educational information. Yet, they do not solve the arising problems of the cognitive organization of work. Marzano's cognitive system (National Training and Education Office, NTEO) complements Bloom's taxonomy and integrates knowledge recovery, comprehension – information synthesis and representation; analysis – similarities, differentiation, systematization, specification, generalization, error analysis; knowledge utilization – decision making, problem-solving, heuristic activities and research (Marzano and Kendall, 2007; Wilson, 2016).

In this study, there was an attempt to determine the type of cognitive difficulties in mastering physics and mathematics at school, identifying the significance of cognitive abilities and skills, and affiliated educational activities – for both participating sides of the educational process – the students and the teachers. The pool of disciplines for which the basic analysis of cognitive skills' evaluations and significance is conducted was not randomly selected:

- It is the natural science, such as mathematics and informatics, that allows adapting – and it is not only applicable to an individual but to humanity in general, is constantly changing world's conditions;
- STEM (science, technology, engineering, and mathematics) is the testing ground for the trials of innovative pedagogical theories and technologies;
- STEM set of disciplines as an instrument for other sciences is the fertilizing ground for forming and developing cognitive abilities (Teodorescu *et al.*, 2014; Villafañe and Lewis, 2016). Often, physics, combined with problem-solving, is considered the discipline most suited for developing critical thinking skills, well beyond the specifics of only the context of physics (Ertmer and Newby, 2013; Yuliati *et al.*, 2018).

The main purpose of the study is to determine cognitive components that assist with a successful implementation of the educational process for physics and mathematics. It is believed that the study results will allow clarifying the extent of the concurrence of points of view for two generations to collaborate in the search and implementation of methods and forms of education.

2. MATERIALS AND METHODS:

In analyzing numerous publications, a reasonable question arose: what did the authors mean by cognitive skills? Often this term was used arbitrarily, and the cognitive skills were confused with cognitive abilities and processes. Despite the similarities and overlaps, it was important to understand that these definitions were different (Figure 1).

Cognitive abilities provided opportunities for collection, selection, accumulation, preservation, and processing of the incoming information and creating new information – therefore, for learning about the world and adapting to the changing conditions in general and the educational process specifically. This happened through cognitive processes. And cognitive abilities were the basis for developing cognitive skills, which, to an extent, could compensate for the minimal abilities in a specific vocation. Skills represented the content of critical thinking and focused on theorists and practitioners of education (Etkina and Planinšič, 2015; Vilia *et al.*, 2017; Yuliati *et al.*, 2018; Santoso *et al.*, 2017). Skills were formed within a certain context by the repetition of actions to make them automatic. For achieving success, subjective cognitive skills (SCS) were very important. Those had been previously formed, stable methods, predispositions, and experience of perceptive and mental activity for studying a specific discipline. Cognitive processes differed by structure and composition and dominance of particular mental activities (Wilson, 2016; Booth *et al.*, 2017; Parameswar, 2018; Ardura and Pérez-Bitrián, 2019; Coyle, 2019).

Studies (Teodorescu *et al.*, 2014; UNESCO, 2014, 2017) demonstrated that most methods and approaches to achieving objectives in physics were grounded in mathematics and logic. There were main stages of solutions – understanding the nature of the process or event (i.e., analysis of conditions), information collection, planning and implementing the solution, evaluating the result achieved and learning from mistakes. Cognitive actions and affiliated skills correlated with the steps of problem-solving in NTEO: problem evaluation →

categorization (what part or segment did the assignment belong to), data visualization → symbolization, conceptualization (the algorithms of information collection and identification) → integration (selection of critical informational components); solution execution → execution; results' analysis → analysis of mistakes and presumptions; understanding and analysis of application → creation; summarizing the results of education → metacognition.

Based on the fundamental determinations of Marzano's new taxonomy and the description of the abovementioned abilities and skills, which were part of the cognitive approach to learning the STEM set of disciplines, and as part of the requirements for questionnaire development, a questionnaire was created for determination of critical (from the standpoint of both teachers and students) actions and skills of the students' cognitive activity. The poll was also designed to identify the main challenges in achieving educational goals by comparing the views of two participating sides of the educational process.

The publicly accessible on the internet "Cognitive Skills" questionnaire included the following participants: 168 students (grades 8 through 11, of which 61% study STEM disciplines, and 39% study humanities), and 105 teachers (51% of physics and mathematics, and 49% of informatics and computer technologies) (CSQ, 2020). Teachers of informatics were included in this sample for the following reasons: a) much older generation teachers of physics and mathematics transitioned to being teachers of informatics; b) integrating digital technologies into the educational process increased the importance of their opinions about SCS in the inter-discipline context.

The following main attributes of respondents were accounted for: their role in the educational process, the disciplines they taught (for teachers), class, and discipline (for students). Questions and answers were represented in multiple formats: yes or no, multiple choices, and grading the list entries. The questionnaire included questions about the cognitive aspects of education in two basic disciplines of the STEM set – mathematics and physics (Figure 2).

The study was conducted in 3 stages: identification of significant challenges for the students in the execution of the educational activities within each discipline, determination of the cognitive skills and abilities that were most in-demand, identification of connections, and determination of matching cognitive abilities and skills.

Integration of digital technologies into the educational process did not soften but rather immensely intensified the issues related to the optimal selection of its tactics and strategy, as well as forms and details of its organization following the challenges of the modern social environment, specific traits of the disciplines, and demands of the process participants (Gierl *et al.*, 2005). Cognition and education played a vital role in the entire life. The individual success of each person was based on, to a large extent, possession of cognitive abilities and skills (UNESCO, 2014). The skills of thinking, aptitude for learning, and problem-solving based on comprehension were listed as fundamental skills of the 21st century (Etkina and Planinšič, 2015; UNESCO, 2017). This was why the search for the optimal types and structure of the educational process was ongoing, and in the process, they were formed, developed, and improved.

P. A. Ertmer and T. J. Newby (2013) pointed out that, despite the multitude of verified and justified educational theories and affiliated verified educational strategies, methods, and instructions for making education easier, designers of the educational process and teachers themselves worked in the conditions of limited theoretical background. This affected the determination of educational goals and near term developments. It was in serious doubt that the teachers were consciously oriented at teaching only. A significant role belonged to the development of skills related to the management of the students' learning activities, feeling pleased with it, and achieving specific individual results. The opportunities for educational success were grounded in the verification of the diagnosed problems in specific conditions of implementation. It was important to assess the attitude towards the complexity of the educational activities and the nature of challenges – for both sides of the educational process – the students, who were the consumers of the main acts of learning, and teachers – as the bearers, transmitters, and moderators of the educational means and materials.

Cognition-focused approach to planning and implementation of the educational process at all levels became a commonly used trend (Gierl *et al.*, 2005; Jang, 2016; Vilia *et al.*, 2017; Lunsford *et al.*, 2018), reflected in national and international educational standards (UNESCO, 2014, 2017). It dictated the necessity of simultaneous forming and development of comprehensive cognitive abilities of the students of either specific discipline or set of disciplines (Booth *et al.*, 2017). However, the authors of innovative cognition-focused approaches to the creation of the educational environment for physics and mathematics, such as R. Teodorescu, C. Bennhold, G. Feldman, and L. Medskerb from George Washington University (Teodorescu *et al.*, 2014) noted, that new educational materials and means were oriented at the necessity of student's active participation in cognitive processing of educational information, but they di not solve the problems arising with the cognitive organization of work. In the works of these authors, descriptions were found and evaluations of the success of the problem-focused learning in physics while taking into account cognitive processes necessary for the successful completion of assignments.

