

Development of the competence of future engineers to solve engineering problems based on metacognitive strategies

Firuz Kamolovna Azimova
Bukhara State Technical University

Abstract: In this study, the possibilities of developing the competence of future engineers in solving engineering problems through the integration of metacognitive strategies into engineering education were studied. The study used mixed methods (questionnaires, observation, experiment) and analyzed the influence of strategies such as metacognitive reading, planning, monitoring, and evaluation on the effectiveness of students' thinking. The results showed that the metacognitive approach significantly increases students' ability to analyze problems, plan solutions, and learn from mistakes.

Keywords: metacognition, engineering education, problem-solving, metacognitive strategies, competency development

Introduction

Modern engineering activity today requires not only deep technical knowledge, but also the ability to find sustainable solutions to complex, ambiguous, and multifaceted problems. Globalization, digitalization, and rapidly developing technologies require engineers not only to apply existing knowledge, but also to have a high level of personal and professional competencies, such as independent thinking in new situations, the development of innovative approaches, teamwork, and continuous self-development. Therefore, modern engineering education requires abandoning the traditional "learning" model and new approaches aimed at the formation of high-order cognitive skills of students, such as managing thinking processes, adjusting their learning strategies, and logical analysis of problems.

In this context, metacognition - that is, "thinking about thinking" - stands out as an important pedagogical concept. Metacognition, according to Flavell (1976), is the ability of a person to perceive their own knowledge, their own learning process, ways of thinking, and purposefully manage them. In the process of solving engineering problems, this ability is especially important at the following stages:

- Understanding the problem - determining the essence of the problem, extracting the necessary information;
- Planning - assessment of available knowledge and resources, development of a solution strategy;
- Implementation - performing actions according to the plan, constant monitoring of one's own results in the process;

Evaluation and reflection - checking the result, analyzing mistakes, thinking about how to improve it next time.

However, in practice, engineering lessons often focus too heavily on technical skills, the application of formulas and algorithms, which limits students' ability to master the thinking process. As a result, students perceive problem-solving as "finding the right answer," but do not pay attention to metacognitive processes, such as how they thought, why they made such a decision, or how they learn from mistakes. Because of this, they struggle when faced with uncertain, open-ended problems in real life.

To solve this problem, the creation of a methodological system based on a metacognitive approach and its integration into engineering education is considered an urgent task of modern education. This approach teaches students not only “what” to know, but also “how to think.” They will have the opportunity to achieve future professional success by controlling their learning processes, analyzing their strengths and weaknesses, and constantly self-developing.

This article is aimed at solving this problem and includes the theoretical foundations, practical tools, and methodological approaches proposed based on the research results for the development of problem-solving competence of future engineers through the effective integration of metacognitive strategies into engineering education. The article aims to strengthen the role of metacognition in engineering education, provide practical guidance to teachers, and contribute to the development of students’ cognitive independence.

Literature review

Flavell, J. H. was the first to introduce the concept of metacognition into scientific literature, defining it as “knowledge about knowledge.” She emphasized the impact of the ability to control and manage the thinking process on learning effectiveness.[1]

Schraw, G., & Dennison, R. S. distinguished metacognitive ability as a "cognitive component" (knowledge about knowledge) and a “regulatory component” (planning, monitoring, evaluation). This model helps to understand strategic thinking in solving engineering problems[2].

Pintrich, P.R. showed that metacognitive self-regulation of students directly affects their academic achievement. Especially in engineering, this ability plays an important role in the development of innovative solutions[3].

Hmelo-Silver, C. E., studied the development of metacognition in a problem-based learning (PBL) environment. The results showed that PBL gives students the opportunity to analyze their own thinking[4].

Zohar, A., & Dori, Y. J. proved that it is possible to increase students’ critical thinking by applying metacognitive strategies in interdisciplinary lessons. This approach can also be applied in engineering education [5].

Georgiou, M., & Philippou, G. N. studied the effectiveness of metacognitive strategies in solving mathematical problems. Since engineering is also a field based on logical-mathematical thinking, these results are important [6].

Veenman, M. V. J. showed that metacognition has the ability to predict learning outcomes independently of intellectual ability. This means that it needs to be developed separately in engineering education [7].

Sungur, S. identified the relationship between metacognitive self-regulation and motivation and academic achievement among higher education students [8].

