OLIY TA’LIMDA MOLEKULYAR FIZIKADAN MAVHUM KONSEPTUAL TUSHUNISHNI TRANSFORMATSIYA QILISHDA SUN’IY INTELLEKTGA ASOSLANGAN ONLINE-MERGE-OFFLINE (OMO) GIBRID FORMATI

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Annotatsiya

Zamonaviy oliy ta’limga sun’iy intellekt (SI) texnologiyalarini integratsiya qilish shaxsiylashtirilgan va adaptiv o‘qitish arxitekturasini yaratish uchun tengsiz imkoniyatlarni taqdim etadi. Mazkur maqolada Yevropa kredit o‘tkazish va to‘plash tizimi (ECTS) doirasida molekulyar fizika ta’limi uchun maxsus ishlab chiqilgan, sun’iy intellektga asoslangan Online-Merge-Offline (OMO) gibrid o‘quv formati taqdim etilgan. An’anaviy ma’ruza darslari ko‘pincha makroskopik kuzatishlardan mikroskopik ehtimollik modellariga o‘tishda kognitiv o‘zgarishlarni ta’minlashda yetarsiz hisoblanadi. Ushbu muammoni hal qilish uchun biz talabalarning mustaqil ta’limi va refleksiv sikllarini qo‘llab-quvvatlash maqsadida generativ SI (ChatGPT) modelini faol "fikrlash agenti" sifatida qamrab olgan o‘quv paradigmasini ishlab chiqdik. Tadqiqot doirasida 60 nafar bakalavriat bosqichidagi fizika yo‘nalishi talabalari ishtirokida kvazi-eksperimental tajriba o‘tkazildi; talabalar teng ravishda eksperimental (SI tomonidan qo‘llab-quvvatlanadigan OMO formati) va nazorat (an’anaviy ma’ruza darslari) guruhlariga ajratildi. Empirik natijalar an’anaviy guruh (Post-test o‘rtacha qiymati: 61.30±9.45) bilan solishtirilganda, eksperimental guruhda ko‘rsatkichlarning yuqori darajada statistik sezilarli o‘sganligini ko‘rsatdi (Post-test o‘rtacha qiymati: 78.45±7.12). Tadqiqot shuni isbotlaydiki, raqamli audit bilan integratsiyalashgan tizimli generativ SI so‘rovlar (prompt) ish oqimi termodinamik xatti-harakatlardagi doimiy konseptual noto‘g‘ri tushunchalarni (miskonsepsiyalarni) samarali bartaraf etishi mumkin.

Kalit so‘zlar: Ta’limda sun’iy intellekt; Online-Merge-Offline (OMO) modeli; ChatGPT promptlari; ECTS tizimi; Konseptual tushunish; Oliy ta’lim.

ГИБРИДНЫЙ ФОРМАТ ONLINE-MERGE-OFFLINE (OMO) НА БАЗЕ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА: ТРАНСФОРМАЦИЯ АБСТРАКТНОГО КОНЦЕПТУАЛЬНОГО ПОНИМАНИЯ В ВЫСШЕМ ОБРАЗОВАНИИ ПО МОЛЕКУЛЯРНОЙ ФИЗИКЕ

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Аннотация

Интеграция искусственного интеллекта (ИИ) в современное высшее образование открывает беспрецедентные возможности для создания персонализированных и адаптивных архитектур обучения. В данной статье представлена гибридная структура обучения Online-Merge-Offline (OMO) на базе

ИИ, разработанная специально для обучения молекулярной физике в рамках Европейской системы перевода и накопления баллов (ECTS). Традиционные лекционные форматы часто оказываются неэффективными для обеспечения когнитивного перехода от макроскопических наблюдений к микроскопическим вероятностным моделям. Для решения этой проблемы авторами была разработана учебная парадигма, включающая поддержку генеративного ИИ (ChatGPT) в качестве активного «агента для размышлений» (agent-to-think-with) для содействия циклам самостоятельного обучения и рефлексии. Было проведено квазиэкспериментальное исследование с участием 60 студентов бакалавриата физических специальностей, разделенных поровну на экспериментальную группу (формат OMO с поддержкой ИИ) и контрольную группу (традиционные лекции). Эмпирические результаты продемонстрировали высокозначимый сдвиг в успеваемости экспериментальной группы (среднее значение пост-теста: 78.45±7.12) по сравнению с контрольной группой (61.30±9.45). Исследование доказывает, что структурированные рабочие процессы генеративных запросов ИИ (промптов), интегрированные с цифровым аудитом, могут эффективно устранять устойчивые концептуальные заблуждения в понимании термодинамического поведения.

Ключевые слова: Искусственный интеллект в образовании; модель Online-Merge-Offline (OMO); промпты ChatGPT; система ECTS; концептуальное понимание; высшее образование.

