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IMPROVING THE PROCESS OF TEACHING STUDENTS OF A PEDAGOGICAL UNIVERSITY IN BIOCHEMISTRY USING KAIZEN TECHNOLOGY

Y. Myktybekova*[1], K. Zhumagulova[2], I. Digel[3]

[1]Department of Biology, Abai Kazakh National Pedagogical University, Republic of Kazakhstan
[2]Faculty of Natural Sciences and Geography,
Abai Kazakh National Pedagogical University, Republic of Kazakhstan
[3]Institute of Bioengineering, Aachen University of Applied Sciences, Germany

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ABSTRACT

This study aims to develop and theoretically support an adaptive model for teaching biochemistry in pedagogical universities based on Kaizen and the Plan, Do, Check, and Act (PDCA) continuous improvement cycle, as well as to analyse its adaptability to Kazakhstan's teacher education system by comparing it to international educational practices. Mixed-methods educational Research and Development was used in the project. Theoretical modelling, pedagogical design, document analysis, a qualitative comparative study of Japan, South Korea, and Singapore, and design-based research were used. Kaizen diaries, reflective student reports, and teacher observation procedures collected qualitative data, while descriptive statistics of students' learning performance and progress dynamics throughout PDCA cycles included quantitative data. The study created a theoretical model of an adaptive biochemistry course using the PDCA stages to plan didactic material, conduct classes with self-control, reflect on learning outcomes, and adjust content. Individualised educational paths, weekly student progress diaries ("Kaizen journals"), knowledge microchecking, and pedagogical time management were major model components. We proposed using interdisciplinary aspects, such as the Fibonacci sequence, to explain protein molecule spatial arrangement, merging biochemistry with arithmetic. Students were given unique autonomous work activities to build modelling, spatial and logical analysis skills. International practices for implementing Kaizen in higher education in Japan, Singapore, and South Korea were analysed to find effective approaches, gamified monitoring tools, mobile applications, and Lean Six Sigma integration for Kazakhstan teacher education.

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Keywords: students; training of specialists; learning; self-improvement; professional competences

INTRODUCTION

The modernisation of science education is closely connected to the global agenda for sustainable development, particularly Sustainable Development Goal 4, which emphasises inclusive and equitable access to lifelong learning opportunities (The Global Goals, 2025). In this context, the preparation of future science teachers is critical for ensuring the dissemination of scientific knowledge and sustainable practices. According to UNESCO, only 39 % of tertiary education systems worldwide have introduced continuous improvement mechanisms in teacher training programs, which reflects an urgent need to develop adaptive models that can respond to the evolving challenges of modern science and technology (UNESCO, 2023). Therefore, improving the methods of teaching biochemistry in pedagogical universities directly contributes to the achievement of SDG 4 by enhancing professional

*Correspondence Address
E-mail: myktybekovayrza048@gmail.com

competencies and fostering innovation and environmental awareness in future educators.

The urgency of this research stems from a recognised discrepancy between rapidly advancing scientific knowledge and the static nature of many educational programs. Data from the OECD indicate that less than half of science graduates demonstrate sufficient problem-solving and reflective learning skills required for modern classrooms (OECD, 2022). This reveals the first research problem: the mismatch between the dynamic development of biochemical science and the limited adaptability of existing pedagogical approaches to teaching biochemistry in teacher education programs. Traditional instructional models insufficiently support continuous feedback, learner reflection, and systematic improvement of learning outcomes.

In response to this challenge, contemporary educational research increasingly turns to continuous improvement frameworks. One such framework is Kaizen, a Japanese philosophy of gradual, systematic enhancement based on feedback, reflection, and collective responsibility. The Kaizen approach, originally applied in industrial management, has recently gained recognition in education as a mechanism for promoting active learning, critical thinking, and sustainable professional growth (Akhitova, 2023; Ufua et al., 2024). However, this framework raises a second research problem: while Kaizen principles are widely discussed at a conceptual or managerial level, their pedagogical operationalisation within specific scientific disciplines remains insufficiently developed.

Preliminary studies in different educational contexts demonstrate the potential of Kaizen to transform learning processes. The application of Kaizen methodologies in the formulation of pedagogical strategies for engineering students addressed the challenges posed by Industry 4.0, while the adoption of continuous improvement facilitated the acquisition of essential practical skills for teacher education, especially in intricate fields like biochemistry (Hasan et al., 2020). This method enabled the development of critical thinking and teamwork skills, making learning more adaptive. The study also emphasised interactions between students during the learning process. Innovative methods of teaching chemistry to students at pedagogical universities highlighted the role of new approaches, where the introduction of Kaizen improved teaching methods and fostered the growth of professional competence. Emphasis was placed on the practical orientation of learning and the active engagement of students in creating an educational environment. The gradual analysis and improvement of teaching practices improved the quality of learning. The development of professional competence among future chemistry teachers through digital technologies reflected the concepts of continuous improvement inherent in Kaizen, as digital tools provided an opportunity to flexibly adapt the learning process to the individual needs of students (Svyrydiuk et al., 2022; Umarova, 2024). Nevertheless, most of these studies focus on general pedagogical effects, leaving unresolved a third research problem: the lack of empirical and methodological evidence on how Kaizen affects discipline-specific competencies in biochemistry, such as biochemical reasoning, analytical accuracy, laboratory self-regulation, and conceptual understanding of complex molecular processes.

The use of virtual reality (VR) in teaching operational management demonstrated that innovations require continuous adjustment and improvement, confirming the applicability of Kaizen principles across disciplines (Netland et al., 2020; Dolzhenko et al., 2024). The use of VR significantly increased motivation and improved learning outcomes, while collecting feedback helped optimise learning scenarios. Training educational leaders through research activities resembled the Kaizen cycle of continuous improvement, as active student involvement in analysing and improving their learning fostered self-reflection and quality management skills (Luzan et al., 2021; Alpert et al., 2023). This approach shaped critical thinking and adaptability in professional environments. The implementation of Kaizen in commercial business provided valuable insights into achieving operational sustainability, which can be applied to educational contexts requiring adaptation and continuous improvement (Titova et al., 2023; Ufua et al., 2024). Attention was given to the involvement of all participants in improvement and the regular evaluation of results, with management playing a key role in establishing a culture of continuous enhancement.

The balance between criticism for improvement and criticism for emancipation in management education added depth to understanding learning processes and their enhancement, confirming the effectiveness of Kaizen in developing critical thinking among pedagogical students (Wallo et al., 2022). To achieve maximum effect, it is important to balance constructive feedback with encouragement for innovation and to develop educational practices that are sensitive to the social context. The creation of laboratories simulating lean manufacturing methods for postgraduate students demonstrated the value of the practical application of Kaizen principles, where practical cases stimulate motivation and professional competence relevant to the labour market (Jasti et al., 2021). Collaboration between humans and artificial intelligence in the development of competency-based curricula complements Kaizen technology through automation and rapid data analysis, ensuring continuous improvement of the learning process (Padovano & Cardamone, 2024). The integration of AI thus enhances the adaptability of curricula to students' individual needs and supports continuous development in education. This points to a fourth research problem: the absence of a systematically modelled, subject-specific framework that integrates continuous improvement cycles (e.g., PDCA), reflective microassessment, digital tools, and interdisciplinary elements within biochemistry teacher training.

