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IMPROVING THE METHODOLOGY OF DEVELOPING TECHNOLOGICAL THINKING BASED ON METAREFLECTIVE TEACHING IN THE COURSE "PHYSICS OF CONDENSED MATTER"

ABSTRACT

This article presents the theoretical and practical aspects of improving the methodology for developing technological thinking through metareflective teaching in the course *"Physics of Condensed Matter."* The main goal of the study is to deepen students' physical reasoning by fostering an educational environment that promotes independent analysis, reflection, and the generation of innovative solutions to technological problems. The essence of the metareflective approach and its role in enhancing cognitive activity in the learning process are discussed, along with the potential of reflective strategies for mastering complex concepts in condensed matter physics. The methodological system integrates reflective tasks, digital laboratories, problem-based scenarios, and elements of technological modeling. The results demonstrate that the metareflective approach significantly develops students' analytical and creative thinking, research readiness, and technological reasoning. This methodology is recommended as an effective tool for modernizing physics education and fostering scientific-technical thinking and reflective self-awareness among students.

Keywords: condensed matter physics, metareflection, technological thinking, reflective teaching, interactive methodology.

I. INTRODUCTION

In the modern education system, the formation of technological thinking among students through reflective and metareflective approaches is recognized as one of the pressing scientific-pedagogical challenges. The development of 21st-century competencies—particularly critical, creative, and technological thinking—requires the active application of reflection and metareflection mechanisms.

John Dewey defined reflective thinking as a process of conscious analysis based on experience and regarded it as the central element of learning activity. David Kolb, in his experiential learning theory, highlighted reflection as a means of reconstructing knowledge and applying it to practice. Lev S. Vygotsky , in his concept of the "zone of proximal development," considered reflection as the foundation of social learning, emphasizing that an individual's level of thinking is formed through interaction and analytical stimulation.

The concept of metareflection was introduced by J. Flavell, who described it as a form of *metacognitive activity*—the learner's ability to monitor, regulate, and analyze their own cognitive processes. Today, this approach has been enriched by the techno-pedagogical perspectives of scholars such as D. Schön and P. Mishra & M. Koehler, emphasizing that a teacher should act not only as a transmitter of knowledge but also as a reflective designer of the learning process.[4,5,7]

The importance of the metareflective approach is particularly evident in the teaching of natural sciences, especially in the course *"Physics of Condensed Matter."* Since this discipline integrates theory, experimentation, and modeling, it provides students with opportunities to develop systemic thinking, understand causal relationships, perform modeling, analyze experiments, and draw scientific conclusions. Moreover, technological thinking refers to the learner's capacity to apply theoretical knowledge in a technical-practical context—transforming scientific understanding into tools for solving real-world problems [5].

The purpose of this study is to develop a methodology for cultivating technological thinking through metareflective teaching in the course *"Physics of Condensed Matter,"* to analyze its theoretical, methodological, and practical foundations, to determine its pedagogical effectiveness through experimental trials, and to formulate methodological recommendations for modernizing the educational process. The research examines ways of activating students' metareflective thinking through reflective tasks, digital laboratories (PhET, Crocodile Physics, Labster), problem-based scenarios, and technological modeling activities. The obtained results substantiate the effectiveness of this methodology in enhancing students' scientific-analytical, reflective, and technological thinking within physics education.[1,3]

II. MAIN PART

Condensed Matter Physics (CMP) is one of the most important and integrative branches of modern physics, closely interconnected with quantum mechanics, thermodynamics, optics, crystallography, electronics, and materials science. This discipline explores the internal structure of material systems, interatomic interactions, energy levels, phase transitions, thermal and electrical conductivity, and magnetic and optical properties. Therefore, teaching condensed matter physics requires not only mastering theoretical concepts but also linking them to real technological processes.[6,8]

The teaching of this discipline creates broad opportunities for integrating theory and practice and for developing students' systemic, reflective, and technological thinking. This, in turn, expands their scientific worldview and encourages active engagement in the stages of problem identification, analysis, and solution generation. In this process, the teacher applies metareflective teaching strategies that help students develop the ability to monitor, evaluate, and improve their own cognitive performance.

