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THE IMPORTANCE OF METACOGNITIVE KNOWLEDGE IN ENGINEERING EDUCATION: STRATEGY AND EXPERIENCE

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Abstract

For engineering education today it is very important to respond to new requests related to changes in the object of engineering, methods, the resulting risks. Metacognitive knowledge allows reconstructing and managing self-understanding during transition to a new engineering paradigm of activity. This study proposes an educational methodology aimed at building metacognitive knowledge and skills based on discursive practices, the ability to identify a metaphysical meaning, problem. Its content is knowledge, methodology, model tasks in philosophy. Philosophical disciplines play a big role in metacognitive knowledge and skills shaping due to the emphasis on the practices of thinking (analysis, synthesis, conceptualization, etc.), as well as the implementation of constant conscious reflection behind them to achieve self-esteem, self-regulation by knowledge. Particular attention is paid to the practice of "round thinking", aimed at identifying an idea, meaning, as well as the practice of statement a problem. The educational strategy of teaching philosophical disciplines in engineering specialties presented in the study was successfully tested at the Yuri Gagarin State Technical University of Saratov.

Keywords: Engineering education, metacognitive knowledge and skills, open-ended problem, philosophical disciplines, self-regulation, self-understanding.

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1. Introduction

The actualization of the topic of modern engineering education has several levels. The first level concerns the issues of transformation of engineering objects themselves. Design, a practical approach to the physical, chemical levels of reality, a synthesis of technology and biosystems give rise to new modular objects (NBIC field) (Jamali et al., 2018). Atom, bit, neuron, gene become the units of manipulation. New technological developments are being introduced into the structures they have created, and they are placed in new living conditions. The resulting objects have fuzzy characteristics, are structurally unstable, and unpredictable in behavior. But it is they who define the field of modern engineering thought and practice, a new reality. The second level of problems stems from the first. The field of new modular subjects requires a synthetic combination of knowledge and areas of many previously disjoint sciences and methods. Engineering objectivity itself exposes the increased requirements for the student, from whom they want to go beyond simple calculation and modeling. It requires metacognitive knowledge (McCord & Matusovich, 2019) to reveal the boundaries of possible modifications of constructed objects, to change their meaning; critical thinking (Solodikhina & Solodikhina, 2019); application of new methods of fragmenting reality. Finally, the third level is about ethics. It is extremely popular today since the "new subject matter" cannot be adapted to social, psychological, economic life without a value status (Dupras et al., 2020; Hofmann, 2020). It must be fixed in the system of law, environmental regulations, adapted to culture while avoiding risks and contradictions.

2. Problem Statement

Rebuilding an engineering education system is not so easy. The leaders of professional educational programs themselves, being at the point of choice, cannot understand what component of training needs to be strengthened. Leaders of professional educational programmes are particularly exposed to the special tensions that emerge between state authorities' and academia's norms and claims for a strengthened research profile on the one side, and the practice-domain on the other side (Tellmann et al., 2020). The most important task of engineering training is the development of neocognitive attributes. They are associated with self-education, discipline, inter-subject relations. Today, this becomes a key factor not only for retaining students in universities and colleges, improving the quality of education but also for assessing the effectiveness of the institutions themselves (Bowman et al., 2019).

This study focuses on the second level of the problem of engineering education: new techniques that combine different levels of knowledge and skills. Metacognitive knowledge and skills are presented in the study through the prism of teaching philosophical disciplines. The authors associate the value of philosophy in the formation of engineering thinking with the special role of understanding and thinking, a conscious, rational assessment of their own activities, and the presence of ethics. The study presents a meaningful methodology for teaching philosophical disciplines, which involves acquiring the skills of reflection, critical thinking, self-presentation, self-esteem, problemization. It includes recognition of the importance of all previously accumulated knowledge, their continuity, the ability to synthesize them with professional skills.