An analysis of articles reveals several research gaps. First, previous studies have concentrated predominantly on the technological or managerial dimensions of Kaizen in education, neglecting its methodological adaptation to specific scientific subjects. Second, while Kaizen's influence on student motivation has been verified (Hasan et al., 2020; Akhitova, 2023), there is a lack of evidence for its effectiveness in enhancing disciplinary competencies such as biochemical reasoning, analytical precision, and laboratory self-regulation. Third, no studies to date have systematically modelled a cyclical framework for biochemistry education that integrates reflective micro-assessment, digital tools, and interdisciplinary approaches such as mathematical modelling (Volodarets et al., 2022; Sulaimanova & Egamberdieva, 2025). The lack of empirical and theoretical synthesis represents the primary research gap examined in this study.

This study aims to develop and theoretically substantiate an innovative model for teaching biochemistry in pedagogical universities based on the Kaizen philosophy, understood as a system of continuous, incremental pedagogical improvement realised through the integration of the Plan–Do–Check–Act (PDCA) cycle into course design, instruction, and assessment. Accordingly, this study addresses the following research questions:

(1) How can a biochemistry course for future biology teachers at a pedagogical university be designed based on Kaizen principles by structurally integrating the PDCA cycle into its content and organisation?

(2) In what ways does the Kaizen-based biochemistry teaching model developed for Kazakhstan's pedagogical universities converge with or differ from the Kaizen-orientated practices of higher education institutions in Japan, South Korea, and Singapore?

(3)What practical recommendations can be formulated to guide the gradual implementation of Kaizen-driven micro-improvement mechanisms in the biochemistry curriculum of pedagogical universities?

This research carries the potential to correct the limitations of previous studies by providing a subject-specific adaptation of Kaizen principles, empirically linking continuous improvement with measurable learning outcomes in biochemistry. The novelty lies in conceptualising Kaizen not merely as a management philosophy but as a sustainable pedagogical technology that aligns teacher training with global educational goals and strengthens the professional competence of future biology teachers.

METHODS

This study employed an educational Research and Development (R&D) methodology with a mixed-methods design (Ponce & Pagán-Maldonado, 2015). The goal of the R&D framework was to develop, refine, and preliminarily evaluate an adaptive biochemistry course model based on Kaizen and the PDCA cycle for biological speciality students at the Faculty of Natural Sciences and Geography of Abai Kazakh National Pedagogical University (Almaty, Kazakhstan). The R&D strategy was chosen because it focuses on building an educational model (the Kaizen-based PDCA course) and testing and improving it.

Using mixed approaches, the three research topics were answered complementarily. Theoretical modelling, document analysis, and expert reflection were used to answer Research Question 1: "How can a biochemistry course for future biology teachers in a pedagogical university be designed on Kaizen principles by structurally integrating the PDCA cycle into its content and organisation?". Research Question 2 ("In what ways does Kazakhstan's pedagogical universities' Kaizen-based biochemistry teaching model converge with or differ from the Kaizen-orientated practices of higher education institutions in Japan, South Korea, and Singapore?") used qualitative comparative analysis of institutional documents and published studies from the participating countries. Research Question 3

("What practical recommendations can be formulated to guide the gradual implementation of Kaizen-driven micro-improvement mechanisms in the biochemistry curriculum of pedagogical universities?") was answered by integrating qualitative findings with quantitative indicators of student learning dynamics and feedback to create evidence-based implementation guidelines.

The R&D process had four interrelated stages that followed standard R&D logic (analysis – design – development – evaluation – revision) and Kaizen methodology's PDCA cycle (Plan – Do – Check – Act). The Kaizen idea of continual micro-improvement required many development and evaluation cycles for each stage's qualitative and quantitative procedures.

First, theoretical modelling was used to revise the biochemistry course structure. The modelling process used system analysis, pedagogical design, and Kaizen philosophy for higher education`s continuous improvement (Hervas, 2021). The conceptual model linked PDCA aspects to curriculum design, instructional delivery, student feedback, and methodological adjustment based on empirical data collected during the R&D process. Data on curriculum design and instructional delivery were obtained from course syllabi, lesson plans, instructional materials, and teacher observation protocols. Student feedback was gathered through weekly Kaizen journals, reflective essays, micro-check sheets, and short post-module surveys. Data-informing methodological adjustments were derived from thematic analysis of student reflections, instructor field notes, and descriptive statistics of students' learning performance across successive PDCA cycles. This stage produced visual flowcharts, schematic models, and written explanations of the adaptive educational process's logical framework and answered Research Question 1.

Several purpose-designed research instruments were used to collect qualitative and quantitative data aligned with the PDCA cycle. The main qualitative instrument was the Kaizen journal, a structured weekly reflective diary in which students recorded learning difficulties, progress, time-management issues, and suggestions for micro-improvements according to PDCA stages. Formative assessment was supported by micro-check sheets containing short conceptual questions and self-check items administered after each module. Additional qualitative data were obtained from reflective essays, short written reports, and structured teacher observation protocols documenting instructional delivery, student engagement, and recurring learning difficulties. Quantitative data were collected from course assessment records, including module test scores and laboratory performance indicators, enabling descriptive statistical analysis of learning dynamics across PDCA cycles.

The second stage developed and implemented a Kaizen approach to teaching biochemistry. Kaizen-based biochemistry course design and development was part of the R&D methodology.

The main research method was design-based (Reeves, 2006), which involves iterative pedagogical innovation creation, implementation, and assessment. The research team developed and piloted Kaizen journals for weekly reflective student feedback, micro-check sheets for formative assessment after each module, time management templates for instructional flow, and individualised learning routes for students with different learning paces within this framework. Field notes, teacher remarks, and Kaizen journal entries detailed how students perceived the new course aspects. Quantitative data comprised mean scores and PDCA cycle progress indicators for biochemistry students. These data types allowed a first verification of the model's viability and internal coherence to answer Research Question 1 and establish the basis for Research Question 3 suggestions.

In the third stage, the emerging Kaizen-based biochemistry course in Kazakhstan was compared to innovative practices in Japan, South Korea, and Singapore, which use Kaizen and Lean principles in higher education. This phase focused on Research Question 2.

Data were acquired from official university documents and course outlines, scholarly publications on Kaizen and Lean in higher education, and open-access institutional reports and websites. The comparative technique (Cohen et al., 2017) and qualitative content analysis (Krippendorff, 2019) identified instructional design, feedback, and continuous improvement patterns and differences. A cross-case comparison matrix showed how the Kazakhstani model compares to foreign cases and which features are transferable or need adaptation.

At the last stage, the theoretical model was integrated into the biochemistry course and enhanced with multidisciplinary mathematical tools to improve biochemical process visualisation. The Fibonacci sequence modelled DNA helices, protein folding, and the physiological cycle's intrinsic symmetry. Fibonacci-based tasks were part of lectures, labs, and individual assignments.

To assess model efficiency during R&D,

qualitative and quantitative data were collected. Qualitative data from Kaizen journals, reflective essays, short student reports, and teacher observation protocols was analysed using thematic coding (Braun & Clarke, 2006) to identify improvement indicators like better reflection, self-regulation, motivation, and biochemical understanding. Descriptive statistics of student performance indicators (mean scores, standard deviation, and progress per PDCA cycle) and frequency analysis of feedback log and micro-check themes were quantitative data.

First, qualitative data were used to explain and contextualise numerical changes in student performance (for example, to understand why certain topics showed greater improvement); second, quantitative trends were used to validate and prioritise qualitatively observed micro-improvements (for example, to determine which Kaizen tools most consistently increased achievement and satisfaction); third, both were integrated. This study's R&D cycle included theoretical model building, initial implementation, and efficacy evaluation in a university instructional context. Kaizen philosophy and educational R&D logic emphasise iterative refining over large-scale experiments.