AI-Driven Online-Merge-Offline (OMO) Hybrid Framework: Transforming Abstract Conceptual Understanding in Molecular Physics Higher Education

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ABSTRACT

The integration of Artificial Intelligence (AI) in modern higher education offers unparalleled opportunities for personalized and adaptive learning architectures. This paper presents an AI-driven Online-Merge-Offline (OMO) hybrid learning framework tailored explicitly for molecular physics education within the European Credit Transfer and Accumulation System (ECTS). Traditional lecture-based environments often fall short in facilitating the cognitive shift from macroscopic observations to microscopic probabilistic models. To address this, we developed an instructional paradigm incorporating generative AI support (ChatGPT) as an active "agent-to-think-with" to assist self-study and reflection cycles. A quasi-experimental study was conducted involving 60 undergraduate physics students split equally into an experimental group (AI-supported OMO framework) and a control group (traditional lecturing). Empirical findings demonstrated a highly significant performance shift in the experimental group (Post-test Mean: 78.45±7.12) compared to the control group (61.30±9.45). The study establishes that structured generative AI prompt workflows integrated with digital auditing can effectively eliminate persistent conceptual misconceptions in thermodynamic behavior.

Keywords: Artificial Intelligence in Education; Online-Merge-Offline (OMO) Model; ChatGPT Prompts; ECTS System; Conceptual Understanding; Higher Education.

1. INTRODUCTION

Molecular physics serves as a foundational milestone in scientific curricula, demanding high levels of abstract reasoning and the mastery of multi-level conceptual paradigms. The discipline encompasses mathematically intensive and conceptually elusive constructs, such as the Maxwell–Boltzmann velocity distribution and statistical thermodynamic equilibrium equations. Under standard pedagogical regimes, undergraduate students frequently struggle with the dual representation of physical properties, leading to deeply rooted misconceptions regarding microscopic molecular behavior.

Simultaneously, contemporary tertiary educational landscapes across Europe and Central Asia are navigating a systemic transition toward credit-module assessment structures (such as ECTS). This operational framework demands a substantial expansion of autonomous student self-study hours, forcing educators to design highly efficient, digitally integrated student-centered learning methodologies. Traditional classroom structures fail to satisfy these requirements due to fixed temporal boundaries and a lack of interactive personalization.

The rapid evolution of Large Language Models (LLMs), such as OpenAI's ChatGPT, introduces a pedagogical mechanism capable of serving as a scalable, 24/7 intelligent tutoring interface. Rather than utilizing AI as a mere information-retrieval engine, contemporary educational theory suggests deploying LLMs as "agents-to-think-with" to trigger continuous metacognitive reflection. By framing these AI tools within an Online-Merge-Offline (OMO) framework, educational institutions can establish a continuous loop where asynchronous digital inquiry directly feeds into synchronous classroom collaboration.

While broad STEM-focused AI research is expanding rapidly, specialized empirical studies targeting the synthesis of generative AI workflows with molecular physics pedagogy under credit-module constraints remain profoundly limited. This paper explicitly presents and evaluates an integrated AI-driven OMO pedagogical architecture designed to cultivate advanced conceptual mastery in undergraduate molecular physics courses.

2. LITERATURE REVIEW

The conceptual core of modern hybrid educational design relies heavily on the Online-Merge-Offline (OMO) instruction paradigm. According to Huang et al. (2024), the OMO model breaks down physical classroom limitations by unifying digital spaces with face-to-face peer dynamics. In physics pedagogy, this cross-environment fluidity allows students to gather foundational conceptual knowledge online before engaging in intensive scientific debate offline.

Concurrently, the philosophical repositioning of artificial intelligence within science education represents a paradigm shift. Moving beyond classical Intelligent Tutoring Systems (ITS) that provide rigid automated drilling routines, contemporary frameworks treat generative AI platforms as dialogic partners. Recent literature emphasizes that when properly scaffolded, LLMs can foster experimental reasoning and prompt-driven critical inquiry. For instance, dos Santos (2023) highlighted the capacity of conversational AI engines to identify specific logical fallacies in student formulations of physical laws.

However, the educational deployment of generative AI introduces significant monitoring risks. Unregulated AI interaction often promotes academic dishonesty, unreflective copy-pasting behaviors, and reliance on scientific "hallucinations" generated by LLMs. Cukurova (2024) notes that the synthesis of AI tools with local learning analytics is critical to building robust "hybrid intelligence" frameworks that optimize human-instructor verification. Despite these theoretical developments, a distinct research gap exists concerning empirical validations of structured AI interaction metrics within credit-module molecular physics curricula.

3. METHODOLOGY

This research utilizes a quantitative quasi-experimental design featuring a standardized pre-test/post-test framework to measure academic progress across parallel cohorts.

Experimental Group (n=30) ──▶ AI-Driven OMO Model ───▶ Post-Test Assessment

▲

Baseline Pre-Test Equivalence Check (p = 0.818) │ (Independent Samples t-test)

▼

Control Group (n=30) ──▶ Traditional Lecture ──▶ Post-Test Assessment

3.1 Participants and Ethical Protocols

The empirical validation was conducted within the Faculty of Physics and Mathematics at a public university in Uzbekistan during a regular academic semester. Sixty undergraduate physics students enrolled in the mandatory Molecular Physics module were selected. The cohort was evenly divided into an Experimental Group ($n = 30$) and a Control Group ($n = 30$). Baseline parity was confirmed using prior GPA metrics to guarantee equivalent academic backgrounds. Institutional review boards authorized the protocol, and all students provided written informed consent regarding the research use of their depersonalized academic tracking data.