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3. Research Questions

The topic of metacognitive knowledge has received its particular methodological development, primarily within the framework of psychological sciences (Biasutti & Frate, 2018; Zumbach et al., 2019). They began to study issues that based not only on an assessment of the level of knowledge itself but also the possibilities of its self-regulation, various strategies for achieving educational or professional goals, self-control and its methodological side, etc. A particular topic was the problem of conflict (Kashapov, 2012), critical thinking (Yakovlev, 2019), motivation to learn, etc. However, it should be stressed that the active development of cognitive technologies within the framework of psychological and pedagogical knowledge would not have taken place if its content base had not been formed. It was determined by philosophical knowledge. The main categories and their genesis, dialectical and metaphysical methods, the basics of formal logic, the ability to reflect – this is the incomplete arsenal that became the conceptual basis for the scientific development of cogitas in the 20th century.

Cognitive psychology studies skills related to decision-making, choice, assesses the role of intelligence in these processes, builds strategies of self-control (Halpern, 2014). And, in general, it is aimed at forming "instructions" to create a sustainable intellectual activity that justifies efficiency. But all this is no longer enough in the modern educational process. To build strategies without taking as a basis the goal, meaning, value, relying on "saving effort" in knowledge means having one-track thinking (M. Heidegger), implying the presence of "hard skills".

Philosophical disciplines develop a rational program "how to think differently", without which it is impossible to discover and form a new engineering subject matter, assess its risks, prospects of existence. They form the matrix of thinking, identify the problem, formulate the goal, clearly indicate ethical standards, which is extremely important for modern engineering. They are aimed at a problematic vision of reality and based on a combination of analytical and synthetic procedures. They form a categorical, conceptual and critical thinking. Meaning, value, concept, along with flexibility, awareness, engagement, synergy, empathy, etc., must be included in our syllabuses and the technological progress must be one of the core areas of this future (Castro & Sancristobal, 2020).

In addition, modern engineers are defined in their activities as people working with the "open-ended problem", such problems that do not have the right one or the only method of solution (Olewnik et al., 2020). Philosophical disciplines allow practicing the ability to problematization (Popper, 1979) – a clear definition of the horizon of the subject of research, manipulation, as well as the ability to fragment (the basis of modern engineering) associated with analysis.

4. Purpose of the Study

The aim of the work is to present the educational strategy and meaningful technique used to teach students in engineering specialties. They include the ability to develop metacognitive knowledge, skills, to put an "open-ended problem" based on studying of philosophical disciplines. The overall goal involves the following tasks:

- developing the content of metacognitive practices based on philosophical disciplines;

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- motivation to develop self-reflection to a better understanding of the essence of the "open-ended problem";
- testing of the developed tasks as part of training in philosophical disciplines.

5. Research Methods

Even in the studies of the last third of the 20th century, the idea of "overeducation" came up, which indirectly addressed the issue of metacognitive, critical thinking. Overeducation closes the discrepancy between the demand of the economy and training (Maltseva, 2019), which is very important in the context of the ongoing development of technology. For a modern engineer, a well-founded strategy of conflict-free, socially oriented, intellectual activity is not enough. It should contain semantic and value self-regulation, doubt, and offer alternative scenarios of thinking and practice. Through them, the opportunity not formally but meaningfully to participate in the processes of reconstruction of reality opens.

Changing the educational strategy in the development of engineering programs is an extremely relevant topic. In addition to the general standards presented by the Ministry of Science and Higher Education of the Russian Federation, there are consolidated educational and methodological commissions in various areas that determine the "approximate" ratio of hours of different units, the competencies, and assessment indicators. The educational institution itself has the right to decide what courses will be called, to distribute hours within individual unites, etc. The Philosophy course is included in the list of compulsory curriculum disciplines in all engineering specialties. However, the number of hours does not always allow to realize the potential of opportunities that philosophy brings for the formation of metacognitive knowledge.

A team of authors developed a unique technique, which included various tasks aimed at developing metacognitive thinking. The tasks involved the passage of various stages. The first two focused on developing skills of analysis, speaking, self-presentation orally. The last stage involved written reporting and was aimed at the ability to identify a problem, express it conceptually.