Data analysis used descriptive and qualitative statistics. Based on Braun and Clarke (2006), qualitative data from Kaizen journals, reflective essays, and interviews were thematically coded to identify improvement indicators like feedback integration, learning motivation, self-regulation, and interdisciplinary understanding. Student assessment and attendance descriptive statistics (means, standard deviations, and change over time) were calculated for quantitative analysis.

Both levels of mixed approaches were integrated. The methods involved parallel collection and triangulation of qualitative and quantitative data during each PDCA cycle (Yin, 2013). Interpretation incorporated information from both strands to answer each study question and validate the Kaizen-based biochemistry course and implementation suggestions. The mixed-methods R&D strategy allowed the Kaizen-based biochemistry model to be developed, tested, and refined while demonstrating its preliminary efficacy and practicality in a pedagogical university.

RESULTS AND DISCUSSION

Before presenting each research question's conclusions, we explain how evidence was acquired, evaluated, and, most importantly, tracked across Kaizen-based biochemistry course PDCA cycles. For each cycle, we documented (a) the proposed micro-change, (b) how it was executed in lectures/laboratories/independent work, (c) the evidence used to check its effect, and (d) the next cycle's adjustment.

Data sources/cycle. Students' "Kaizen journals" (weekly reflective diaries), short reflective reports on assignments (including Fibonacci-based protein modelling tasks), end-of-module reflective essays, and structured teacher observation protocols after lectures and labs provided qualitative evidence. Each cycle yielded a comparable "snapshot" of student challenges, perceived tool utility (journals, microchecks, and modelling activities), and teacher observations of involvement and misconceptions.

Cycle-based qualitative analysis. All qualitative data was coded using reflexive thematic analysis (Braun & Clarke, 2006). Inductively created open codes (e.g., blunders, time pressure, multidisciplinary analogies) were consolidated into stable themes. After each PDCA cycle, new entries were reread and coded against the framework, theme definitions were refined only when recurring new patterns appeared, and analytic memos were used to record (i) what changed in student experience compared to the previous cycle and (ii) which course element likely caused that change.

Triangulation inside and between cycles. Methodological triangulation involved comparing topics from Kaizen diaries, reflective reports, essays, and observation protocols in the same cycle. Perspective triangulation was done by comparing student reflections with teacher observations and course artefacts (lecture materials, lab instructions, microcheck sheets). Mixed-method triangulation was used to determine whether qualitative improvements (e.g., better error analysis) converged with or diverged from performance trends by interpreting qualitative themes alongside cycle-level quantitative indicators (assessment results and progress dynamics across cycles). This cycle-based triangulation helped us determine which micro-changes were likely to improve and which needed further tweaking.

How can the Kaizen-based PDCA model be used to design an adaptive biochemistry course in a pedagogical university?

In the context of higher pedagogical education, it is relevant to develop in students not only fundamental knowledge of biochemistry but also skills for continuous self-improvement, reflection on their learning processes, and rapid adaptation to new challenges in science and practice.

Students majoring in biology at the Faculty of Natural Science and Geography of Abai Kazakh National Pedagogical University face the challenge of mastering interdisciplinary concepts, from the molecular structure of proteins and nucleic acids to the mechanisms of metabolic regulation in the cell. Their success necessitates the introduction of pedagogical technologies grounded in contemporary learning theory that intensify learners' cognitive activity through active engagement with content, ensure continuous formative feedback between teacher and student, and provide a systematic framework for monitoring, analysing, and correcting learning trajectories at each stage of instruction. From the perspective of constructivist and self-regulated learning theories, such technologies support knowledge construction through reflection, error analysis, and iterative improvement, while ongoing feedback functions as a mechanism for metacognitive regulation and timely instructional adjustment. One of the promising strategies for solving these problems is the Kaizen technology, a Japanese concept of continuous, step-by-step improvement of work processes through small but regular improvements (Zhong, 2025). In the context of a training course, Kaizen involves not innovations but adherence to daily actions: each lecture, laboratory session, and independent work becomes the object of careful analysis, planning of changes, implementation of adjustments, and subsequent verification of their effectiveness. This approach allows the teacher to respond promptly to difficulties in students' understanding of biochemical mechanisms and for students to take an active part in their learning, systematically assessing and improving their cognitive competence.

Kaizen technology formalises the Plan – Do – Check – Act cycle in each course module, from generating and updating didactic materials to assessing test and lab results. This allows Almaty Pedagogical University to construct a variable and adaptable biochemistry teaching approach for each student (Han et al., 2023). This culture of continual improvement helps students learn biochemistry better and develop self-management, critical thinking, and pedagogical reflection abilities that will help them succeed in the workplace. The model in Figure 1 shows the dynamic interaction between the four biochemistry course modules and the main PDCA cycle phases, integrated using Kaizen.

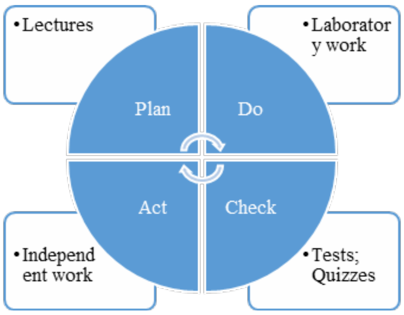

Figure 1. Theoretical Model of Kaizen Technology Implementation in Teaching Biochemistry Based on the PDCA Cycle

Note: This model is conceptually related to the lesson study approach, as both are based on a cyclical logic of planning, implementation, observation, and revision grounded in reflective practice and formative assessment. While lesson study traditionally focuses on analysing individual lessons through collective teacher reflection, the Kaizen–PDCA model extends this logic to the course level by integrating continuous feedback, student self-reflection, and systematic micro-adjustments across all instructional components.

Improving a biochemistry course based on Kaizen technology using the PDCA cycle is an innovative approach that systematically enhances the quality of the learning process through small, consistent changes informed by continuous analysis of results and feedback. This approach helps to increase the effectiveness of teaching, ensure the adaptability of the course to the needs of students, and promote the development of their independence, critical thinking, and self-reflection.

In each PDCA cycle, the Plan phase specified a small, testable instructional improvement (e.g., revising a module's microquestions, adding a reflection prompt, or adjusting an interdisciplinary modelling task) along with the expected learning difficulty it aimed to address. The planning package typically included updated learning objectives, revised monitoring tools (micro-check sheets), and the weekly "Kaizen journal" prompts used to capture student-reported obstacles and improvement proposals.

The Do phase implemented the planned micro-change in lectures, laboratory sessions, and independent work. For example, during the "Proteins: Structure and Function" topic, an interdisciplinary Fibonacci-based protein-helix modelling task was implemented alongside structured self-checking and short reflective reporting, while students also provided anonymous comments on pacing, clarity, and perceived applicability of topics.

The Check phase analysed evidence generated during the cycle, combining (i) thematic patterns from Kaizen journals and reflective texts, (ii) structured teacher observations of recurring misconceptions and engagement, and (iii) cycle-level learning indicators derived from assessment and laboratory performance records.

The Act phase translated the "Check" results into concrete revisions for the subsequent cycle, for instance, updating slide materials, clarifying laboratory instructions, adding scaffolding to interdisciplinary tasks, and revising micro-check questions to target persistent gaps, so that each new cycle began with documented adjustments rather than repeating an unchanged module design (Leticia et al., 2024).

To address the requirement for transparent reporting of iterative improvement, Table 1 summarises how each PDCA cycle was operationalised: what was planned, what was implemented, what evidence was checked, and what was adjusted in response. This structure makes the course development traceable as an R&D process rather than a one-time description of PDCA stages.