The forms of knowledge monitoring that existed in most countries did not include reproductive actions during all types of tests, including questionnaires, in person and online testing, but rather entail the use of all cognitive abilities (for example, SAT (SATM) (Gierl *et al.*, 2005; Lunsford *et al.*, 2018). Additionally, the new forms of education described in the study (Nikulova and Bobrova, 2016) involved a significant cognitive burden on students, already at the stage of planning their educational trajectory, collecting and selecting necessary and sufficient information, virtual and real-life project creation.

The absolute priority was the ability to think independently and apply SCS in practice (DTEUH, 2015; Yilmaz, 2011; Vilia *et al.*, 2017). This was a fact that reflected the imperative demands of the society for thinkers, able to pose questions and find answers based on experience and information available in the digital environment (Coyle, 2019). Moving further with the study, the older respondents' opinions began to differ from those of the younger. Teachers attributed success in education to cognitive abilities and skills, which comprised the gist of critical thinking (Booth *et al.*, 2017, Tolstenko *et al.*, 2019). The students were geared towards instant results and assign a second place to the skills of quickly switching between the types of cognitive activity. These abilities were customary for one of the education styles – "activist", where the users of this style preferred action, often at the expense of consideration. However, subsequently, the order of succession of cognitive abilities and skills in descending order of importance exactly corresponded to that established by teachers with a shift of one position. (Lunsford *et al.*, 2018). "Tendency to test ideas through experience" and "ability to act and arrive at conclusions quickly and decisively" was the lowest in the ranking order, where the general range of every cognitive component was calculated. This was possibly the result of partial virtualization of the service industry, including educational services (Teodorescu *et al.*, 2014; Mutmainah *et al.*, 2019).

Based on the collective opinion of all participants of the study, completing assignments was ranked as the most difficult among the disciplines considered. In the study, it was determined that the most popular among both the teachers and the students were the resources, oriented at the description of approaches to solving problems of an advanced level of complexity. This indirectly confirmed that both sides of the educational process were interested in possession of specific skills (74% – teacher's evaluation, 61% – students of humanities, 53% – Math students). One of the main obstacles to solving problems in physics was the inability to analyze the set condition and, therefore, the "Where Did I Begin" type of challenges that followed. The reason was that the students underestimated the importance of analysis and synthesis of knowledge obtained and the skills required to apply that knowledge in new conditions. Surprising was also the underestimation of operations used by students to generalize and systematize knowledge. This testified to the low level of metacognitive skills for intellectual self-evaluation. Students were more often fixated on memorizing the facts, laws, and rules at the expense of thinking about their manifestations, limitations, and essence. Teachers saw cause-and-effect connections between successfully mastering the subject and a higher level of SCS, including components of critical thinking (see Figure 1). They considered lab work and oral answers the easiest. However, it was difficult for the students to formulate conclusions based on the results of lab work. Significant differences were also observed in both groups of respondents when comparing complex action choices while studying math. Analytical activities proved most problematic: 57% of teachers considered the analysis of graphic assignments and their results most difficult, and 53% assigned the highest level of difficulty to work with equations. Opinions differed mostly on evaluating the level of difficulty in expressing one of the approaches: 49% of teachers against 9–14% of students. However, this is a critical skill for STEM. Teachers considered oral answers and building graphs the least difficult in math. The common trend was clear – it was the orientation of students towards reproductive education and simple actions.

3. RESULTS AND DISCUSSION:

3.1. Stage I. Determination of significant challenges in execution of educational activities

As shown in Figure 2, the types of educational activities for STEM disciplines connected to SCS of students are different for physics as compared to mathematics.

Respondents had to choose 1-3 positions out of the list offered and answer which of the educational activities are most difficult for students. Results for physics are shown in Figures 3 and 4. Letters represent activities shown in Figure 2.

According to teachers, the most difficult in physics is problem-solving (74%), knowledge generalization and systematization (65%), and control/diagnostics (59%).

Light color columns in Figure 4 – represent the answers of humanities students (HS), dark – those of students of math (EM). Students in both groups consider solving physics problems most difficult (53% math students and 61% – humanities students). Second in difficulty are diagnostics when connected to problem-solving.

The least difficult in physics, according to students, is generalization and systematization of knowledge, and according to teachers – oral answers and lab work. The assessment results of difficulties in the study of mathematics are given in Figures 5 and 6.

More than half (57%) of teachers opine that the most difficult is graphs analysis, while 53% think it is equations. 49% noted significant difficulties with an expression of one quantity. According to teachers, the least difficult are oral answers and building graphs.

Math students did not demonstrate that they have a domineering difficulty: each activity received 22-30% of the votes. Humanities students chose F, which corresponds to graphs analysis (41%). Most of the teachers (57%) concurred. Next in the level of difficulty, according to teachers, are equations (53%) and diagnostics (41%). Students consider the expression of one of the quantities the easiest (D): 14% of Math students and 9% Humanities students. However, 49% of teachers consider this task difficult because it often leads to errors in problem-solving. According to teachers, graph building is the least difficult.

These differences are most likely due to students expressing opinions on how they feel in the process of various educational activities and the teachers describing impressions derived from the results of educational activities.

3.2. Stage II. Determination of the most significant cognitive abilities and skills used in the execution of educational tasks

The success of the educational process is closely connected with cognitive abilities and cognitive skills (cognitive competencies). Respondents were offered to rank the cognitive competencies in demand for the STEM set of disciplines (Figure 2).

According to the hypothesis, there is a connection between cognitive abilities and corresponding applicable cognitive skills (Figure 7).

In part II of the questionnaire, it is asked the respondents to rank abilities and skills necessary for one type of educational activity by dragging each position up or down, according to its subjective significance. The information was particularly interested in the following two aspects:

- Which SCS are important for teachers, vs. for students
- What is the connection between cognitive abilities and skills?

Four types of activities significant for the STEM set of disciplines were selected for ranking:

1. Lab work completion;
2. Tasks solving in physics and mathematics;
3. Graphical tasks solving;
4. Preparation for control and diagnostics measures.

Results of ranking cognitive abilities and skills necessary for successful completion of lab work are shown in Tables 1 and 2.

Figures in the top horizontal row of the table signify rank (place by significance) of the ability or skill; letters listed vertically in the far left column correspond to cognitive abilities and skills from the original list. Poll results are presented as percentage points of the total number of teachers.

To determine the significance of cognitive abilities and skills based on the aggregate data, the generalized rank is calculated (GR) by Equation 1:

$$GR = \sum_{i}^{N} \frac{x_i}{k_i}, \quad \text{(Eq. 1)}$$

Where x_i – frequency of selection of this position during ranking of the specific cognitive component (A-H) in percentage points; k_i – the meaning of the rank; *N* changes from 0 to 8 by the number of positions in the list.