The first stage meaningfully implied the creation and justification of the logical series of concepts in the given semantic framework related to the category proposed by the teacher. The second stage was associated with access to "round thinking" (Florensky, 2001). This task was aimed at scrapping the circuit given by the framework of analysis and allowed to think of the proposed category through free "whirling" created by arbitrary logical series. According to Florensky, this immerses the cognizer in the "whirlpool of thought" itself, allowing to reveal its metaphysical content. Here the skill of reflection (the product of self-esteem) and criticality, the ability to overcome the usual pattern of thinking to discover meaning, is formed. The third stage included a task related to finding a problem in a given "circle". The area of the «circle» ranged from extremely abstract (philosophical) to subject-specific (professional). Detection of a problem and justification for its conceptual expression was carried out by the student individually, while the previous stages implied the work of the group. At the last stage, having in the arsenal an idea of the logical series of concepts that rationally reveal the problem, its metaphysical basis, the student revealed its context, attracted the history of thought for its more complete understanding and expression. The result was writing creative work on the identified problem. A group of students from engineering specialties of

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Yuri Gagarin State Technical University of Saratov, studying in 2018, 2019, 2020, took part in the testing of the methodology.

As a result of the research work, the following assumptions were formulated:

- practicing logical analysis allows to develop meta-presentation skills, which reflects a palette of cognitive processes (images, associations, etc.) through clear forms of concepts, judgments;
- the clash of the most demanded today levels of "Everyday Life" and "Engineering rationality", demonstrates their cultural and scientific gap through the field of concepts. It can be overcome by metaphysical thinking, as well as creative engineering;
- philosophical disciplines allow not only to develop the student's analytical abilities but also lead to the development of a synthetic, conceptual skill. It is based on the formation of self-assessment of the achieved (Fernandez-Castro & Martinez-Manrique, 2020), critical approach, overcoming the usual patterns of thinking;
- metacognitive knowledge allows to achieve not an intuitive, but a meaningful discovery of the problem area, clearly formulate the point of "failure" in the system of semantic expectations. It is the problem that is the key to understanding the essence of engineering today.

To confirm the assumptions, the authors used the method of analysis and descriptive description of the educational methodology, which allowed to draw systemic and critical conclusions about its use in the further stages of the formation of engineering thinking.

6. Findings

Metacognitive knowledge is, first of all, "knowledge of knowledge", its boundaries, truth, and content. It is accompanied by a critical approach, logical checks, justification. It is important to be able to manage your own knowledge. But for this, it is necessary to evaluate it correctly. For example, a lack of a conceptual understanding of a problem can simply distort it. Philosophy allows learning to follow the meaning, rather than a profitable, more "saving" strategy for applying knowledge.

Cognitive skills and their assessment are the mainstream of modern education. A large number of test tasks have been developed, and monitoring systems have been created for observing intelligence, its flexibility, mobility, and growth (Popov & Vlasov, 2018). Cognitive skills are generally considered a «predictor of professional success» (Maltseva, 2019). Modern developments on this issue include linguistics and didactics; body-intelligence connections; medicine in neuroprocesses, clinical modeling; artificial intelligence; pedagogy and problems of higher education, etc. Metacognitive assessments are extremely popular in the field of education and educational technologies (McCord & Matusovich, 2019) since they guide the personality not only to assess their own thinking, activities but also to their control and regulation.

The educational technology proposed by the authors contains three important stages of metacognitive competence formation. The first stage of the assignments is related to the acquisition of logical analysis skills and the ability to build linear, discursive connections between concepts of various levels: "Philosophy", "Everyday Life", "Engineering Rationality". Students are assigned a given or chosen category of modern philosophy and are invited to build a logical series of concepts related to it at

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the three proposed levels. Logical series need to be justified through examples. This task demonstrates the obviousness and non-obviousness of certain connections, which stimulates interest in a unique logical construction, as well as a non-trivial explanation of the presented number of concepts (which students demonstrated). The teacher's task was to bring to the conclusion about the rigidity of analytics, the presence of given schemes in thinking.