Table 1. Tracking Micro-Improvements Across PDCA Cycles (Condensed)

PDCA cycle focus	Plan (micro-change)	Do (implementation)	Check (evidence)	Act (next-cycle adjustment)
Feedback & monitoring	Add/reshape micro-questions + Kaizen journal prompts	Embed micro-checks; collect weekly journals + anonymous comments	Journals + reflective texts + observation protocols + assessment patterns	Revise prompts/questions; adjust pacing/clarity where issues persist
Interdisciplinary modelling	Introduce/refine the Fibonacci protein-modelling task	Run modelling lab + short reflective report	Reports + observations + common errors	Add scaffolding; clarify instructions; link math steps to biochemical meaning
Laboratory autonomy	Modularise lab instructions + reflection blocks	Run labs with adjustable steps and self-reflection	Journals + lab performance indicators	Rewrite confusing steps; add targeted supports/resources

Next, the study developed a conceptual pedagogical methodology using Kaizen philosophy to teach biology to pedagogical university students. This approach was founded on steady improvement, a learning process focus, participant involvement in educational reforms, and systemic pedagogical thought. The process involved incremental daily changes to lectures, lab workshops, didactic materials, and assessment systems. Regularly updating control and test tasks, using micro-check tools (self-check), creating individual reflection routes for learning, building a culture of feedback between teacher and student, and collecting suggestions for improvement from both parties are part of the methodology (Sun et al., 2019; Tkach et al., 2020). The methodology also included pedagogical time management (clear class time planning, accommodating learning paces), variable learning routes for individualisation, and systematic collective analysis of biochemical material learning mistakes and failures. The methodology theoretically underpins the revolutionary biochemistry course transformation at the Abai Kazakh National Pedagogical University Faculty of Natural Sciences. The goal was to sustain future biology teachers' professional, pedagogical, and research skills in the framework of continual educational progress (Figure 2).

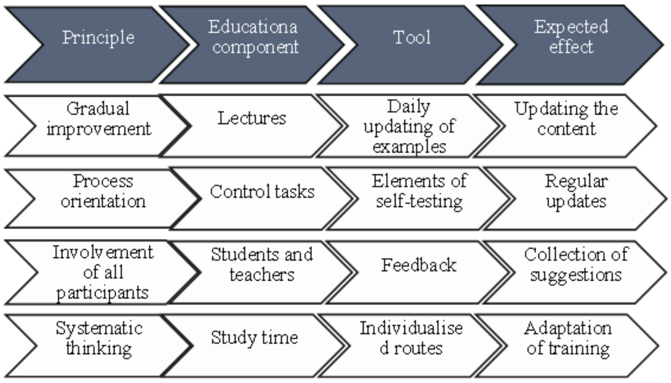

Figure 2. Theoretical Model of an Advanced Biochemistry Course Based on Kaizen Technology, according to the PDCA Cycle

The Kaizen philosophy and PDCA cycle-based theoretical model for enhancing biochemistry teaching supported an innovative approach to educational organisation at a pedagogical university (Costabile et al., 2024). It logically and consistently improved lectures, laboratory courses, test control, and student independent work using the stages "Planning – Execution – Checking – Adjustment" (Kregel, 2019). This made biochemistry instructions customisable, flexible, and dynamic. The model's cyclical nature allowed for instructor and student improvement. From formulating goals to executing micro-changes, each element was incorporated into a single pedagogical logic, where each stage's outcome informed the next. Self-reflection and feedback tools helped diagnose and address issues during the learning process, not afterwards. The model improved biology students' research and professional skills. The gradual updating of lecture content, the improvement of laboratory tasks with mathematical modelling (specifically the Fibonacci sequence), and the integration of micro-questions, checklists, and individual educational routes created a personalised and highly engaged learning environment (Khalid et al., 2019). The methodological substantiation created a logical and structural educational paradigm based on continual development.

The modelling made it possible to create a specific teaching method that would micro-change the content and forms of learning, create a culture of continuous self-improvement among students, make self-assessment more important, improve critical thinking skills, and generalise information (Feola et al., 2023). Involving students in a reflective analysis of their learning progress, as well as a collective discussion of the results, helped increase their motivation and make their learning more meaningful and effective. Thus, the theoretical modelling and subsequent design of a pedagogical methodology based on Kaizen technology demonstrated the potential of this philosophy as a tool for innovative science education.

How does the Kazakhstani Kaizen-based biochemistry course relate to international models of Kaizen implementation in higher education?

The biochemistry course was modelled using mathematical methods, particularly the Fibonacci sequence, which enabled multidisciplinary integration. It was shown that the Fibonacci sequence is preserved in the structure of natural biomolecules, including DNA helices, protein macromolecules, and metabolic reaction phase rhythms. This notion was used to create visual representations and analytical challenges that showed biological processes' intrinsic rhythm and symmetry in a pedagogical university biochemistry course. Based on this notion, a Fibonacci number educational platform was created. The lectures used sequence diagrams (1, 1, 2, 3, 5, 8...) to describe polypeptide chain structure, active enzyme centre generation, etc. Students used Fibonacci spiral patterns to model the spatial structure of molecules in lab work, developing subject matter understanding, spatial, and logical thinking. Number sequences were also applied to the pupils' own work: creating diagrams, self-checking by filling in increasingly complex blocks, and analysing biological symmetry formations. This technique increased the course's transdisciplinary potential and made complicated biochemical ideas easier to understand due to its logical composition. In Table 2, educational students in a biochemistry course utilise Fibonacci numbers to complete an assignment. Interdisciplinary mathematical principles (Fibonacci sequence) were used to reinforce protein spatial structure and production patterns.

Table 2. Structural Organisation of Protein Molecules, Tasks for Independent Work

Stages of the Task	Description of Actions
1. Familiarisation	Read an example of a helical structure of a protein molecule in which the number of amino acids in each turn increases in the Fibonacci sequence: 1 → 1 → 2 → 3 → 5 → 8
2. Modelling	Construct a diagram of this molecule fragment in helix form. Each turn should contain the corresponding number of amino acids. Draw the amino acids as circles and enumerate them.
3. Structure analysis	Analyse: a) What type of protein structure (primary, secondary, tertiary) is best illustrated by this structure? b) What is the biological significance of symmetry or rhythmicity in the structure of proteins? c) How can Fibonacci patterns be used to predict or model the structure of other biomolecules?
4. Reflective report	Write a short reflective report (up to 200 words) answering the following questions: a) What helped you to better understand the structure of the molecule? b) Were there any difficulties in reconciling the mathematical and biochemical ideas?
5. Extra (optional)	Create an analogous model using PowerPoint or a graphic tool (e.g., Canva, BioRender) and attach it to your report.

This task improves protein structural knowledge, interdisciplinary thinking, modelling, natural pattern recognition, and pedagogical creativity (Kregel & Coners, 2020). To determine if Kaizen can be used to teach biochemistry to biological speciality students, models of Kaizen technology implementation in Kazakhstan, Japan, Singapore, and South Korea, where Kaizen principles are already used in higher education, were reviewed (Table 3).