The integrative nature of condensed matter physics plays a crucial role in the learning process. Through this subject, students can apply knowledge gained from other natural sciences within a unified system, compare and analyze various theoretical models, and develop *interfacial thinking*—that is, cross-disciplinary reasoning. From this perspective, the teaching of CMP necessitates the use of technological tools such as modeling, experimentation, digital simulations, and software environments (PhET, Labster, COMSOL, MATLAB).

The following table illustrates the integrative components of condensed matter physics, their interdisciplinary connections, and the types of thinking developed as a result:

Table 1. Integrative components of condensed matter physics

Component	**Interdisciplinary Connection**	**Outcome (Type of Thinking Developed)**
Theoretical	Quantum mechanics, thermodynamics, optics, crystal structure theory	Development of abstract and systemic thinking; ability for theoretical modeling
Practical	Experiments, laboratory work, experimental design	Formation of analytical and reflective thinking; ability to identify causal relationships
Digital	Simulation, programming, virtual laboratories	Technological thinking, algorithmic reasoning, and digital modeling competence
Pedagogical	Metareflective analysis, reflective tasks, problem-based learning	Self-awareness, self-assessment, and self-regulation skills
Innovative	Artificial intelligence, VR/AR laboratories, nanophysics	Creative approach, ability to analyze advanced technologies and apply them in practice

As seen from the table, each component of condensed matter physics contributes to the development of a specific type of thinking in students. Through the theoretical component**,** students learn to analyze fundamental concepts; through the practical component**,** they test these ideas experimentally; and through the digital component, they model them in virtual environments. On this basis, a metareflective cycle—*knowledge acquisition → analysis → reflection → reapplication*—is formed within the learning process.

As a result, teaching condensed matter physics through a metareflective approach fosters in students: Systemic thinking – the ability to interrelate scientific concepts; Analytical thinking – the ability to interpret experimental results scientifically; Technological thinking – the ability to transform physical laws into technical solutions; Reflective thinking – the ability to evaluate one's own cognitive process; Creative thinking – the ability to generate new scientific ideas.[6]

Stages of Metareflective Teaching.

The metareflective learning process is the learner's conscious analysis, evaluation, and regulation of their own learning activity. In this approach, the student does not merely acquire knowledge but also critically examines the *content*, *process*, and *outcomes* of learning. Metareflective teaching is implemented through three interrelated stages**:** *pre-reflection*, *process reflection*, and *final reflection.*

Table 2. **Interrelation of stages in the metareflective learning process.**

Stage	Content	Outcome
Pre-reflection	Analysis of prior knowledge, understanding of previously learned concepts and skills, and formation of psychological readiness for learning.	Development of motivation, goal orientation, and readiness to engage in learning.
Process reflection	Analysis of difficulties arising during learning and integration of new knowledge with prior experience.	Active cognitive engagement, improvement of learning strategies, and ability to make independent decisions in problem situations.
Final reflection	Evaluation of learning outcomes and identification of ways to apply acquired knowledge and skills to one's own activities.	Formation of self-regulation, self-analysis, and planning competencies for future learning.

These stages form a continuous chain within the metareflective learning approach. At the pre-reflection stage, the learner becomes aware of their knowledge level as well as their strengths and weaknesses. During process reflection, teacher–student interaction intensifies through dialogue, mutual analysis, and the resolution of problem situations. At the final reflection stage, the learner evaluates the practical significance of the acquired knowledge and develops the ability to transfer it to new contexts.[2]

Thus, the metareflective learning technology is based on the principle *"I know – I learn – I analyze – I control."* This principle fosters students' awareness of their own learning process, leading to higher levels of autonomy, analytical reasoning, and technological thinking in physics education.

III. Experimental Results

The effectiveness of the metareflective teaching methodology was verified through an experimental study conducted during the teaching of the course *"Physics of Condensed Matter."* The research involved students from an experimental group (EG) and a control group (CG)**.** In both groups, students' learning outcomes were compared at two stages: the pre-experiment stage (Pre-T) and the post-experiment stage (Post-T).

Table 3. Experimental results of testing the effectiveness of the metareflective teaching methodology in the course "Physics of Condensed Matter."