Teachers consider most important for lab work the ability to think independently and apply skills and abilities to solve the problems that arise (in grey) (B) and tendency to test ideas through personal experience (F).

The meaning of EMR – the result of GR for Math students; HumR's component – GR for Humanities students. According to students, the most important is the ability to think independently and apply skills and abilities to solve problems that arise (B).

Similar calculations were conducted for other types of activities. Tables 3 and 4 demonstrate *GR* by type of educational activity.

Table 3. *GR of cognitive abilities and skills (teachers). (Source: the author)*

	1	2	3	4
A	26.046	24.824	26.991	26.329
B	57.669	60.867	51.333	45.067
C	29.056	33.25	35.807	30.955
D	27.706	23.136	22.412	28.491
E	28.527	64.552	57.067	44.236
F	29.824	24.757	43.519	59.712
G	21.18	17.586	15.471	19.393
H	50.095	17.723	16.592	14.82

The experts (teachers) designated the ability to think independently and apply skills and abilities as the absolute leader among all types of activities considered (B); for laboratory work, it is important to have a tendency to test ideas empirically (H); for types 2-4 also important is the ability to think rationally and logically (D); and for diagnostics preparation most important is systematization (F).

Schoolchildren opinions differ from expert ones. Globally important for them is thinking independently and applying skills and abilities for solving the problems that arise (B); to successfully solve physics and mathematics problems. Math students selected the ability to think rationally and logically (E); for solving graphic problems and preparing for control, the skills that allow switching fast are significant (A).

3.3. Stage III. Determination of correlation of cognitive abilities and skills

To verify the original hypothesis that cognitive abilities and skills correlate, the Pearson linear correlation coefficient was calculated for the teachers' answers, paired, at the expert selection. Critical value of Pearson coefficient for n = 105, degree of freedom $df = N - 2 = 102$, $r_{кр}$ = 0.194 for the probability of significance value p = 0.05 of one criterion (sample of more than 30 participants).

Most prominent are inverse correlations ($p < 0$) between most abilities and skills. However, for GA, in all cases, there is a pronounced direct correlation. Less pronounced are the correlations in other pairs of "ability-skill". It can conclude that the most pronounced ability to think independently and apply skills and abilities (B) is most correlated with the skills of anticipation of possible problems and taking others' experience into account (D). Ability to think logically and rationally (E) – with systematizing the data and arriving at conclusions. (F). Additionally, there is a definite correlation between abilities E and B and between ability H and skill D.

Inverse correlations appear rather interesting, and among the most pronounced are BH (- 0.550), AE (-0.500), DE (-0.537), FG (-0.508). Therefore, it can state with certainty that cognitive components in pairs "Ability to think rationally and logically", "Skills of quick switching between types of cognitive activity", "Ability to think independently and apply skills and abilities to problem-solving", "Tendency to test ideas through experience", "Ability to act and draw conclusions quickly and decisively", and "Skills to systematize data and draw conclusions" are in anti-phase. It is possibly not the abilities that influence the development of these skills, but rather the personality type of the students, which predetermines the genetic contradiction between "speed" and "systematic approach" in students, where the educational process is concerned.

The analysis of the generalized range of cognitive competencies, based on the questionnaire's results, allowed ranking them in the order of decreasing significance to the success of educational activities (Figure 8).

Deviation in students' answers can be due to metacognitive aspects of educational activities (14), an emotional reaction (1), for example, for humanities students, who evaluate activities in subject matters that are not most important to them. The results derived correlate with the process and skills analysis, in general, by the novices (in this case – students) and experts (teachers). Novices immediately move to the process of obtaining a solution (cognitive skills of lower level), using the already known algorithms and procedures, and they do not always understand the results they receive. Experts begin with the analysis – of the conditions and specifics of the situation. They finish with analysis, too – to verify that the result or answer is justifiable and valid. Experts are aware of their own approaches to problem solving and skills, identifying strengths and weaknesses. Novices suffer cognitive overload (selective insufficiency of separating what is essential) and spend their intellectual resources on procedures. R. Teodorescu points out the necessity to help students form "advanced habits" (sustainable skills) for categorization, classification, and schematization of problems (Teodorescu *et al.*, 2014).

Undertaking the correlation analysis in pairs of cognitive ability-cognitive skills allowed to correct the initial assumptions about their interconnection. The changes mostly pertain to the central part of the chart, where a strong connection was discovered between the ability to think rationally and logically and skills of data systematization and the ability to think independently and apply skills and abilities. The anti-phase of abilities to rational and logical thinking (E) and skills to anticipate possible problems and consider others' mistakes and experience (D), most likely, is due to these components being part of different types of activities – thinking and procedural. Therefore, as a result of the correlation analysis between cognitive components, the pattern of interconnections of skills and abilities have changed, new connections were identified, and it can presume they are related to the change in conditions of the educational process implementation (Gierl *et al.*, 2005; Villafañe and Lewis, 2016; Vilia *et al.*, 2017; Lunsford *et al.*, 2018; Mutmainah *et al.*, 2019) (Figure 9).

Based on the number of connections, the leader of the chart is the ability to think rationally and logically – the gist of critical thinking.

4. CONCLUSIONS:

Thus, the types of studies that presented the most difficulties to students were identified and the interconnection between the cognitive competencies. Differences were revealed when comparing the answers of both groups of respondents about the complexity and importance of educational actions in the study of physics and mathematics and the attitude type of schoolchildren to the reproductive level of education or the clearest and memorable algorithms of actions. Competencies most significant to the success of the educational process were extrapolated. Correlation analysis in pairs of cognitive ability/cognitive skill made it possible to correct the initial ideas about their relationship. The data derived from this study allow to correct and design the educational process in the digital environment more consciously and to take into account the points of view of both students and teachers about the demands in developing their cognitive skills. The data collected allowed establishing the complexity of the educational activities and significant cognitive subject-applied abilities and skills. Systematizing the results of studying the subjective opinions of students and teachers about the importance of cognitive competencies for STEM makes it possible to purposefully transform the educational process, taking into account the needs of its participants and society. Therefore, modern education aims to overcome the disconnection between thinking skills and the ability to act. It is to keep the educational process for students to create stimuli and motivation to act while thinking and think while keeping the next action in mind.

5. ACKNOWLEDGMENT:

In closing, the authors wish to express sincere gratitude to the Expert Committee responsible for grading the Unified State Exam in physics in the Lipetsk region. Their professional contributions to the questionnaire increased the quality of results and provided with certainty about the necessity and importance of this study's subject matter.