Table 3. Overview of Models for Implementing Kaizen Technologies in Educational Institutions

Educational Institution	Country	Scope of Application Kaizen/Lean
Abai Kazakh National Pedagogical University (Department of Biology, Almaty)	Kazakhstan	Conventional lecture-practice scheme without formalised feedback and correction cycles
University of Tokyo	Japan	Application of Lean principles (continuous improvement) in the redesign of academic programmes: reduction of “wasteful” stages, introduction of PDCA cycles in course development and student assessment
Seoul National University	South Korea	Pilot projects “Weekly Kaizen for Teachers”, mobile application “Kaizen GO” for gamification, and monitoring of learning activities
Nanyang Technological University (Nanyang Business School, NTU-PACE Professional Certificate)	Singapore	Integration of Lean Six Sigma and Agile into the curriculum: Lean Operations & Analytics course; Continuous Improvement Management professional certificate

A comparison of the traditional biochemistry curriculum at Abai Kazakh National Pedagogical University and innovative models at top universities in Japan, South Korea, and Singapore showed the importance of small but systematic improvements to science education. At the University of Tokyo, where Lean principles were integrated into all educational processes, PDCA cycles allowed clear tracking of learning dynamics and rapid problem-solving. Seoul National University demonstrated that daily minor adjustments using Kaizen GO mobile tools can inspire both professors and students, creating a culture of ongoing improvement. The successful integration of Lean Six Sigma and Agile into the curriculum at Nanyang Technological University proved that an interdisciplinary approach and teacher certification drive educational practice growth (Duran & Mertol, 2020). The research at Abai Kazakh National University, based on these best international examples, laid the groundwork for biochemistry instruction with Kaizen technology. Continuous monitoring, daily reflection, and prompt class content and form adjustments created an adaptive system that greatly increases learning. Thus, a clear system for planning and assessing outcomes that integrates lecture, laboratory, and autonomous course components into a dynamic network evolved.

What recommendations can guide the gradual implementation of Kaizen-driven micro-improvements in biochemistry teaching?

Improving the teaching of biochemistry based on the Kaizen concept requires, first of all, the creation of a comprehensive system of professional development for teachers. It is recommended to organise regular internal trainings and seminars where teachers will be able to get acquainted with the philosophy of small daily improvements, master the tools of the Plan – Do – Check – Act cycles, and practice their application in their lecture and laboratory modules. The creation of a team of "Kaizen ambassadors" among the teaching staff will help to disseminate best practices and maintain a constant dialogue on improvement techniques. These activities should also include the exchange of successful cases of microchanging in biochemical explanations, which will enable teachers to see tangible results and be inspired by the innovations of their colleagues.

Teaching materials should be adapted to the principles of continuous improvement. Presentations and lecture notes should be updated after each feedback cycle. The instructor should develop a template for updating slides with clear fields for students' comments and ideas and introduce short surveys at the end of each class. Constantly updating illustrations, using interactive visualisations based on Fibonacci numbers, and modelling protein structures will help make the material more accessible and, at the same time, emphasise the interdisciplinary nature of the course. The laboratory component of the course needs to be more flexible and focused on experimental self-improvement. It is worth developing a series of universal instructions that can be adjusted based on the results of each practical session. For instance, after completing an exercise on modelling a protein helix using the Fibonacci pattern, the instructor can organise a brief discussion where students point out any awkward or unclear points. These comments are then integrated into the revised instructions for the next class. This approach ensures that the laboratory activities are constantly adapted to the needs of the students and develop their skills in critical analysis of the entire experiment process.

Control tasks and the testing system should also be subject to continuous improvement. It is recommended to introduce micro-questions after each theoretical unit, which students will complete immediately at the beginning of the next class. This will help to quickly identify gaps in learning and prepare corrective exercises in time. In parallel, automated results processing should be introduced, e.g., through the integration of Moodle or another learning management system (LMS), so that the teacher can quickly see progress statistics and analyse trends. Based on this data, updated assignments should be created to address concrete problems identified.

Particular attention should be paid to the organisation of students' independent work. The development of personalised learning routes allows each student to choose their optimal pace of learning. Teachers can create a set of independent tasks of varying levels of difficulty and offer the student to complete a certain number of exercises or reflective notes in the "Kaizen journal" daily. This journal should contain blocks for recording achievements, difficulties, and ideas for self-improvement. Regular analysis of such journals will create a database for continuous improvement of the forms and content of independent work.

Developing a culture of feedback is a critical success factor. Instructors should hold short group discussions after each major module of the course, during which students can openly express their views on the effectiveness of the methods and offer their ideas. To ensure openness and constructiveness, anonymous surveys or real-time voting tools should be used. Analysing this data will help identify the most resonant topics for improvement and set priorities for change. Teachers also need to learn basic pedagogical time management skills to optimally combine preparation of materials, analysis of results, and classroom instruction. Establishing a clear schedule for course updates and regular analytical sessions to discuss changes will ensure consistency and avoid chaotic adjustments. It is also a good idea to make a calendar of PDCA cycles for the school year with clear dates for planning, doing, checking, and fixing. This will help everyone involved in the learning process keep track of the schedule of improvements (Fu & Liu, 2022). In the context of international cooperation, it is also recommended to draw on the practices of foreign HEIs that successfully implemented Kaizen in the research and educational environment. Regular webinars, exchanges of faculty visits and joint inter-university projects will enable the integration of global small improvement practices into local courses. This approach will not only facilitate the technical mastery of tools but also the development of an international vision of a culture of continuous improvement among teachers and students.

To ensure an objective measurement of the effectiveness of the changes being implemented, clear indicators of success must be developed. Key performance indicators (KPIs) may include the average grade for course modules, student satisfaction, the number of corrections suggested by students, and the dynamics of learning about individual topics. These indicators must be regularly reviewed and updated in line with new challenges and analysis results. The use of dashboards in LMS and built-in analytical dashboards will help visualise the dynamics of changes and serve as a transparent monitoring tool (Titova & Sosnytska, 2020). A separate area of recommendation is the integration of virtual and augmented reality technologies, especially when modelling the spatial structures of molecules based on the principles of Fibonacci numbers. The use of VR labs and augmented reality (AR) applications will enable students to imaginatively study the internal architecture of protein helices and investigate enzyme interactions at the atomic level. Such an experience will increase motivation, create conditions for a deeper understanding of the material, and help develop spatial thinking and scientific modelling skills.

Considering potential obstacles such as resistance to the conventional format, distrust of new tools, and lack of time for preparation, a support system should be provided. The university management should approve regulations that prescribe a cyclical approach to updating courses and provide teachers with resources: access to online platforms, consultations with methodologists, and time in the schedule to work on improvements (Berkimbaev et al., 2013; Ramankulov, 2015). A specially created role of the Kaizen coordinator in the teaching team will help coordinate the process, collect feedback, and resolve organisational issues promptly.

To prepare students for an active role in the improvement process, it is necessary to explain in detail how the PDCA cycle works and to encourage their participation in course adjustments, which will help them become aware of their mistakes and initiatives; these elements serve as resources for the teacher, while student responsibility for the quality of learning is integral to the academic culture. Conducting workshops on self-analysis and constructive criticism will help students develop self-management skills and collective intelligence.

Finally, the implementation of recommendations should be viewed as an ongoing project rather than a one-time campaign. Teachers should get into the habit of analysing the results monthly, planning microadjustments early, and documenting them. Systematic work within the framework of a Kaizen journal and company-wide reviews of PDCA cycles will help maintain momentum and not lose focus on long-term goals. Such an approach ensures that the biochemistry course stays a flexible, relevant, and effective means of developing highly qualified biology teachers.

Synthesis of findings across research questions and comparison with previous studies

When improving educational technology in higher pedagogical education, it is vital to analyse approaches that contribute to improving the quality of learning (Huan & Nasri, 2022). The study considered the significance of applying Kaizen technology in teaching biochemistry and compared the relevant scientific approaches of researchers. The positive results, including the design of a pedagogical methodology based on Kaizen technology, demonstrated the potential of this philosophy as a tool for the innovative development of science education and coincided with the findings that the use of the Kaizen model in a virtual educational environment contributed to the development of a responsible attitude towards learning, increased task performance, and preparedness of students for independent work (Adekenov et al., 1992; Merkhatuly et al., 2023; Elihami et al., 2024). The result was also confirmed by research showing the effectiveness of the Kaizen approach in improving the quality of online teaching, particularly in adapting the feedback between teacher and student to ensure continuous improvement (Dragolea & Topor, 2022).

