ASEE AMERICAN SOCIETY FOR ENGINEERING EDUCATION

2017 ASEE International Forum:
Columbus , Ohio Jun 28 Paper ID #20734

The Role of Metacognitive Skills in Engineering Education

Dr. Elvira Valeyeva, Kazan National Research Technological University Russian Federation

I am an Associate Professor at Kazan National Research Technological University. I received my specialty in Social Work in 2005 and PhD in Pedagogics in 2008. My professional career covers: teaching at undergraduate and graduate level; planning, developing and managing project in the areas of Educational Systems. My research interest include the process of implementation of the Bologna Agreement in the Russian Higher Education System

Dr. Roman V Kupriyanov, Kazan National Research Technological University

Roman Kupriyanov, PhD in Pedagogy, Assistant Professor of Kazan National Research Technological University. He was a post-graduate student at the specialty of "Social psychology". Roman defended the thesis on Socio-Psychological Mechanisms of Conflict in the Dyad Teacher-Student of a University. He is an author of more than 60 scientific articles in pedagogics and psychology. Research interest include the possibility of the use of the functional approach to the analysis and design of multi-level system of training of professionals, and also points of contact of competence-based and functional approach from the perspective of activity-based concept.

Prof. Nailya Sh. Valeyeva, Kazan National Research Technological University

I am a Professor, Dean of the Faculty of Socio-Technical Systems; Head of Department of Social Work, Psychology and Pedagogics; Deputy Director of Institute of Innovation Management in Kazan National Research Technological University; and Honored Scientist of the Republic of Tatarstan. I received my specialty in Physics in 1975 at Kazan State University and PhD in Pedagogics in 1990. Since 1998 I am a Doctor of Pedagogical Sciences. My professional career covers: teaching at undergraduate, graduate and post-graduate level; planning, developing and managing project in the areas of Educational Systems. My research interest include the foreign educational programs, dual degree, project training, foreign industrial practice. I am a member of Russian Academy of Natural Science and Academy of Social Education.

Dr. Galina Romanova, Kazan National Research Technological University

Galina Romanova, PhD in Pedagogy, Associate Professor at the Department of Foreign Languages at Kazan National Research Technological University. The topic of her PhD study was titled "Creativity Development of Engineering Students in the USA and Western Europe". She is an author of more than 60 publications including monographs, scientific articles and study guides.

Ms. Dzhamilia Renatovna Nugmanova, Kazan National Research Technological University

Dzhamilia Nugmanova, post -graduate student of Kazan National Research Technological University. She finished Master of psychological therapy of children and adolescents in the University Miguel Hernández of Spain in 2016. During the 9 years she worked at the Kazan Federal University. She is an author of more than 15 scientific articles in psychology. Research interests include adaptation processes of students, psychological therapy of anxiety disorders, applications of gestalt therapy and psychological trauma therapy.

The Role of Metacognitive Skills in Engineering Education

Introduction. The necessity of research in the field of professional self-development and self-study is due to the high-level requirements of the modern civilization to human potential. Modern technologies nowadays are developing at a quick rate and are going out of date the same fast. As a result, engineering education often goes behind the onrush of technology, due to the fact that educational process takes a few years. Therefore, self-study skills formation is very important in engineering training. Scientific research shows that an engineer alongside with professional knowledge, skills, qualities and competences has to intentionally participate in the process of personal and professional self-development in order to adapt to constantly developing technologies and effectively fulfill employment functions. This also relates to one one of important objective of the Bologna process – to improve the quality of European education, increase its global competitiveness[11, 13]. Therefore, it is obvious that high-quality professional engineering education must be based on an interdisciplinary approach and comprise humanitarian component[14].

The importance of professional self-development and self-study competences formation in the process of future engineers' training is stated in the Educational Standards of Russia (FSES of Higher Education in Russian Federation) and Europe (The EUR-ACE® Standards) emphasizing the necessity of forming the ability to recognise the need for and to engage in independent life-long learning.

One of the conditions for effective professional self-development competence formation is a high level of metacognitive skills. Hence, one of the tasks of engineering education alongside with basic engineering knowledge and skills aqcuisition is mastering metacognitive skills.

Recent 10-15 years have seen a resurgence of interest in the metacognitive skills development in engeneering education[1, 2, 3, 4, 12, 15, 16]. Today there is no doubt that the development of metacognitive skills is considered as critically important to engineering student learning and particularly instrumental in problem-solving[3, 12]. According to some authors «Metacognition plays a key role in the development of an effective, reflective engineering student who is learning to solve ill-structured problems»[16].