6. REFERENCES:

1. Ardura, D., and Pérez-Bitrián, A. (2019). Motivational pathways towards academic achievement in physics and chemistry: A comparison between students who opt out and those who persist. *Chemistry Education Research and Practice*, *20*, 618–632.
2. Booth, J. L., McGinn, K. M., Barbieri, C., Begolli, K. N., Chang, B., Miller-Cotto, D., Young, L. K. and Davenport, J. L. (2017). Evidence for cognitive science principles that impact learning in mathematics. In D. C. Geary, D. B. Berch, R. Ochsendorf and K. M. Koepke (Eds.). *Acquisition of complex arithmetic skills and higher-order mathematics* (pp: 297–325). London: Elsevier.
3. Cognitive Skills questionnaire (CSQ). (2020). https://testograf.ru/ru/oprosi/aktualnie/0170d0e97fd349eee.html
4. Coyle, T. R. (2019) Tech tilt predicts jobs, college majors, and specific abilities: Support for investment theories. *Intelligence*, *75*, 33–40.
5. Department of Teacher Education University of Helsinki (DTEUH). (2015). Innovative schools: Teaching and learning in the digital era. Brussels: European Parliament. https://www.europarl.europa.eu/RegData/etudes/STUD/2015/563389/IPOL_STU(2015)563389_EN.pdf
6. Ertmer, P. A., and Newby T. J. (2013). Behaviorism, cognitivism, constructivism: comparing critical features from an instructional design perspective. *Performance Improvement Quarterly*, *26*(2), 43–71.
7. Etkina, E., and Planinšič, G. (2015). Defining and developing ‘critical thinking’ through devising and testing multiple explanations of the same phenomenon. *Physics Teacher*, *53*(7), 432–437.
8. Gierl, M. J., Tan, X., and Wang, C. (2005). Identifying content and cognitive dimensions on the SAT (Ser.: College Board Research Report, No. 11). New York: The College Board. https://files.eric.ed.gov/fulltext/ED562685.pdf
9. Jang, H. (2016). Identifying 21st century STEM competencies using workplace data. *Journal of Science Education and Technology*, *25*, 284–301.
10. Lunsford, M. L., Poplin, P. L., and Pederson, J. G. (2018). From research to practice: Using assessment and early intervention to improve student success in introductory statistics. *Journal of Statistics Education*, *26*(2), 125–134.
11. Marzano, R. J., and Kendall, J. S. (2007). The new taxonomy of educational objectives. Thousands Oaks, USA: Corwin Press.
12. Mutmainah, M., Taruh, E., Abbas, N., and Umar, M. K. (2019). The influence of blended learning-based guided inquiry learning model and self-efficacy on students’ scientific literacy. *European Journal of Education Studies*, *6*(6), 137–150.
13. Nikulova, G. A., and Bobrova, L. N. (2016). Online education resources and student needs: Stylistic aspects. *Indian Journal of Science and Technology*, *9*(42), 1–10.
14. Parameswar, H. (2018). Developing problem solving and critical thinking skills in physics and engineering physics courses. https://www.researchgate.net/publication/237638083_Developing_Problem_Solving_and_Critical_Thinking_Skills_in_Physics_and_Engineering_Physics_Courses
15. Santoso, T., Yuanita, L., and Erman, E. (2017). The role of student's critical asking question in developing student's critical thinking skills. *Journal of Physics: Conference Series*, *953*, 012042.
16. ,Teodorescu, R. E., Bennholda, C., Feldman, G., and Medskerb, L. (2014). Curricular reforms that improve students’ attitudes and problem-solving performance. *European Journal of Physics Education*, *5*(1), 15–44.
17. Tolstenko, A., Baltovskij, L., and Radikov, I. (2019). Chance of civic education in Russia. *Sage Open, 9(3),* 1–16.
18. UNESCO. (2014). Unesco education strategy 2014-2021. Paris: Unesco. https://unesdoc.unesco.org/ark:/48223/pf0000231288http://www.unesco.org/new/fileadmin/MULTIMEDIA/FIELD/Santiago/pdf/

Habilidades-SXXI-Buenos-Aires-Eng.pdf

19. UNESCO. (2017). E2030: Education and skills for the 21st century January 31, 2017. Paris: Unesco. http://www.unesco.org/new/fileadmin/MULTIMEDIA/FIELD/Santiago/pdf/Habilidades-SXXI-Buenos-Aires-Eng.pdf

20. Vilia, P. N., Candeias, A. A., Neto, A. S., Franco, G. S., and Melo, M. (2017), Academic achievement in physics-chemistry: The predictive effect of attitudes and reasoning abilities. *Frontiers in Psychology*, *8*, Article 1064.

21. Villafañe, S. M., and Lewis, J. E. (2016). Exploring a measure of science attitude for different groups of students enrolled in introductory college chemistry. *Chemistry Education Research and Practice*, *17*(4), 731–742.

22. Wilson, L. O. (2016). Anderson and Krathwohl Bloom's taxonomy revised: Understanding the new version of Bloom's taxonomy. – https://quincycollege.edu/content/uploads/Anderson-and-Krathwohl_Revised-Blooms-Taxonomy.pdf

23. Yilmaz, K. (2011). The cognitive perspective on learning: its theoretical underpinnings and implications for classroom practices. *The Clearing House*, *84*, 204–212.

24. Yuliati, L., Fauziah, R., and Hidayat, A. (2018) Student's critical thinking skills in authentic problem based learning. *IOP Conf. Series: Journal of Physics*, *1013*(1), Article 012025.