The integration of Kaizen technology in biochemistry teaching contributed to the development of flexible thinking and increased the ability to independently analyse complex scientific information, which is crucial in the context of the pedagogical training of future science teachers. This result was in line with findings that the development of problem-solving and strategic-thinking skills positively affects students' performance in complex learning situations (O'Sullivan et al., 2022; Burke & Stewart, 2024). The findings also confirmed conclusions that educational interventions based on a continuous improvement model increase the effectiveness of teaching strategies as well as the quality of learning in general (Hervas, 2021). This suggests that the Kaizen methodology is not a purely industrial tool but has enormous potential for adaptation in the educational environment.

The increase in student satisfaction with the learning process was consistent with results showing that targeted improvement of educational conditions (including technological solutions and student support) positively correlates with learning satisfaction and motivation (Bakhsh et al., 2021; Abdrakhmanov et al., 2024). Comparison of the results indicated consistency with the conclusion that the transition to integrated (blended) learning after the COVID-19 pandemic increased learning efficiency (Awajan et al., 2024). Analogously, Kaizen technology facilitated flexible adaptation of the teaching process and met new student demands. The study found that applying the principles of continuous improvement caused positive dynamics in the development of students' emotional stability, social inclusion, and willingness to cooperate, which was consistent with the view that emotional support and inclusive learning environments are crucial under pandemic conditions (Mariani et al., 2022). Improving the academic performance of biochemistry students using Kaizen technology was consistent with evidence that the guided-inquiry method in physics teaching contributes to a significant improvement in educational outcomes (Arroco, 2021; Sammour & Al-Balkhi, 2024). In both cases, emphasis was placed on the active involvement of students in the learning process through participation, reflection, and self-assessment, which are characteristic features of the Kaizen approach. The results of the study also reflected aspects of findings that innovative, contextually orientated methods promote the development of authentic educational experiences (Abreu-Pederzini & Suárez-Barraza, 2020). The effectiveness of applying the principle of continuous improvement to the academic environment was confirmed by research emphasising the role of emotional intelligence and prosocial behaviour as predictors of academic achievement (Getahun Abera, 2023). The observed increase in emotional interaction among students indicated the positive influence of the educational environment organised according to Kaizen principles.

The findings aligned with evidence proving the effectiveness of Kaizen engineering methods in improving practical skills in microsurgery (Villanueva et al., 2024). Although the contexts differed, the key idea (stepwise improvement through small, targeted changes) proved universal. This approach was also supported by data showing that qualitative transformations in universities were made possible by the systematic implementation of total quality management elements compatible with the Kaizen philosophy (Naqvi & Naz, 2025). The significance of the findings was that the introduction of Kaizen technology allowed viewing the educational process as a system with continuous feedback and constant adaptation, in line with ideas on staff-development programmes for creating a new teaching culture in medical schools (Maestre et al., 2024). Such a culture, focused on the gradual improvement of educational quality, created conditions for sustainable professional growth for both students and teachers. Another aspect confirming the value of the methodology used was the increase in student engagement, which corresponds to findings that gamification and innovative approaches in medical education increase participant activity (Salehi et al., 2023). Analogous observations were recorded in the present study, as students noted a higher interest in biochemistry topics due to clear microgoals, constant feedback, and personalised remedial strategies. Notably, not all aspects of the study were fully consistent with existing literature. Some research emphasised the passive resistance of teachers to innovation in neoliberal universities, whereas the present study found a constructive approach from teachers involved in creating improvement scenarios, likely due to their participation at the planning stage (Niyazova et al., 2013; Ross et al., 2020).

The use of Kaizen technology also provided conditions for increasing student autonomy, consistent with ideas about the effectiveness of technological and gamified approaches in medical education (Walker et al., 2022; Elhousni et al., 2024). Students more actively planned their learning, analysed knowledge gaps, and proposed solutions, which contributed to self-reflection and critical thinking. Kaizen enabled prompt identification of bottlenecks in learning complex topics such as metabolism and enzymatic activity and allowed rapid modification of teaching strategies, which agrees with arguments that flexibility is a key factor for successful implementation of lean approaches (Schulze & Dallasega, 2023; Titova, Luzan, et al., 2023). The findings also confirmed that students became more responsible for their learning outcomes. Continuous improvement was shown to reduce microaggressions in the work environment by stimulating open communication and psychological safety, and similar effects were observed in learning, where interpersonal conflicts decreased, and cooperation improved (Sodhi, 2025). The results were also comparable to evidence that participation in international collaborative learning improved educational outcomes and required sustainable development of safety and quality competencies (Sanford et al., 2021). Likewise, in the biochemistry course, the development of self-control, attention to detail, and error analysis correlated with higher overall training levels. In the context of training specialists for high-tech environments, the results supported conclusions about the necessity of adaptive educational strategies in response to the challenges of the fourth industrial revolution (Wessner & Howell, 2020; Hayati et al., 2024). Teaching using the Kaizen methodology developed students' self-regulation, adaptability, and systems thinking, which are relevant for pedagogical specialists.

Overall contribution to Kaizen-based science education

This work theoretically and methodologically supports a Kaizen-based adaptive biochemistry course, which is scientifically innovative. For the first time, a subject-specific biochemistry teaching model structurally integrates the PDCA cycle into every curriculum module, ensuring systematic feedback and micro-adjustments throughout the learning process. The study uses the Fibonacci sequence to depict intrinsic symmetries in biomolecular structures, integrating biochemical substances with mathematical modelling. This method integrates biological, analytical, and spatial thinking. The study also shows that "Kaizen journals" improve students' reflection, self-regulation, and professional accountability. These findings make the proposed paradigm a novel framework for sustainable, learner-centred science teaching.

Furthermore, this study applies Kaizen to biochemistry education rather than applying continuous improvement to pedagogy, unlike earlier studies. Unlike previous studies that focused on management or engineering, this study shows how the PDCA framework may be systematically integrated into a science curriculum to improve cognitive and reflective learning. By teaching biology teachers self-assessment, time management, and data-driven course customisation, the proposed methodology is practicable. Kaizen diaries, microchecking tools, and mathematical modelling exercises boost student performance, engagement, and autonomy. These findings can be applied to other disciplines that need iterative learning and reflective practice, making the concept suitable for natural and pedagogical sciences.

CONCLUSION

This study was conducted in response to a clearly identified research problem: the insufficient adaptability of traditional biochemistry teaching in pedagogical universities to the dynamic development of scientific knowledge, the limited pedagogical operationalisation of Kaizen principles within discipline-specific instruction, and the absence of a systematically modelled framework that integrates continuous improvement cycles, reflective micro-assessment, and interdisciplinary elements in biochemistry teacher training. Addressing this gap, the research aimed to theoretically substantiate and model a Kaizen-based approach to biochemistry education through the structured integration of the Plan–Do–Check–Act (PDCA) cycle.

The findings demonstrate that the proposed Kaizen-PDCA model effectively resolves this research problem by transforming the biochemistry course into a coherent system of continuous pedagogical improvement. The systematic application of PDCA stages to lectures, laboratory classes, assessment procedures, and independent student work enabled the formalisation of feedback, reflection, and timely instructional adjustments. As a result, biochemistry teaching evolved from a static content-delivery model into a self-correcting and adaptive educational system capable of responding to students' learning difficulties and developmental needs in real time. This directly addresses the identified mismatch between rapidly evolving biochemical knowledge and inflexible instructional practices.