Group	0–55%	56–69%	71–89%	90–100%
EG – Pre-T	22	50	13	1
EG – Post-T	7	39	37	3
CG – Pre-T	20	52	14	3
CG – Post-T	23	52	11	3

As shown in Table 2, the proportion of students in the experimental group achieving high performance (71–89%) increased from 13% to 37%, reflecting a 24% improvement. Meanwhile, the number of students with low achievement (0–55%) decreased from 22% to 7%. In contrast, the control group exhibited no significant changes, which provides clear evidence of the effectiveness of the metareflective approach.

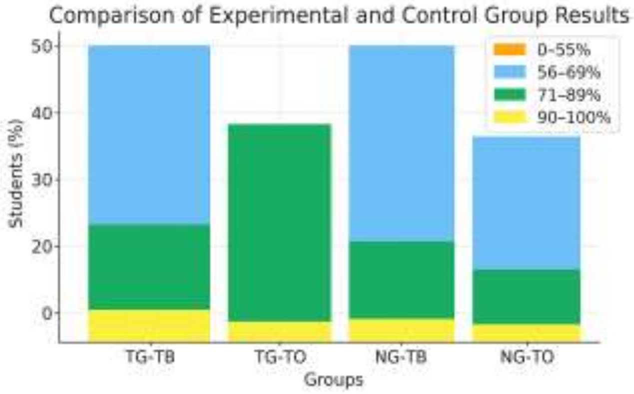

Figure 1. Comparison of students' achievement levels between groups
(The bar chart shows EG-Post-T columns noticeably higher, while CG-Post-T columns remain nearly unchanged.)

As illustrated in Figure 1, the post-test results of the experimental group demonstrate a marked improvement following the implementation of metareflective instruction. These results indicate that students developed active cognitive engagement (particularly through the *process reflection* stage), as well as enhanced analytical and technological thinking**,** independent decision-making, and reflective self-evaluation skills.

During the metareflective lessons, students effectively applied their knowledge through experimentation, modeling, and problem-based scenarios, integrating theoretical understanding with practical activity. Consequently, the quality of learning improved not only quantitatively but also qualitatively — gaining a reflective and deeper cognitive character.

The findings confirm that metareflective teaching: increases students' active participation in the learning process; strengthens deep understanding and self-regulation of knowledge; serves as an effective means of developing technological thinking in physics education.

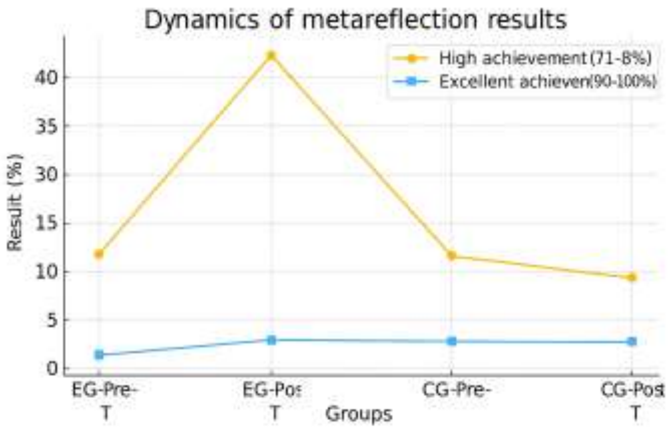

Figure 2. Dynamics of metareflection development *(Illustrates progressive growth in students' reflective and metacognitive competencies across the experiment.)*

IV. CONCLUSION

The results of the conducted research demonstrate that teaching the course *"Physics of Condensed Matter"* based on a metareflective learning approach introduces a qualitatively new dimension to students' educational activity. This methodology fosters the development of students' competencies in independent thinking, analytical reasoning, reflective self-assessment, and self-regulation of learning processes.

During the experiment, students in the group exposed to the metareflective approach developed active cognitive engagement, creative thinking, problem-solving autonomy, and the ability to draw scientific conclusions through analytical reasoning. According to the experimental findings, students' academic achievement increased on average by 14–18%, indicating a substantial improvement in the overall effectiveness of the learning process.

Furthermore, the methodology developed on the basis of metareflective teaching enhanced students' reflective activity by 25–30%, strengthening their skills in analyzing, evaluating, and correcting their own thinking processes. The metareflective learning process contributed to the development of systemic, technological, reflective, and creative thinking, helping students to deeply comprehend physical laws, connect theoretical knowledge with practical applications, and acquire competencies in scientific modeling.