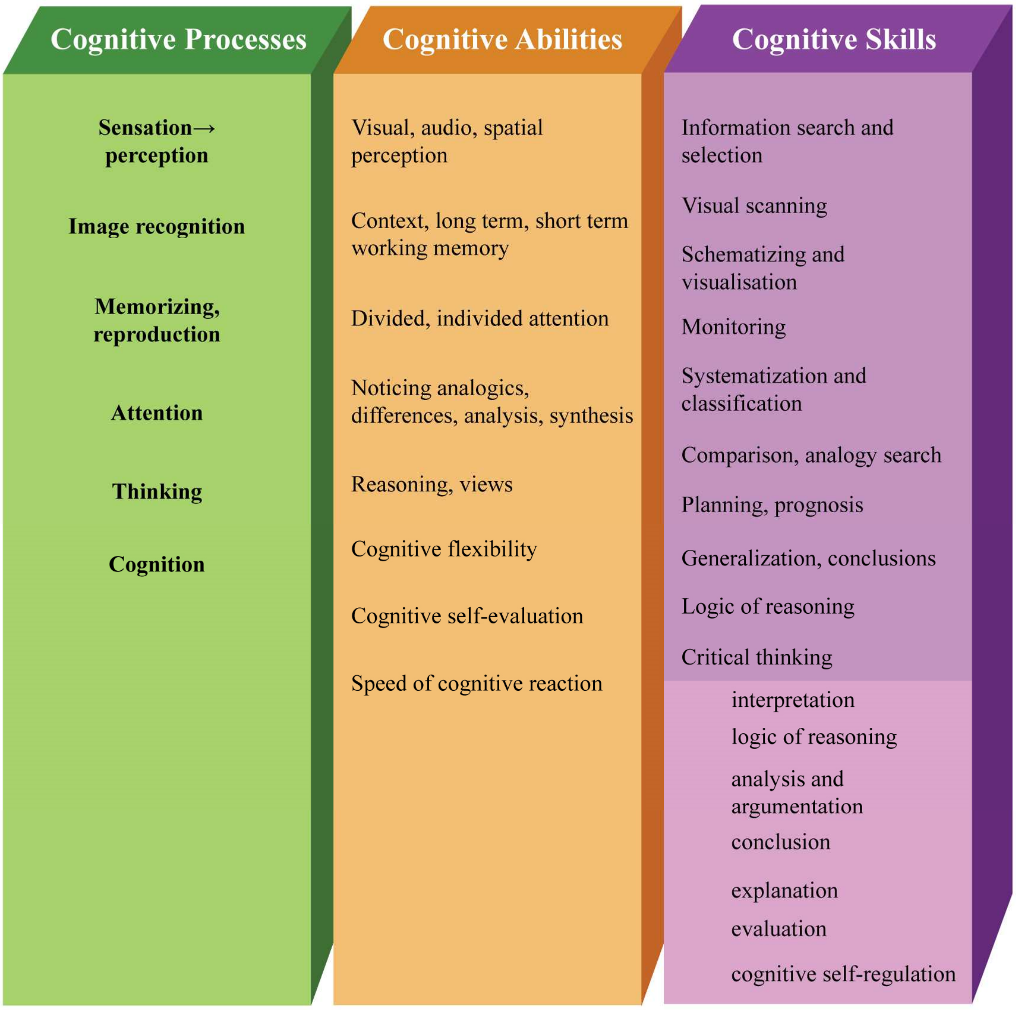

Figure 1. *Differentiation of general cognitive processes, abilities, skills. Source: the author*

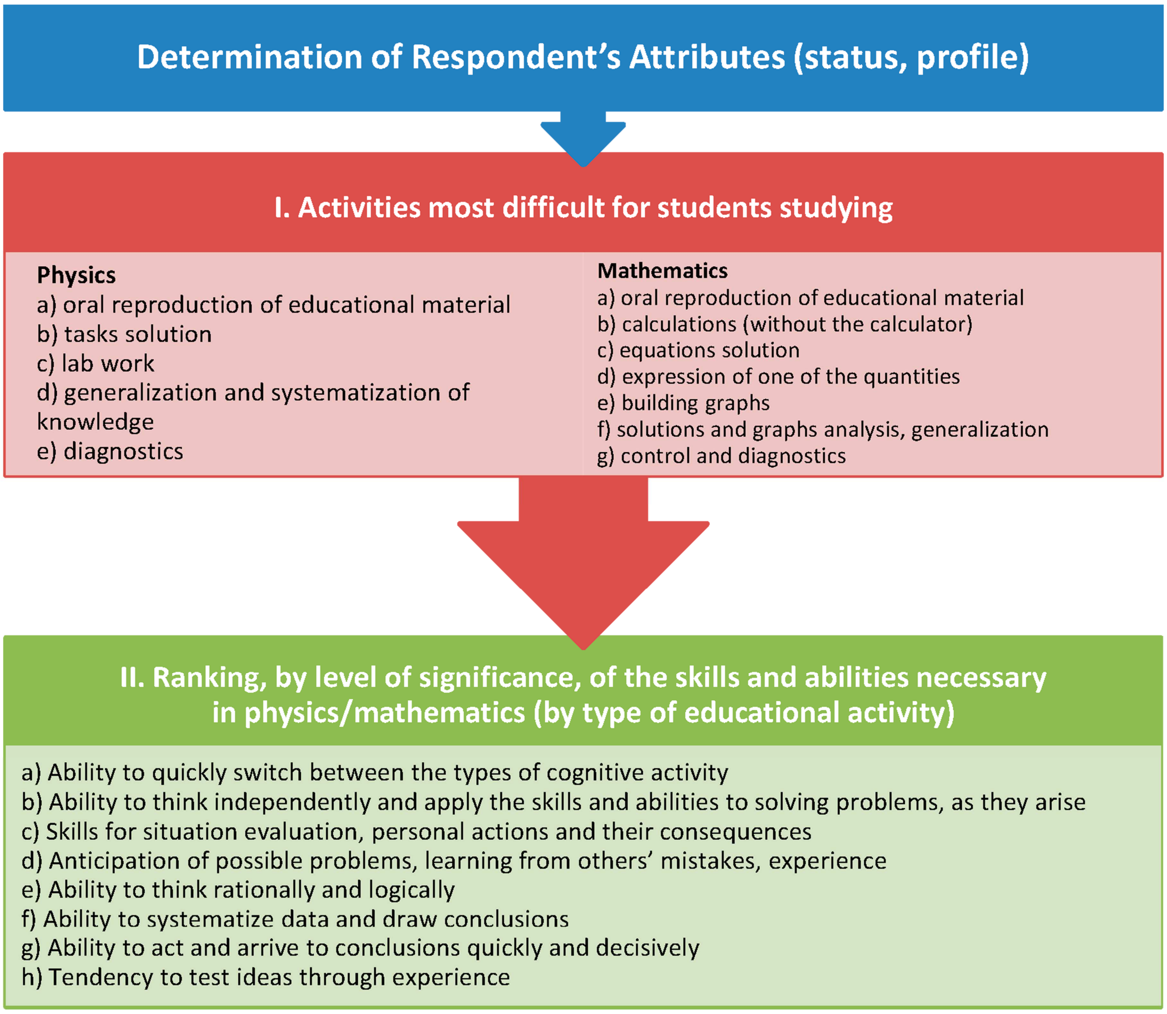

Figure 2. *Cognitive skills questionnaire. Source: the author*

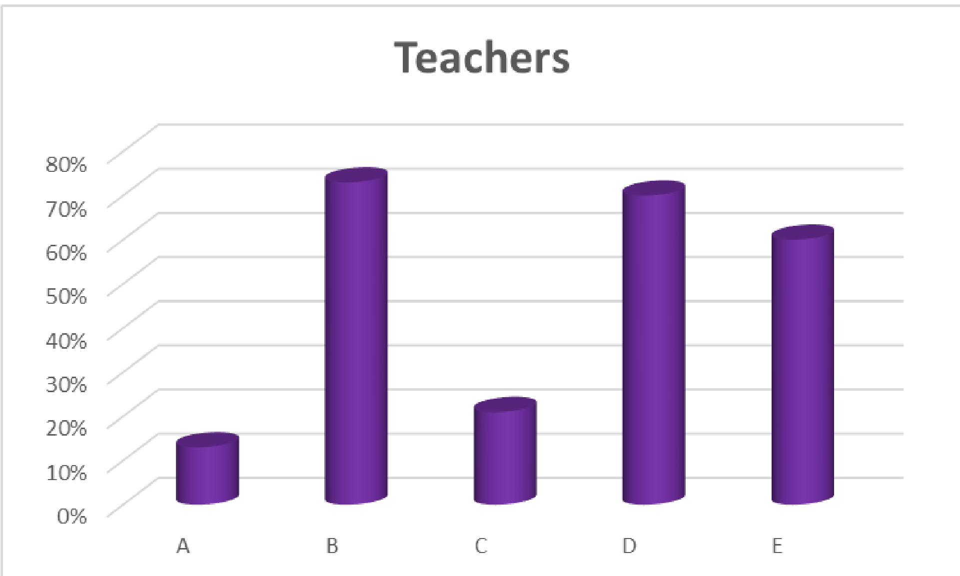

Figure 3. *Ranking of the main challenges that students of physics face (teachers' opinions). Source: the author*