The first stage develops the ability of meta-presentation (Fernandez-Castro & Martinez-Manrique, 2020). Logical series require justification in order to learn how to represent "own thoughts" not in their simple expression or fuzzy associative connection of images, but in a logical, conceptual form. Language clarity requirements allow for a higher level of cognitive activity (Balashov et al., 2018). Social inclusion helps not only to present their own judgments but also to compare them with those of others, who implicitly express perceptions of the most important points of a clash with reality.

The second stage of educational technology is aimed at incorporating the experience of synthetic philosophical reflection into the formation of the thinking of a modern engineer. It is associated with the discovery of "round thinking" skills. It is described by Florensky (2001) ("At the watershed of thought"), contrasting «round thinking» with linear. The structure of such mental tissue is not linear, not a chain, but mesh, with countless nodes of individual thoughts in pairs, so that from any starting point of this network, having made a circular detour and capturing any combination of other thoughts along the way, moreover, in any or almost any sequence, we return to it (Florensky, 2001). Such thinking allows us to open the field contemplatively, moving from analytical to synthetic, dialectical experience. To the combination of everyday life and engineering rationality, not through analysis, but by "moving" meaning. This can only be achieved through the experience of combining various paths of thought. "Circling" around the chosen idea (category) linguistically, logically deepens its meaning. For example, the concept of «mind» can be approached not only from the connection with actual everyday life, but also from biological, neurophysiological, social and other conceptual foundations, from understanding the "mind" through art or, say, sport. All this not only reveals the depth of the concept but also demonstrates its "life", mobility in accordance with current reality. Thus, students consider the category, not within the proposed levels ("Philosophy", "Everyday Life", "Engineering Rationality"), but arbitrarily, independently expand its connection with other concepts. They break disciplinary guidelines based on stable language expressions, common sense, personal practice of using categories in a particular situation. This allows returning to the pre-systemic meaning of the word, to capture its mobility and, at the same time, semantic stability. The completion of this stage of the assignments is an oral summary of the student, which aims to disclose in the concept of a certain "reference point" – an idea that is not too influenced by time, culture.

Thus, at the second stage, the formation of self-esteem in the achieved knowledge is realized (Fernandez-Castro & Martinez-Manrique, 2020). Acquisition of the skill of revealing the metaphysical meaning of a concept is achieved by criticism, involving cultural context, analysis of its linguistic variability. The comprehension of meaning demonstrates how important it is to be able to abandon the usual patterns of thinking.

At the third stage, getting on the ground of the metaphysical concept, the student opens the field of the problem. The self-esteem of the achieved understanding (metaphysical meaning) determines the «expectation system» of the individual in relation to reality. The problem is recorded as a violation or

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failure in the "waiting system". Identification of the problem, the ability to formulate its field clearly and accurately is the most important part of the competence that forms the new engineering thinking. It demonstrates the point of contact of thought and reality, metacognitive knowledge with practice. The result is connected with the writing of a creative work devoted to an independent conceptual vision of the problem, its consideration through various texts of philosophical sources. At the same time, the student develops a metacognitive skill which allows producing self-assessment of knowledge, in which shortcomings and voids can be identified (knowledge about "ignorance"). It is they who demonstrate limitations that do not allow reaching the level of the problem and turn to self-development.

Metacognitive knowledge includes self-knowledge, of others, knowledge of universals, as well as a regulatory factor of all designated levels (Hofmann, 2020). Using this educational method allows not only reconstructing self-understanding through the acquisition of the practice of breaking down the usual logical, analytical patterns of thinking and the inclusion of metaphysical meaning, learning self-presentation and assessment of knowledge, but also identifying and formulating the problem. A modern engineer is declared precisely as "problem solvers" (Olewnik et al., 2020). In fact, the problem is a source of the rational statement of tasks, building strategies for solving, evaluating their effectiveness. It is the basis of regulation. Engineering today at all levels needs the correct use of knowledge, skills, understanding of goals, objects of manipulation. In the study on geoengineering by Curvelo and Pereira (2016), is noted that the purpose itself remains unclear with numerous operational actions on new objects (ambivalent creatures, hybrid products, etc.): preparing for the probable climate changes, reducing risks, exploring new objects?