This research is based on the statements developed in didactics, educational psychology, and intelligence psychology by Vygotsky, L.S. (1978, 1982, 1983), Galperin, P.Ya. (1985), Piaget, J. (1972), Davydov, V.V. (1986, 2000), Elkonin, D.B. (1989), Flavell, J.H. (1976), Brown, A.L. (1978), etc.

The concept of metacognition was introduced in psychology by J. Flavell in 1970 for cognitive development investigation. He showed that children develop skills to assess their cognitive system capabilities stage by stage as in case with the skill of information storage. Further, metacognition was investigated as one of the significant structures defining the efficiency of cognitive system performance. J. Flavell defined metacognition as a system of knowledge of one's own cognitive processes and the ability to deliberately monitor and regulate these processes.

According to V. Davydov, it is very important for the student to reflect (i.e. to carry out metacognitive activity) on the activities, to single out fundamental schemes and principles and to use them in other situations[5].

There is a variety of techniques ensuring knowledge absorption; most of them aim at learning the information, the contents of a particular study problem. Metacognitive techniques, however, belong to another category of techniques that contribute to organizing and managing the cognitive activity. These techniques create an individual style of cognitive activity, providing its self-regulation, self-management, autonomy, activity and flexibility. These techniques include particular methods to understand complex information, to control attention, to memorize things, to choose strategies for solving problems, and etc.

I. Yakimanskaya considers intellectual activity methods as meta-knowledge, techniques and methods of cognition[17]. She uses the term "methods of educational activity" including the development of procedural skills, which play a vital role in successful education. The methods of educational activity show the subjective way of processing of educational material demonstrating the level of metacognitive skills development.

Unfortunately, universities pay insufficient attention to the development of the most important metacognitive skills within the degree programs. Therefore, students show a slow rate of metacognitive activity development, and, in some cases, irrational ways of thinking. This fact comes from the educational process organization, where teachers pay their main attention to what they teach, the knowledge of the subject, rather than to metacognitive skills. As a result, many students master metacognitive skills spontaneously, by trial and error.

Thus, the importance of metacognitive skills development as one of the most significant tasks of training students in the engineering educational process is evident. The aim of this pilot research activity is to study possibilities of metacognitive skills development in the engineering educational process.

As an example, we present the experience of Kazan National Research Technological University (KNRTU). The "The Culture of Mental Work" course is a part of engineering curriculum. This academic discipline is an interdisciplinary course combining elements of such academic disciplines as psychology, pedagogy, psychodiagnostics and so on. This discipline provides great opportunities for self-knowledge, for each student to understand his own individual ways of mental activity, his psychological characteristics. The course "The Culture of Mental Work" includes the study and analysis of the following topics: Perception as the primary basis of cognition and learning; The nature of Attention and its role in educational and professional activities; Memory development; Development of Thinking; Factors of effective mental activity; Developing reflexive skills; Methods of understanding complex information, etc. Thus, the training course "The Culture of Mental Work" has a reflexive character and helps students develop metacognitive skills in classroom settings.

The course is based on the ideas of applying the metacognitive methods of teaching presented in the researches of N.Goncharuk, A.V.Hutorskoy, R.L.Khon[6, 7, 10]. According to them in the learning process it is necessary:

- encourage students to use metacognitive strategies in independent work;
- show students the use of metacognitive strategies; explain its essence and content; show the use of strategies in the diverse areas of student's learning activities;
- emphasize the effectiveness of various metacognitive strategies for success in the process of education, for future professional activities;
- convince students that thanks to metacognitive skills one can learn much more

successfully; that the mastering of a particular metacognitive strategy should be considered as a way to increase the level of intellectual development.

Methods of the Study. In this Work, we used the following methods:

1) for metacognitive skills development: reflexive tasks (an essays).
2) for metacognitive skills development assessment: reflexivity study technique (reflexivity questionnaire by A.V.Karpov[9])

The Experimental Base of the Study. The pilot study was organized in Kazan National Research Technological University. Students at the age of 18-20 took part in the experiment. The total number of students engaged in the experiment was 160.

Teaching methods. The cognitive reflexivity can be considered as the basis for efficient metacognitive skills development. Reflexivity is a prosess of self-cognition, a necessary tool of thinking, a source of internal development. The intellectual difficulties encountered by students while performing their intellectual activity is constitute the subject of cognitive reflexivity. Deep assimilation of knowledge and skills is impossible without students understanding the techniques of their learning, methods of cognition and thinking.

Some authors[15] emphasize the following methods of teaching in order to carry out purposeful work on the development of metacognitive skills:

(i) methods of developing self-evaluation and self-control;
(ii) methods of developing reflexivity.