In response to the second research problem concerning the lack of subject-specific implementation of Kaizen principles, the study provides a theoretically grounded methodology tailored to biochemistry education. The use of Kaizen tools, such as reflective Kaizen journals, microchecklists, formative self-assessment, and individualised learning pathways, was shown to enhance students' self-regulation, learning motivation, and engagement. These mechanisms operationalise Kaizen not as an abstract management philosophy but as a concrete pedagogical technology embedded in daily instructional practices. Consequently, the study contributes methodological clarity to the pedagogical use of Kaizen within science education.

The interdisciplinary integration of the Fibonacci sequence as a conceptual and visual framework for modelling protein structures addresses the third research problem related to the development of discipline-specific competencies. This approach supported students' spatial reasoning, analytical thinking, and conceptual understanding of complex biochemical processes, thereby strengthening core biochemical competencies rather than merely improving general learning motivation. By embedding mathematical modelling within biochemical instruction, the model demonstrates how interdisciplinary elements can be systematically incorporated into continuous improvement cycles.

The comparative analysis with Kaizen-orientated practices in Japan, South Korea, and Singapore further confirms the relevance and transferability of the proposed model. Consistent with international experience, the findings indicate that sustained micro-improvements, when embedded in a structured feedback system, lead to measurable qualitative enhancements in educational quality. At the same time, the Kazakh model adapts these principles to the specific context of pedagogical universities by emphasising teacher training, reflective learning, and discipline-specific methodological development.

The study confirms that the Kaizen-based PDCA model provides a viable solution to the identified research problems by aligning biochemistry instruction with contemporary demands for adaptability, student-centred learning, and continuous quality enhancement. Its implementation supports the formation of future biology teachers who are capable of independent learning, systematic reflection, and creative problem-solving, competencies that are essential for sustainable professional development in modern education systems. Future research should empirically examine the long-term effects of the model on academic achievement and professional readiness, test its scalability across different institutional contexts, and explore the integration of digital and immersive technologies to further enhance biochemical modelling and learning outcomes.

REFERENCES

Abdrakhmanov, R., Zhaxanova, A., Karatayeva, M., Niyazova, G. Z., Berkimbayev, K., & Tuimebayev, A. (2024). Development of a Framework for Predicting Students' Academic Performance in STEM Education using Machine Learning Methods. *International Journal of Advanced Computer Science and Applications*, *15*(1).

Abreu-Pederzini, G. D., & Suárez-Barraza, M. F. (2020). Just Let Us Be: Domination, the Postcolonial Condition, and the Global Field of Business Schools. *Academy of Management Learning & Education*, *19*(1), 40–58.

Adekenov, S. M., Gafurov, N. M., Turdybekov, K. M., Lindeman, S. V., & Struchkov, Yu. T. (1992). Transannular cyclization of the E,E-germacradienolide hanphyllin. *Chemistry of Natural Compounds*, *28*(5), 444–451.

Akhitova, R. (2023). Kaizen continuous improvement technology in the educational process of future computer science teachers: A case study in Kazakhstan. *Global Journal of Engineering Education*, *25*(3), 163–170.

Alpert, S., Dean, M., & Ewell, W. (2023). Preparing educational leaders through action research. *Action Research*, *21*(1), 124–143.

Arroco, S. (2021). Educational outcomes from learning physics through guided inquiry. *Bicol University R & D Journal*, *24*(2), 39–51.

Awajan, N. W., Malkawi, N., Al-Hyari, K., & Haffar, M. (2024). Have we really benefited from integrating blended learning in higher education programs after COVID-19? Jordan as a case study. *Cogent Education*, *11*(1).

Bakhsh, A. A., Rizwan, A. K. A. B., Khoshaim, A. B., Abualsauod, E. H., & Altamirano, G. C. (2021). Implications of COVID-19 on student learning satisfaction (SLS): A remedial framework for universities. *International Journal of Engineering Education*, *37*(6), 1582–1593.

Berkimbaev, K. M., Sarybayeva, A. K., Ormanova, G. K., Usembaeva, I. B., & Ramankulov, S. Z. (2013). To the question of the use of electronic educational resources for preparation of future physics teachers. *Life Science Journal*, *10*(SPL.ISSUE10), 105–108.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101.

Burke, A., & Stewart, S. (2024). Learning problem solving to manage school-life challenges: The impact on student success in college. *Active Learning in Higher Education*, *25*(2), 169–183.

Cohen, L., Manion, L., & Morrison, K. (2017). *Research Methods in Education*. Routledge.

Costabile, M., Simpson, B., Turkanovic, J., & Hughes, B. P. (2024). Enhancing teaching effectiveness in biochemistry labs: Author reflections and improvement strategies. *Biochemistry and Molecular Biology Education*, *52*(5), 559–568.

Dolzhenko, N., Assilbekova, I., Abzhapbarova, A., Mussayeva, G., & Sarzhanov, T. (2024). Unification of Training Programs for Aviation Professionals as a Flight Safety Criterion. *Journal of Aerospace Technology and Management*, *16*.

Dragolea, L. L., & Topor, D. I. (2022). Perspectives on implementing Kaizen method for the improvement of academic online teaching. *Annals of the University of Apulensis-Economic Series*, *24*(1), 70–80.

Duran, V., & Mertol, H. (2020). Kaizen Perspective in Curriculum Development. *Asian Journal of Education and Training*, *6*(3), 384–396.

Elhousni, Z., Zerhane, R., & Janati-Idrissi, R. (2024). A look at biochemistry learning difficulties in the undergraduate level. *Multidisciplinary Science Journal*, *7*(2), 2025049.

Elihami, E., Lin, M., & Biqing, C. (2024). Teaching Model of Education Management through Google Classroom: The Trend of "The Kaizen Model." *Journal of Innovation in Educational and Cultural Research*, *5*(1), 73–82.

Feola, S., Lemons, P. P., Loertscher, J. A., Minderhout, V., & Lewis, J. E. (2023). Assessor in action: assessment literacy development in a biochemistry context. *Chemistry Education Research and Practice*, *24*(3), 914–937.

Fu, J., & Liu, X. (2022). Application research of PDCA cycle theory in the improvement of professional teachers' competency in higher vocational colleges. *Advances in Vocational and Technical Education*, *4*(4), 19–26.

Getahun Abera, W. (2023). Emotional Intelligence and Pro-Social Behavior as Predictors of Academic Achievement Among University Students. *Community Health Equity Research & Policy*, *43*(4), 431–441.

Han, L., Su, H., Wu, Z., Ke, Y., Lin, L., & Zhang, J. (2023). *The Cultivation of Students' Autonomous Learning Ability and the Construction of Evaluation System in Biochemistry Teaching* (pp. 280–287).

Hasan, Md. Z., Mallik, A., & Tsou, J.-C. (2020). Learning method design for engineering students to be prepared for Industry 4.0: a Kaizen approach. *Higher Education, Skills and Work-Based Learning*, *11*(1), 182–198.

Hayati, R., Nurdin, D., Prihatin, E., & Triatna, C. (2024). Quality Analysis of PDCA-Based Edupreneurship in 21st-Century Higher Education. *AL-ISHLAH: Jurnal Pendidikan*, *16*(1), 460–475.

Hervas, G. (2021). Lesson Study as a Faculty Development Initiative in Higher Education: A Systematic Review. *AERA Open*, *7*.

Huan, C. W., & Nasri, N. M. (2022). Teacher teaching practices based on the PDCA model: A systematic literature review. *International Journal of Academic Research in Progressive Education and Development*, *11*(3), 542–553.