That is, the problem is not clearly formulated. Metacognitive knowledge allows conceptualizing the field of engineering goals, discovering it as a unity of meaning, unconscious forms of perception, artistic images, empathy, a context of culture and reality. Philosophical disciplines transfer the emphasis of educational technologies from assessment, fixing psychological states to a conceptual, semantic level. This is where the source of creative solutions to modern engineering problems is located.

The role of philosophical disciplines in modern engineering education has been noted by many Western researchers and programs. Just one example used in the United States. In accordance with The Integrative Graduate Education and Research Traineeship (IGERT) program (Table 1), young scientists with a philosophical degree are involved in the work in the field of converging technologies. The Worcester Polytechnic Institute's engineering program for a researcher with a degree in philosophy sets the goal of "identifying problems that no one has identified before" (IGERT, 2020).

Table 01. Examples of tasks and results of achieved competencies

Stages	Task Example	Step-by-step example of solving a task			Results
I stage	Choose the basic category of modern philosophy and build a logical series of concepts of the proposed level, revealing it. Give justification for logical linear connection with examples, demonstrating the impossibility of	Philosophy Level "Technique" - art - beauty - Aphrodite - perfection - space…	Daily Level "Technique" - machine - engine - power -fuel - price...	Level of Engineering Rationality "Technique" - production - technology - algorithm - programming -the code…	Mastering the analytical method through discursive practices. Ability to self-presentation

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	interchangeability of the concept of a different level. Examples of concepts: "technology", "creativity", "virtuality".				
II stage	To consider the selected basic category of modern philosophy in the framework of P. Florensky's idea of "round thinking". Demonstrate the mobility of meaning, which can be revealed in various ways of eras, languages and cultures. Formulate an idea as something unchanging.	"Technique" - speech technique - rhetoric - skill... "Technique" - motion technique - sporting achievements ... "Technique" - machinery - artificial - artifact... "Technique" - virtuality - code system - artificial intelligence... "Technique" - production - serialization - automatism - failure... "Technique" - artificial organs - chips - cybersystems... "Technique" - art - aesthetics – "spirit of the time" - technological civilization... "Technique" as something that is born together with a person, his physicality (organs), which cannot be understood and given only in the form of production, because it is connected with the very method (skill) of introducing artificial objects into the world (culture).			Distinction between logical and metaphysical concepts. Ability to think critically, synthesize, reach the level of "idea".
III stage	Identify the problem within the limits of the established "circle" of thinking.	Problem: technology as an alternative to the human body (body reconstruction, "body-clothing", "body-rudiment"). Reveal the metaphysical meaning of the problem, its impact on everyday life, the development of engineering technologies. Examples of texts used to substantiate the problem: M. Heidegger, "Question of Technology"; H. Beck "The essence of technology".			Ability to identify a problem, express it as a concept using various sources

7. Conclusion

The approach to engineering education presented in this study, based on a meaningful methodology for teaching philosophical disciplines, will make it possible to implement only one of the components of the general strategy for creating new engineering thinking. It is based on the formation of the ability to self-presentation and self-assessment of knowledge for penetration into the metaphysical meaning of the concept. Metaphysical meaning allows fixing the wider horizons of concepts connection with reality, breaks the established patterns of habitual thinking. It is the self-assessment of knowledge that allows reaching the level of the problem, which is recorded as a discrepancy, a "failure" between the expected (conceivable) and the real. This experience is very important for engineering. It is easily transferred to the boundaries of engineering design, working not only with meanings but, above all, with

the "open-ended problem", with their expression in images, codes, mechanical, organic, genetic structures and other stable forms. Metacognitive knowledge, skills make it possible not just to evaluate appropriately the acquired knowledge, but regulate it – to think critically, "differently". It is this paradigm of thinking in engineering that arouses creativity, interactivity, and ethical responsibility.

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