Speaking about engineers especially important is seemed the reflexivity development. There are various techniques of the reflexivity development: discussion; written questioning; graphic representation of the changes occurring in the students cognitive processes during the lecture/class, as well as during specific period of study the topic. Special reflexive tasks provide a transition to metacognitive activity, i.e. to the conscious use of one's own methods of constructing algorithms, cognitive learning strategies, heuristics, etc. As an example of such tasks we suggest to use the tasks allowing students to master reflexive procedures in relation to methods and ways of identification, understanding, memorization, reproduction of the educational information. Tasks for the compilation of the summary of the lecture/scientific and educational literature/abstracts serve as an important methodological tool for advanced management of the formation of reflexive skills. The result of applying the reflexive method can be a constructed concept, a formulated contradiction, found functional connections/relationships/regularities, a schematic construction, the structure of the studied material.

Results. Assessment of the level of development of metacognitive skills was conducted on the basis of the "The Culture of Mental Work"course.

To study the level of development of metacognitive skills, we used:

(i) special reflexive tasks and essays, and
(ii) reflexivity study technique (reflexivity questionnaire by A.V.Karpov).

Students performed special reflexive tasks, where a reflexive analysis of their cognitive activity is required, at the end of each lesson. It should be noted that reflexive tasks are both diagnostic and forming metacognitive skills. For example, tasks developing reflexive skills while its executing are where the recommendations or instructions should be made: "How to verify the reliability of the presentation of theoretical material?". "What are the criteria for understanding complex texts?", "What is the algorithm for solving problems of this type?",

"How to evaluate the correctness of the solution of this problem?", etc.

In this paper, the following techniques for the development of reflexivity were used: forcing to the use of reflexive analysis (in the form of self-report, self-observation, self-esteem); discussion, written questionnaires, special reflexive tasks, which provide a transition to metacognitive activity, i.e. to the conscious use of their own methods of constructing algorithms, cognitive strategies. Examples include the following: "Name the ways to maintain attention, explain the main causes of inattention and how they can be overcome", "Using your own experience, give examples of positive and negative manifestation of the properties of perception" "What challenges did you face when memorizing new information?", and so on.

Each students work was evaluated according to four criteria for the development of metacognitive skills, which were determined on the basis of the analysis of scientific literature (N.Goncharuk, A.V.Hutorskoy, R.L.Khon). The following criteria were determined:

1. The ability to express verbally the characteristics of the cognitive activity, describe the methods of mental actions used. This report should be stated in your own words, and not be a formal retelling of the learned phrases.
2. The ability to understand deeply the essence of one's own cognitive activity. There are three levels of comprehension of the experience of persons cognitive activity: a) initial level – student provide the transfer of ways of mental activity that were previously explained by the teacher; b) middle level - student demonstrate an aspiration to penetrate deeply into the given situation, to correlate the learned ways with internal experience; c) high level - student is able to describe those ways and techniques that he consciously used in cognitive activity and can evaluate their effectiveness.
3. The ability to reflect: analyze your actions, understand the need for corrective actions, understand the need for self-change, find the best ways to solve the cognitive problem.
4. The ability to identify and assess the degree of cognitive difficulties. It is about the ability to identify and analyze one’s own cognitive difficulties and challenges, to identify its causes, to find ways to overcome the difficulties.

Each criteria was evaluated by experts (professors, faculty) on a six-point scale (0-5), where 5 - the highest level of development, and 1 - the minimum. Depending on the scores received, the students were divided into three subgroups with low (0-1 points), medium (up to 2-3 points) and high (4-5 points) levels of reflexive skills development. The percentage of these groups is shown in Table 1. As can be seen from the data in the table, there are positive changes in the structure of the metacognitive skills of students in the experimental group. After mastering the course, the proportion of students with a low level of development of reflexive skills decreased, and accordingly the share increased with the middle and high levels. Significantly improved results for such indicators as: the ability to deeply understand the essence of their own cognitive activity; the ability to express verbally the characteristics of cognitive activity, the ability to find cognitive difficulties.

During the experiment, students identified the following cognitive difficulties: misunderstanding of the meaning of new complex concepts; insufficient development of cognitive processes (attention, memory, thinking); difficulties associated with the unstructured information; difficulties with the systematization the material and highlighting the main idea in it; many terms can not be expressed in their own words to make the

material get easier to understand; complexity in finding meaning, if the material has a large volume, etc.

Table 1. Distribution of students in the experimental group according to the level of their reflexive skills development (% of total).