3.2 Technological and Pedagogical Architecture

The Experimental Group was subjected to an AI-driven OMO framework governed by ECTS self-study operational requirements. The structural components of this workflow integrated specific generative AI interactions:

- The Input Layer: Real-world non-routine thermodynamic scenarios requiring qualitative analysis were delivered via the institutional LMS.
- The Online AI Scaffold: Students executed structured dialogic loops using ChatGPT. The AI was restricted via custom instructions from delivering final equations or answers directly. It was confined to acting as a Socratic guide.

- Logistical Auditing Workflow: To bypass real-time multi-student monitoring limits, a rigorous digital audit layout was implemented. At the conclusion of each module, students generated and exported persistent web-links of their entire ChatGPT session histories alongside mandatory PDF transcripts. These were submitted to the LMS for evaluation of student prompt-engineering paths and reasoning logic.

3.3 Guided Instructional Prompt Samples

To ensure standardized scientific inquiry, students operated within fixed prompt classes:

1. *Conceptual Breakdown Prompt:* "Explain the temperature dependence of the Maxwell–Boltzmann distribution graph in simple language without using advanced mathematical derivations."
2. *Comparative Analytical Prompt:* "Provide a conceptual comparison between microscopic molecular motion and macroscopic thermodynamic behavior."
3. *Error Diagnostics Prompt:* "Identify possible conceptual mistakes in the following interpretation of the kinetic theory of gases."

The Control Group was taught the exact same syllabus content over identical time blocks by utilizing conventional teacher-centered lecture presentation formats, entirely isolated from generative AI scaffolding tools.

4. RESULTS AND DATA ANALYSIS

Statistical processing was executed via Python using the SciPy.stats module and the Pingouin analytics package to calculate parametric inferential data and effect sizes.

4.1 Quantitative Baseline and Progress Verification

The pre-test metric verified that the groups possessed statistically equal prior conceptual knowledge before intervention. The experimental group recorded a baseline mean score of 54.20±8.35, while the control group registered 53.75±6.90. An independent samples t-test confirmed no baseline gap ($t(58) = 0.231$, $p = 0.818$).

Following the implementation of the AI-driven OMO framework, post-test examinations revealed an extensive performance divergence. The experimental group achieved a post-test mean score of 78.45±7.12, whereas the traditional control group reached a mean of 61.30±9.45. The independent samples t-test established a highly significant advantage for the AI-assisted cohort ($t(58) = 7.942$, $p < 0.001$).

4.2 Effect Size Assessment

To compute the educational magnitude of the OMO framework, Cohen's d was calculated:

$$d = \frac{M_1 - M_2}{SD_{pooled}}$$

The formula yielded a value of 1.98, representing an exceptionally large practical educational impact size according to classical pedagogical interpretation scales.

Evaluation Stage	Group	N	Mean Score	Standard Deviation (SD)	t-value	p-value	Cohen's d

Pre-test	**Experimental**	**30**	**54.20**	**8.35**	**0.231**	**0.818 (ns)**	**0.06**
	Control	**30**	**53.75**	**6.90**			
Post-test	**Experimental**	**30**	**78.45**	**7.12**	**7.942**	**< 0.001 *****	**1.98**
	Control	**30**	**61.30**	**9.45**			

Note: ns = not significant ($p > 0.05$); *** = highly statistically significant ($p < 0.001$).

4.3 Qualitative Perceptions and Metacognitive Shifts

Likert-scale psychometric tracking confirmed a positive transformation in student learning behaviors. Eighty-two percent (82%) of participants agreed that interactive AI tools successfully supported independent reflection and self-study cycles. Qualitative transcript validation via LMS logs supported these numbers. As one student observed: *“AI did not simply provide formulas; it guided me through questions that helped me understand how the equations were derived.”*

5. DISCUSSION AND CONCLUSION

The experimental findings confirm that structured generative AI integration within an OMO learning framework effectively enhances conceptual mastery in molecular physics. The performance shift observed in the experimental cohort suggests that transitioning the AI's role from an automatic solution oracle to a conversational partner stimulates deeper cognitive engagement. This mirrors constructivist principles, which state that robust knowledge acquisition requires active processing and iterative conceptual testing.

The implementation of the digital transcript auditing framework resolved a common challenge in AI education: tracking independent student engagement. Requiring web-link exports and transcript submissions discouraged passive copying and helped instructors evaluate student prompt-engineering progression. This structural oversight ensured that AI platforms functioned correctly as personalized learning scaffolds.

In conclusion, this study demonstrates that an AI-driven OMO hybrid framework provides a scalable model for modern credit-module physics education. By combining conversational AI structures with regular instructor validation, institutions can improve independent self-study hours and promote deep conceptual understanding of abstract physical processes.

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