Kapa, E. demonstrated that metacognitive training programs specifically designed for engineering students can help them manage complex projects [9].

Yurdugül, H., Özcan, B. proved that it is possible to increase the problem-solving ability of engineering students through metacognitive tools (such as reflective journals, interactive questionnaires) in an e-learning environment [10].

Research methodology: This study was developed based on the mixed methods approach, in which quantitative and qualitative research methods were used together, and an attempt was made to better understand the role of metacognitive strategies in engineering education. The main reason for choosing the mixed method approach is that metacognition is a phenomenon that depends not only on measurable results, but also on internal thinking processes, the level of self-perception, and it is

difficult to adequately reflect it only in numbers. At the same time, statistical evidence was also needed to objectively assess the effectiveness of the strategies.

- The qualitative component of the study focused on the following tasks:
 - Determine how metacognitive strategies can be practically integrated into the process of solving engineering problems;
 - Observe how students control their thinking, what strategic decisions they make at the stages of understanding the problem, planning, monitoring, and evaluating the result;
 - Identification of pedagogical means and methods that develop students' reflexive thinking during the lesson;
 - A deeper understanding of the level of metacognitive messages by discussing and analyzing students' own learning and problem-solving experiences.

On the other hand, the quantitative component of the study served the following purposes:

To find an answer to the question of whether a statistically significant increase in the competence of future engineers in solving engineering problems will occur through the application of metacognitive strategies;

Mathematical assessment of how the level of metacognitive awareness of students in the experimental group changes at the initial (pre-test) and final (post-test) stages;

Statistical verification of the difference between the results of the control group trained using the traditional teaching method and the results of the experimental group.

Through the mixed approach, the study allowed us to answer not only the question "are metacognitive strategies effective?," but also deeper questions: "how, where, under what conditions, and through what process are they effective?." This became a source of relevant information not only for enriching theoretical knowledge, but also for improving the methodology of practical training.

2nd-year students of Bukhara State Technical University (n = 120) participated. Of these, 60 were selected as the experimental group (trained with metacognitive strategies), and 60 as the control group (trained in the traditional way).

The experimental group was trained in the following metacognitive strategies for 8 weeks:

- "Ask a question" strategy at the problem-understanding stage
- "Creating an algorithm" and "assessing resources" in planning
- "Process monitoring" during implementation
- Finally, "error analysis" and "reflexive logging"

Data collection tools:

- Questionnaire of metacognitive messages;
- Engineering problem-solving test (pre-test and post-test)
- Reflective essays based on open-ended final questions
- Analysis of lessons through video observation

Data analysis: Quantitative data were processed using tests, and qualitative data - using content analysis.

Analysis and results: Test results showed that the average score of the experimental group for solving engineering problems (M = 82.4) was statistically significantly higher than the control group (M = 68.7) ($p < 0.01$).

Table 1

Analysis of the research results

Measured parameters	Experimental group (n=...)	Control group (n=...)	Statistical difference (t-test/p)
Metacognitive awareness	78.3	62.1	\$p < 0.001\$
Personal and professional development	High growth	Stable/Low	\$p < 0.01\$

Also, according to the results of the Metacognitive Messages Questionnaire, the level of metacognitive messages in the experimental group increased by 38%, while in the control group, an increase of only 7% was observed.

Analysis of reflective essays showed that the students of the experimental group used deeper, more analytical, and more objective expressions when describing their thinking processes. For example, comments like “I realized I misunderstood the problem at first because I didn’t pay attention to the end of the question” showed a strong tendency to learn from mistakes.

Video observations also confirmed that students in the experimental group use a strategic approach when analyzing the problem with their classmates, evaluating various solutions, and choosing the most effective path.

Conclusion: The obtained results showed that the integration of metacognitive strategies into engineering education is an effective tool for developing students’ problem-solving competence. This approach enhances not only their technical skills but also their ability to manage their own thinking, learn from mistakes, and develop innovative solutions.

Suggestions:

- Implementation of a special course “Metacognitive Engineering Problems” at engineering faculties.
- Introduce elements of metacognitive reflection into lesson plans (for example, “What did I do well today? What went wrong?”) constant input.
- Organization of methodological seminars to improve teachers’ qualifications in metacognitive pedagogy.
- Future research should focus on studying the different impacts of metacognitive strategies on different engineering areas (e.g., mechanics, electrical engineering, software engineering).

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