№	Reflexive skill	Levels						χ^2
		Low		Middle		High		
		Before	After	Before	After	Before	After	
1.	Understanding the essence of one's own cognitive activity	36	4	52	56	12	40	94
2.	The ability to reflect	42	12	48	52	10	36	89.3
3.	The ability to express verbally the characteristics of the cognitive activity	40	12	52	52	8	36	117.6
4.	The ability to identify and assess the degree of cognitive difficulties	34	14	46	64	8	22	53.8

In addition to special reflexive tasks, the Reflexivity Study Technique (reflexivity questionnaire by A.V.Karpov) was used. The questionnaire consists of 27 statements that characterise the comprehension of cognitive actions and behavior. Student evaluates each statement on a 7-point Likert scale, where 1 point means “Absolutely incorrect”, and 7 points – “Absolutely correct”. The sum of points characterise the overall degree of individual's reflexivity development. Verification of validity was carried out by the author of this technique.

Reflexivity study technique allows to assess three types of reflexivity: situational (actual), retrospective and perspective[9].

Situational reflexivity provides direct self-control of a person's behavior in an actual situation, comprehension of its elements, analysis of what is happening, the subject's ability to correlate his actions with the situation and coordinate them in accordance with changing conditions and his own condition. Behavioral characteristics of this type of reflexivity are: the time spending by person to reflexivity of current activity; the frequency of analysis of what is happening; the degree of deployment of decision-making processes; the tendency to introspection in specific life situations.

Retrospective reflexivity is manifested in a tendency to analyze past activities and past events. In this case, the objects of reflexivity are: the prerequisites, motives and reasons for what happened; the content of past behavior, as well as its performance parameters and, in particular, mistakes made. This reflexivity is expressed, in particular, in how often and for how long the subject analyzes and evaluates the events that occurred, whether he is inclined to analyze the past and himself in it at all.

Perspective reflexivity is correlated with: analyzing the upcoming activity, behavior; planning; forecasting of probable outcomes, etc. Its main behavioral characteristics are:

careful planning of the details of behavior; frequency of addressing the future events; orientation to the future.

The evaluation of the level of reflexivity was carried out by technique developed by A.V. Karpov. Table 2 shows the results obtained before and after the experiment.

Table 2. Dynamics of reflexive level development among students in the experimental group (% of total).

Types of reflexion	Levels						χ^2
	Low		Intermediate		High		
	Before	After	Before	After	Before	After	
Retrospective	12	0	72	60	16	40	50
Situational	12	4	68	68	20	28	8.5
Perspective	28	8	48	52	24	40	21

As can be seen from the table, the share of students with a low level of development of reflexive skills decreased after the mastering the course "The Culture of Mental Work", and accordingly the share increased with middle and high levels. This data are consistent with the results of evaluating reflexive skills using special reflexive tasks. Major changes occurred on the scale of "retrospective reflexivity", which means that students become more aware of their own motives, as well as the prerequisites and reasons for the events that have occurred to them.

Mathematical processing of the study results using the Wilcoxon t-test confirmed that an increase in the level of development of reflexive skills after the experiment was statistically reliable. In order to check the statistical significance of the changes that occurred in the development of metacognitive skills, the Pearson criterion $\chi 2$ (chi-square) was used. For the null hypothesis, the following thesis was adopted: master the course on "The Culture of Mental Work" had no effect on the level of metacognitive skills development. Since in all experimental studies we had three categories for the distribution of a random variable, for a significance level of 0.05, the critical value of $\chi 2$ is equal to 5.99. Calculation of $\chi 2$ for all experiments has shown that in all cases the value of $\chi 2$ exceeds the above critical value. Based on this, the null hypothesis was rejected with a credible probability of 0.95. An alternative hypothesis was adopted: master the course on "The Culture of Mental Work" had an impact on increasing the level of development of metacognitive skills.

The side effect of this experiment was an increase in cognitive motivation in students. As a result of a qualitative analysis of written students' essays, it was revealed that interest in learning increased, as did the desire to develop their metacognitive skills.

The results of pilot study revealed that the students underwent significant changes in self-regulation and reflexive skills development. The results of the experiment also prove that significant changes have occurred in the students' structure of motivation. The findings confirm the idea that "…although intellectual virtues (such as open-mindedness, love of

knowledge and intellectual autonomy) cannot be taught directly, they can be fostered in the appropriate environment"[8].