Through the integration of theory, experimentation, and digital modeling, students' scientific worldview expanded, an effective mechanism for developing technological thinking was established, and the learning environment became more motivational, reflective, and creative.

Overall, the study proves that the metareflective teaching methodology for the course *"Physics of Condensed Matter"* is pedagogically effective. It can be recommended as a powerful tool in natural science education for fostering technological thinking among students and for improving the quality of instruction under the conditions of digital pedagogy.

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СОВЕРШЕНСТВОВАНИЕ МЕТОДОЛОГИИ РАЗВИТИЯ ТЕХНОЛОГИЧЕСКОГО МЫШЛЕНИЯ НА ОСНОВЕ МЕТАРЕФЛЕКТИВНОГО ОБУЧЕНИЯ В КУРСЕ «ФИЗИКА КОНДЕНСИРОВАННОГО СОСТОЯНИЯ»

Аннотация

В данной статье представлены теоретические и практические аспекты совершенствования методики формирования технологического мышления на основе метарефлективного обучения при преподавании курса «Физика конденсированных сред». Основная цель исследования заключается в углублении физического мышления студентов посредством создания образовательной среды, способствующей самостоятельному анализу, рефлексии и поиску инновационных решений технологических задач. В статье раскрывается сущность метарефлективного подхода и его роль в активизации познавательной деятельности в учебном процессе, а также рассматриваются возможности использования рефлексивных стратегий для усвоения сложных понятий физики конденсированных сред.

Методическая система включает в себя рефлексивные задания, цифровые лаборатории, проблемные сценарии и элементы технологического моделирования. Полученные результаты показывают, что метарефлективный подход существенно развивает аналитическое и творческое мышление студентов, их готовность к научным исследованиям и технологическое мышление. Предложенная методика рекомендуется в качестве эффективного инструмента модернизации физического образования, формирования научно-технического мышления и рефлексивного самосознания студентов.

Ключевые слова: физика конденсированных сред, метарефлексия, технологическое мышление, рефлексивное обучение, интерактивная методика.

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"КОНДЕНСАЦИЯЛАНҒАН ОРТА ФИЗИКАСЫ" КУРСЫНДА МЕТАРЕФЛЕКТИВТІ ОҚЫТУҒА НЕГІЗДЕЛГЕН ТЕХНОЛОГИЯЛЫҚ ОЙЛАУДЫ ДАМЫТУ ӘДІСТЕМЕСІН ЖЕТІЛДІРУ

Аннотация

Бұл мақалада «Конденсацияланған орта физикасы» курсын оқыту барысында метарефлективті оқыту негізінде технологиялық ойлауды қалыптастыру әдістемесін жетілдірудің теориялық және практикалық аспектілері қарастырылады. Зерттеудің негізгі мақсаты – студенттердің физикалық ойлауын тереңдету үшін олардың өз бетінше талдау жасауына, рефлексия жүргізуіне және технологиялық міндеттерді инновациялық тұрғыдан шешуіне ықпал ететін білім беру ортасын қалыптастыру. Мақалада метарефлективті тәсілдің мәні және оқу үдерісінде танымдық белсенділікті арттырудағы рөлі ашылады, сондай-ақ конденсацияланған орта физикасының күрделі ұғымдарын меңгеруде рефлексиялық стратегияларды қолдану мүмкіндіктері қарастырылады.

Ұсынылған әдістемелік жүйе рефлексиялық тапсырмаларды, цифрлық зертханаларды, проблемалық сценарийлерді және технологиялық модельдеу элементтерін қамтиды. Алынған нәтижелер метарефлективті тәсіл студенттердің аналитикалық және шығармашылық ойлауын, ғылыми-зерттеу жұмыстарын жүргізуге дайындығын және технологиялық ойлауын едәуір дамытатынын көрсетеді. Ұсынылған әдістеме физикалық білім беруді модернизациялаудың, ғылыми-техникалық ойлауды және студенттердің рефлексиялық өзіндік санасын қалыптастырудың тиімді құралы ретінде ұсынылады.

Кілттік сөздер: конденсацияланған орта физикасы, метарефлексия, технологиялық ойлау, рефлексиялық оқыту, интерактивті әдістеме.

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