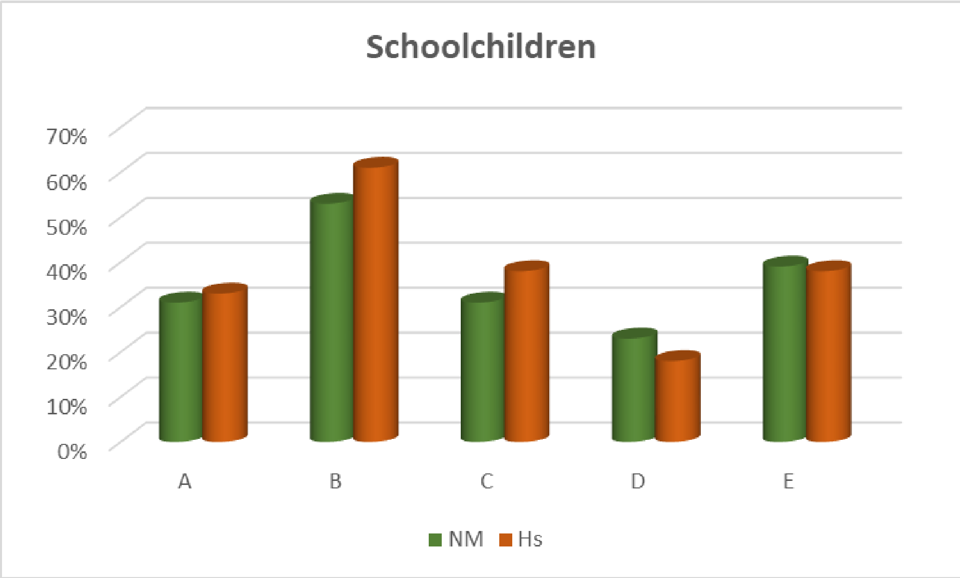

Figure 4. *Ranking of the difficulties in studying physics (students' opinion). Source: the author*

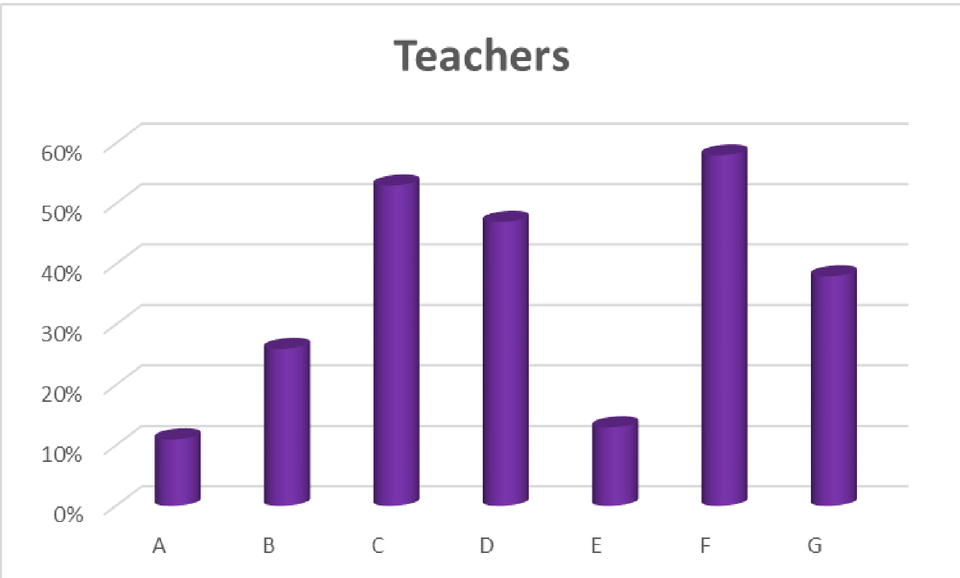

Figure 5. *Ranking of the difficulties in studying math (teachers' opinion). Source: the author*

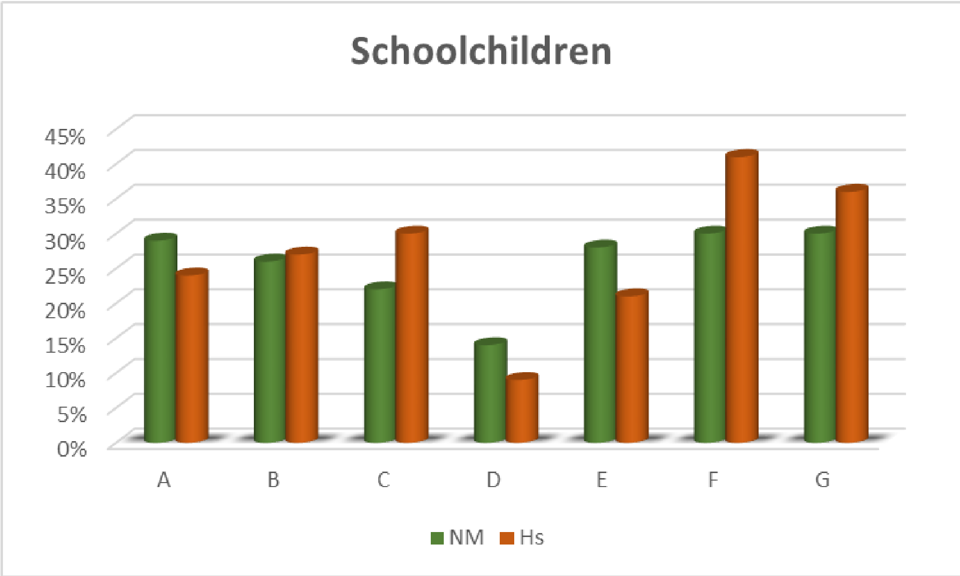

Figure 6. *Ranking of the difficulties while studying math (students' opinion). Source: the author*