Conclusion. Study shows that it is often difficult for students to learn because they do not understand what they need to do to perceive information in such a way that it is understood and stored in memory. They are unfamiliar with many principles and rules concerning the process of learning and cognition. The purposeful development of metacognitive skills with the help of a special academic discipline "The Culture of Mental Work", which is part of the engineering curriculum in KNRTU, is important for the training of engineers who can meet the demands of the modern labor market.

The undertaken pilot study showed that the suggested methods are effective developing metacognitive skills of the future engineers. The experience of teaching and feedback received from students who have mastered the course "The Culture of Mental Work" show that the acquired skills are highly appreciated by engineers and can benefit them in the process of their training and in their future career.

Thus, the experience of engineering training at KNRTU demonstrates the abilities of educational system in developing students' metacognitive skills.

References

[1] Anderson, M. L., & Oates, T. (2007). *A review of recent research in metareasoning and metalearning.* AI Magazine, 28(1), 7-16.

[2] Cox, M. T. (2005). *Metacognition in computation: A selected research review.* Artificial Intelligence, 169(2), 104-141. doi:10.1016/j.artint.2005.10.009

[3] Cunningham, P., Matusovich, H. M., Hunter, D. A. N., & McCord, R. E. (2014). *Teaching metacognition: Helping engineering students take ownership of their own learning.* Paper presented at the Proceedings - Frontiers in Education Conference, FIE, , 2014 doi:10.1109/FIE.2015.7344080

[4] Cunningham, P., Matusovich, H. M., Morelock, J. R., & Hunter, D. -. N. (2016). *Beginning to understand and promote engineering students' metacognitive development.* Paper presented at the ASEE Annual Conference and Exposition, Conference Proceedings, 2016-June.

[5] Davydov, V.V. (1986). *Problems of Developmental Teaching.* Moscow: Nauka Press. (In Russian)

[6] Goncharuk, N., & Evgeniya, K. (2013). *The development of future engineers' intellectual competence in the information society.* Paper presented at the IEEE Global Engineering Education Conference, EDUCON, 472-473. doi:10.1109/EduCon.2013.6530147

[7] Hutorskoy, A.V. (2003) *Didactic heuristics. Theory and Creative Learning Technology.* Moscow: Publishing House in Moscow State University. (In Russian)

[8] Karimov, A., & Kazakova, V. (2015). *Intellectual virtues and education practice.* Social Sciences (Pakistan), 10(6), 1317-1323. doi:10.3923/sscience.2015.1317.1323

[9] Karpov, A.V. (2003). *Reflexivity as a mental property and methods of its diagnostics.* Psychological journal, 24 (5), 45-57. (In Russian)

[10] Khon, R.L. (2002). *Pedagogical psychology. Teaching Principles.* Moscow: Delovaya Kniga Press. (In Russian)

[11] Kupriyanov, R.V., & Gorodetskaya, I.M. (2015) *Global trends in higher education and thier impact on engineering training in Russia.* International Conference on Interactive Collaborative Learning (ICL), pp. 244-250.

[12] Subramanian, K., & Suresh, S. (2012). *A meta-cognitive sequential learning algorithm for neuro-fuzzy inference system.* Applied Soft Computing Journal, 12(11), 3603-3614. doi:10.1016/j.asoc.2012.06.012

[13] Valeyeva, N. S., Kupriyanov, R. V., & Valeyeva, E. R. (2015). *Results and challenges of russia's integration into bologna process.* Paper presented at the Proceedings of 2015 International Conference on Interactive Collaborative Learning, ICL 2015, 404-406. doi:10.1109/ICL.2015.7318063

[14] Valeyeva, N. S., Kupriyanov, R. V., & Valeyeva, E. R. (2016). *The role of the socio-psychological disciplines in the training of engineers (KNRTU experience).* Paper presented at the ASEE 2016 International Forum, Retrieved from www.scopus.com

[15] Valeyeva, N. S., Kupriyanov, R., & Valeyeva, E. R. (2017). *Metacognition and Metacognitive Skills: Intellectual Skills Development Technology.* In E. Railean, A. Elçi, & A. Elçi (Eds.), Metacognition and Successful Learning Strategies in Higher Education (pp. 63-84). Hershey, PA: IGI Global. doi:10.4018/978-1-5225-2218-8.ch004

[16] Williams, S. A., Morelock, J., Matusovich, H. M., & Cunningham, P. (2016). *Lessons in transfer: Better understanding of engineering students' metacognitive development.* Paper presented at the Proceedings - Frontiers in Education Conference, FIE, , 2016-November doi:10.1109/FIE.2016.7757476

[17] Yakimanskaya, I.S. (1996). *Developing education*. Moscow: Pedagokika Press. 144 p. (In Russian)