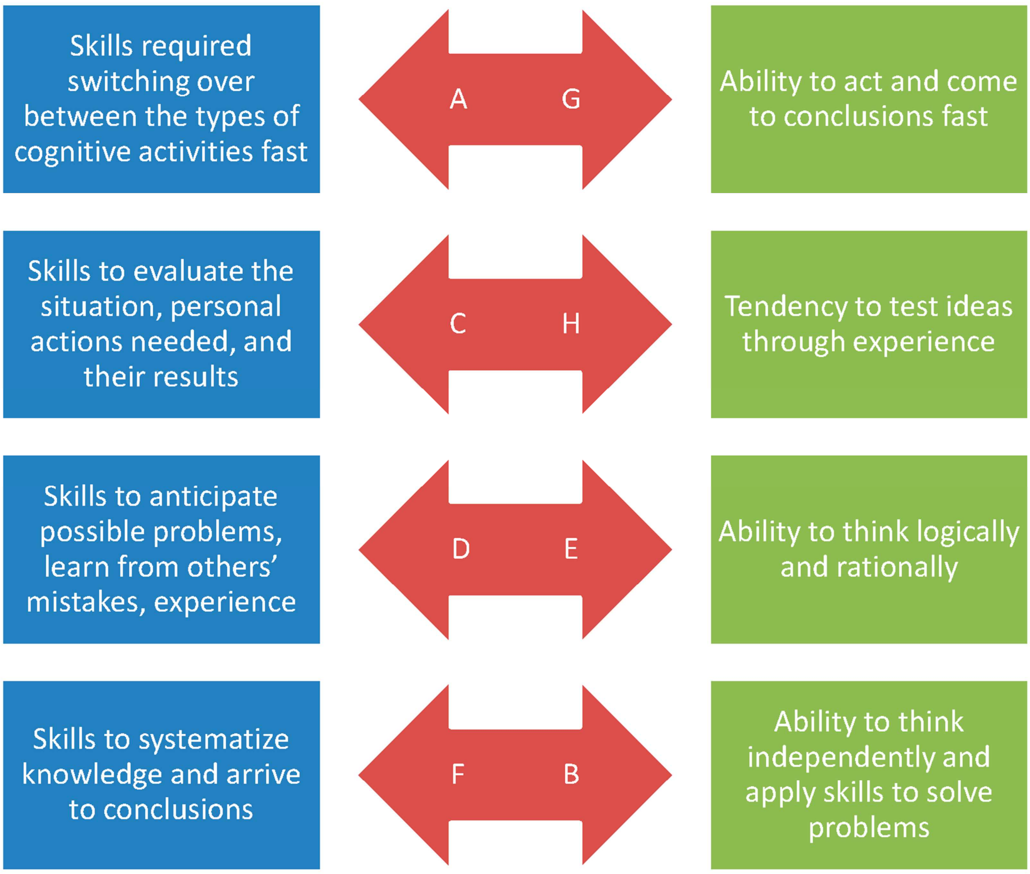

Figure 7. *Correlation between cognitive abilities and SCS. Source: the author*

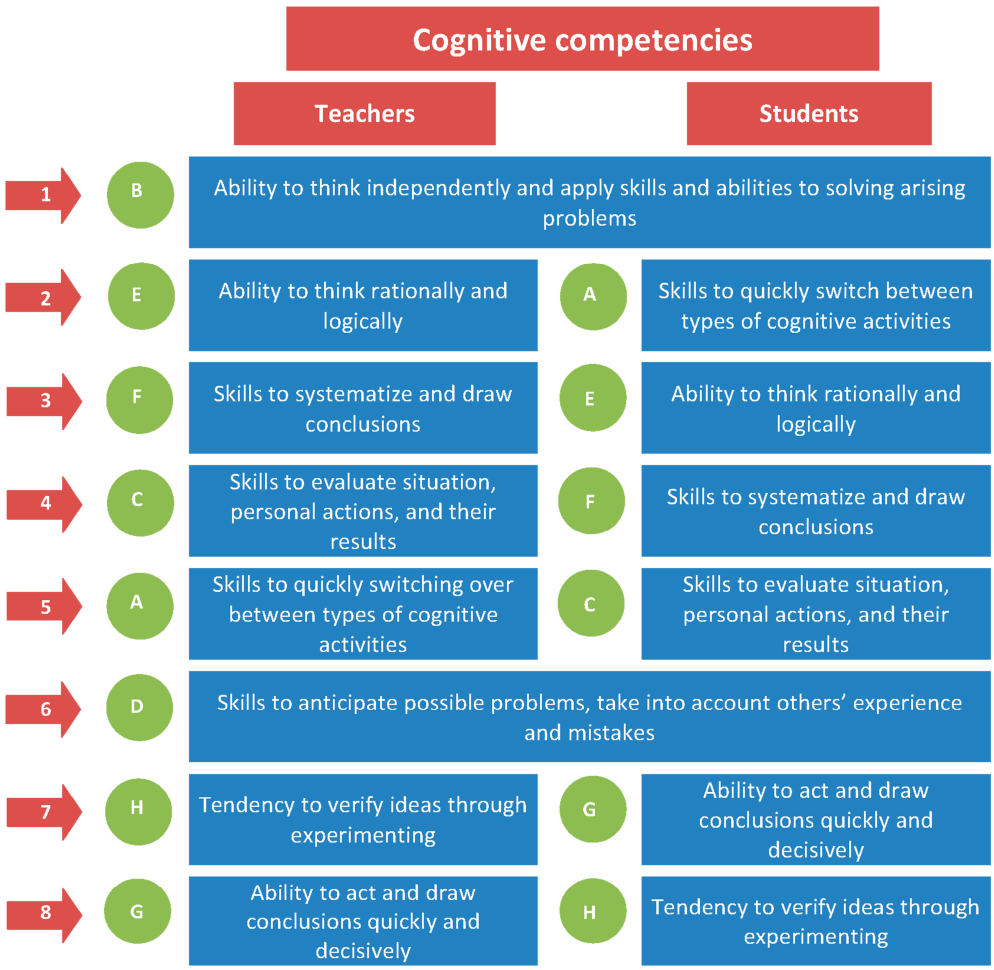

Figure 8. *Ranking of cognitive competencies by their significance to the educational process. Source: the author*

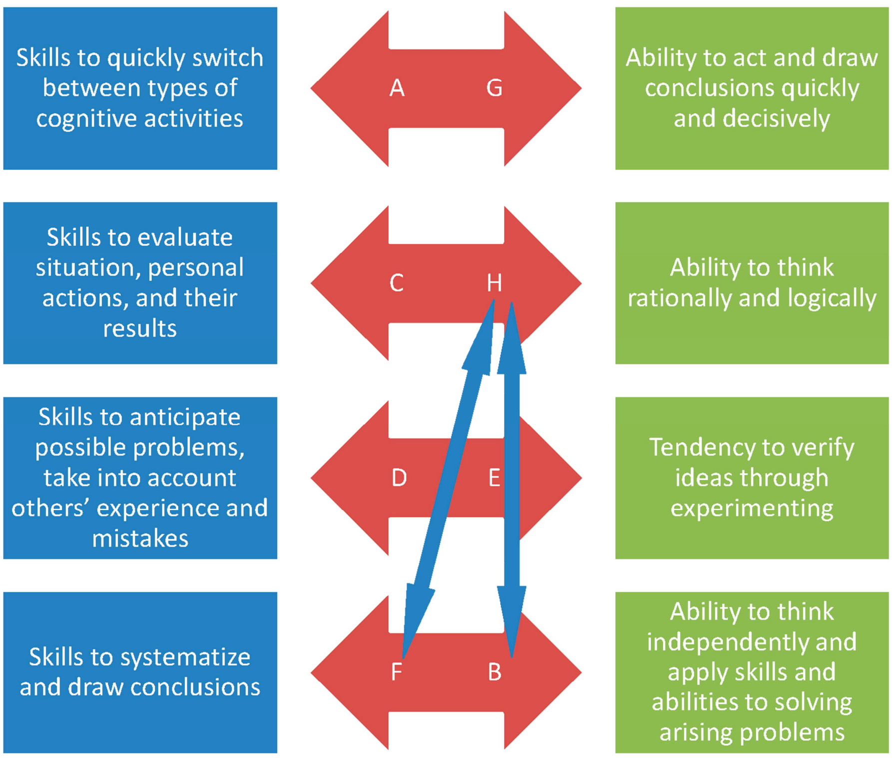

Figure 9. *Correlations between cognitive abilities and cognitive skills after verification of correlation parameters. Source: the author*

Table 1. *Results of ranking SCS and cognitive abilities by teachers (for lab work), %. Source: the author*

Types of activity/cognitive components	1	2	3	4	5	6	7	8	GR
A	6	7	13	13	8	10	18	25	26.04643
B	37	19	17	7	14	4	2	0	57.66905
C	3	18	16	14	19	11	12	7	29.05595
D	3	18	7	18	16	17	12	9	27.70595
E	4	15	12	17	16	22	9	5	28.52738
F	6	13	17	13	14	21	6	10	29.82381
G	3	3	11	9	7	10	32	25	21.17976
H	36	7	7	10	5	5	10	20	50.09524

Table 2. *Results of ranking SCS and cognitive abilities by students (for lab work), %. Source: the author*

	1		2		3		4		5		6		7		8		MathR	HumR
	Math	Hum	Math	Hum	Math	Hum	Math	Hum	Math	Hum	Math	Hum	Math	Hum	Math	Hum		
A	15	12	11	5	9	9	7	16	10	14	8	10	11	17	29	17	33.78	30.52
B	34	29	23	21	16	27	7	7	11	9	5	2	2	3	2	2	56.15	53.06
C	3	9	10	19	13	22	27	14	17	9	15	18	8	7	7	2	27.00	35.38
D	7	7	7	9	1	12	19	16	21	16	14	17	14	9	7	14	28.33	28.57
E	14	18	22	21	7	12	14	13	12	16	17	6	9	8	5	6	37.98	41.84
F	11	12	12	10	24	5	6	16	9	5	17	22	11	21	10	9	33.95	31.46
G	5	7	7	9	8	9	13	12	10	21	13	10	31	18	13	14	24.0	27.69
H	9	5	9	5	12	3	8	7	9	16	12	12	14	16	27	36	28.68	22.24

Table 4. *GR of cognitive abilities and skills (schoolchildren). Source: the author*

	1		2		3		4	
	Math	Hum	Math	Hum	Math	Hum	Math	Hum
A	33.78	30.52	43.87	37.75	46.94	51.34	52.05	44.42
B	56.15	53.06	52.57	56.79	46.98	47.49	43.71	50.35
C	27	35.38	31.73	34.72	31.2	32	32.57	35.5
D	28.33	28.57	23.4	24.01	23.63	23.87	35.49	26.75
E	37.98	41.84	49.75	45.45	40.35	39.67	27.51	32.56
F	33.95	31.46	31.73	27.29	39.71	34.19	33.57	36.89
G	24.64	27.69	20.26	27.68	20.29	25.29	25.23	28.51
H	28.68	22.24	22.24	18.37	22.7	20.15	21.29	16.33

Appendix. The questionnaire

Cognitive skills in learning activities

Welcome to our survey page!
It will not take much time, but it can significantly help teachers and organizers to correctly and effectively build the educational process itself.
Thank you very much for your participation!

- Your status (in relation to training)
• student
• teacher
• schoolboy
• parent
• administrator
- **What class do you study in?**
- Indicate the form of training
- What is the profile of the direction of your study/teaching
- What types of educational activities cause the greatest difficulties in the study of physics? *you can choose several answers, but no more than 3*
• oral reproduction of educational material
• solving problems
•laboratory works
• generalization and systematization of knowledge
• control and diagnostic measures
- What types of learning activities are the most difficult when studying mathematics? *You can choose several answers, but no more than 3*
• verbal response
• performing calculations (without a calculator)
• solving equations
• expression of one of the quantities
• plotting
• graph analysis
• control and diagnostic measures
- Rank the skills, abilities, and abilities required to successfully complete laboratory work (for example, physics, chemistry, etc.)
You should grab the desired item with the mouse and drag it to the appropriate place. The most important points should be higher
□ Skills to quickly switch between types of cognitive activities during academic work
□ Ability to think independently and apply skills and abilities to solve emerging problems
□ Skills in assessing the learning situation, their actions, and their results
□ Skills of anticipating possible problems and taking into account other people's experience, mistakes
□ Ability for rational and logical thinking
□ Skills to organize data and draw conclusions
□ Ability for quick and decisive action and conclusions
□ A tendency to test ideas empirically
- Rank the skills, abilities, and abilities required to successfully solve physics and math problems in order of importance *You should grab the desired item with the mouse and drag it to the appropriate place. The most important points should be higher*
□ Skills to quickly switch between types of cognitive activities during academic work
□ Ability to think independently and apply skills and abilities to solve emerging problems
□ Skills in assessing the learning situation, their actions, and their results
□ Skills of anticipating possible problems and taking into account other people's experience, mistakes
□ Ability for rational and logical thinking
□ Skills to organize data and draw conclusions
□ Ability for quick and decisive action and conclusions
□ A tendency to test ideas empirically
- Rank the skills, abilities, and abilities needed to successfully solve graphics problems (physics, mathematics) *You should grab the desired item with the mouse and drag it to the appropriate place. The most important points should be higher*
□ Skills to quickly switch between types of cognitive activities during academic work
□ Ability to think independently and apply skills and abilities to solve emerging problems
□ Skills in assessing the learning situation, their actions, and their results
□ Skills of anticipating possible problems and taking into account other people's experience, mistakes
□ Ability for rational and logical thinking

 Skills to organize data and draw conclusions
 Ability for quick and decisive action and conclusions
 A tendency to test ideas empirically
- Rank the skills, abilities, and abilities necessary for successful preparation for control and diagnostic activities (systematization, generalization of training materials, creation of reference notes) *You should grab the desired item with the mouse and drag it to the appropriate place. The most important points should be higher*
 Skills to quickly switch between types of cognitive activities during academic work
 Ability to think independently and apply skills and abilities to solve emerging problems
 Skills in assessing the learning situation, their actions, and their results
 Skills of anticipating possible problems and taking into account other people's experience, mistakes
 Ability for rational and logical thinking
 Skills to organize data and draw conclusions
 Ability for quick and decisive action and conclusions
 A tendency to test ideas empirically
- What difficulties are significant when performing laboratory work? *You can choose no more than 3 answers.*
• assembly of the installation and search for an error if it does not work
• work with equipment (selection of the desired device, setting)
• conducting experiment or measurements
• processing of results (calculations, graphing)
• analysis of experiment results
• formulation of conclusions
- Name the main difficulties in solving problems and assignments in physics, mathematics, chemistry.
You can choose several answers, but no more than 3.
• analysis of the condition of the problem and consideration of where to start solving
• a short record of the condition (given) and the conversion of units into the required system
• building a schedule or diagram according to the condition of the problem
• defining data from a picture or graph
• carrying out mathematical transformations
• analysis of the solution result (for likelihood)
- Indicate the main difficulties in verbal response *You can choose several answers, but no more than 3.*
• remember what to tell
• build the logic of the response (sequence)
• highlight the main idea or definition
• explain and prove your point of view with additional questions
• perform a generalization and systematization of the material (classification, conclusions)
• give examples on the topic

The survey was available at the link https://www.testograf.ru/ru/oprosi/aktualnie/0170d0e97fd349eee.html 04/16/2018 (08:47) - 04/16/2019 (12:00)