Jasti, N. V., Kota, S., & Venkataraman, P. (2021). Development of a lean manufacturing simulation laboratory for continuing education students. *Journal of Adult and Continuing Education*, *27*(2), 292–323.

Khalid, N., Ahmed, U., Islam, D. M. Z., Lee, H., & Salykova, L. (2019). Public sector universities and performance in the 21st century: Underlining high time for entrepreneurship in the higher education sector. *International Journal of Innovation Creativity and Change*, *6*(10), 11–26.

Kregel, I. (2019). Kaizen in university teaching: continuous course improvement. *International Journal of Lean Six Sigma*, *10*(4), 975–991.

Kregel, I., & Coners, A. (2020). Kaizen and Its Role in the Higher Education Sector. In *Lean Six Sigma for Higher Education* (pp. 21–38). WORLD SCIENTIFIC (EUROPE).

Krippendorff, K. (2019). *Content Analysis: An Introduction to Its Methodology*. SAGE Publications, Inc.

Leticia, Z.-G. A., Patricia, K.-S. M., Esteban, T.-Z. A., Jesus, B.-C. T. del, & Eduardo, M.-C. J. (2024). Influence of didactic strategies in the learning of biochemistry in students of a university in the Mexican Southeast. *International Journal of Innovative Research and Scientific Studies*, *7*(3), 1301–1307.

Luzan, P., Titova, O., Kurok, R., & Mosia, I. (2021). The Methodology for Assessment of Engineering Students Outcomes. *2021 IEEE International Conference on Modern Electrical and Energy Systems (MEES)*, 1–6.

Maestre, J. M., Roussin, C., Rojo Santos, E., Holanda Peña, M., & del Moral, I. (2024). Implementing a Culture Change in Specialized Healthcare Education Through Training Programs for Preceptors and Residents. In *Fostering Interpersonal Skills in a Healthcare Context* (pp. 15–35). Springer Nature Singapore.

Mariani, M., Bayani, J., & Farmanara Kneidel, L. (2022). Addressing the Social/Emotional Needs of Students During the Pandemic. *Professional School Counseling*, *26*(1).

Merkhatuly, N., Iskanderov, A. N., Abeuova, S. B., & Iskanderov, A. N. (2023). Synthesis of Push-Pull Azulene-Based Compounds. *EURASIAN JOURNAL OF CHEMISTRY*, *28*(2 (110)).

Naqvi, S. U. E. L., & Naz, F. (2025). Quality Leaders' Journey: An Exploratory Discussion From Pakistani Universities Employing Total Quality Management Approaches Through Quality Enhancement Cells. *SAGE Open*, *15*(2).

Netland, T. H., von Dzengelevski, O., Maghazei, O., & Brown, K. (2020). Teaching Operations Management with Virtual Reality: Bringing the Factory to the Students. *Journal of Management Education*, *44*(3), 313–341.

Niyazova, G. Z., Berkimbaev, K. M., Pralieva, R. E., Berdi, D. K., & Bimaganbetova, A. K. (2013). To the question of professional competence of the future teacher of chemistry. *Life Science Journal*, *10*(SPEC. ISSUE 9), 193–197.

OECD. (2022). *Trends Shaping Education 2022*.

O'Sullivan, S., Campos, L. A., & Baltatu, O. C. (2022). "Involve Me and I Learn": Active Learning in a Hybrid Medical Biochemistry First Year Course on an American-Style MD Program in the UAE. *Medical Science Educator*, *32*(3), 703–709.

Padovano, A., & Cardamone, M. (2024). Towards human-AI collaboration in the competency-based curriculum development process: The case of industrial engineering and management education. *Computers and Education: Artificial Intelligence*, *7*, 100256.

Ponce, O. A., & Pagán-Maldonado, N. (2015). Mixed methods research in education: Capturing the complexity of the profession. *International Journal of Educational Excellence*, *1*(1), 111–135.

Ramankulov, S. Z. (2015). Didactic conditions of implementation of ICT in the formation of creativity of future teachers of physics. *Asian Social Science*, *11*(28), 51.

Reeves, T. C. (2006). Design research from a technology perspective. In J. Van den Akker, K. Gravemeijer, S. McKenney, & N. Nieveen (Eds.), *Educational Design Research* (pp. 64–78). Routledge.

Ross, S., Savage, L., & Watson, J. (2020). University Teachers and Resistance in the Neoliberal University. *Labor Studies Journal*, *45*(3), 227–249.

Salehi, A. M., Mohammadi, H. A., Jenabi, E., Khanlarzadeh, E., & Ashtari, K. (2023). Quality of Evidence and Pedagogical Strategy in Using Gamification in Medical Education Literature: A Systematic Review. *Simulation & Gaming*, *54*(6), 598–620.

Sammour, A. M., & Al-Balkhi, R. (2024). The importance of the continuous improvement strategy (Kaizen) in raising the efficiency of institutional performance in organizations. *Educational Administration: Theory and Practice*, *30*(5), 8691–8698.

Sanford, J., Argenbright, C., Sherwood, G., Jordan, P. J., Jiménez-Herrera, M. F., Bengtsson, M., Moriyama, M., Peng Lui, L., & McDonald, M. (2021). Student outcomes of an international learning collaborative to develop patient safety and quality competencies in nursing. *Journal of Research in Nursing*, *26*(1–2), 81–94.

Schulze, F., & Dallasega, P. (2023). Barriers to lean implementation in engineer-to-order manufacturing with subsequent assembly on-site: state of the art and future directions. *Production Planning & Control*, *34*(1), 91–115.

Sodhi, M. S. (2025). How to Reduce Microaggression and Other Negative Racial Experiences at Work with Continuous Improvement. *Production and Operations Management*, *34*(3), 423–435.

Sulaimanova, R., & Egamberdieva, A. (2025). Professional development of teachers in the context of digital transformation. *Bulletin of the Jusup Balasagyn Kyrgyz National University*, 9–20.

Sun, N., Wang, Y., & Liu, Y. (2019). *Teaching through assessment and feedback in biochemistry education*. 020049.

Svyrydiuk, V., Luzan, P., Svyrydiuk, O., Titova, O., & Popova, O. (2022). Electronic Textbooks as Means for Developing Professional Competencies of Engineering Students. In V. Tonkonogyi, V. Ivanov, J. Trojanowska, G. Oborskyi, & I. Pavlenko (Eds.), *Advanced Manufacturing Processes III. InterPartner 2021. Lecture Notes in Mechanical Engineering* (pp. 707–716). Springer.

The Global Goals. (2025). *4 quality education*.

Titova, O., Ishchenko, T., Yershova, L., Bazyl, L., & Kruchek, V. (2023). *Entrepreneurial Mindset Development in Engineering Students Through a Business Canvas Approach* (pp. 400–409).

Titova, O., Luzan, P., Davlatzoda, Q. Q., Mosia, I., & Kabysh, M. (2023). The Taxonomy Approach for Engineering Students' Outcomes Assessment. In V. Tonkonogyi, V. Ivanov, J. Trojanowska, G. Oborskyi, & I. Pavlenko (Eds.), *Advanced Manufacturing Processes IV. InterPartner 2022. Lecture Notes in Mechanical Engineering* (pp. 380–390). Springer.

Titova, O., & Sosnytska, N. (2020). The Engineer's Creative Potential Scales. *2020 IEEE Problems of Automated Electrodrive. Theory and Practice (PAEP)*, 1–4.

Tkach, V. V., Kushnir, M. V., de Oliveira, S. C., Ivanushko, Y. G., Velyka, A. V., Molodianu, A. F., Yagodynets, P. I., Kormosh, Z. O., Dos Reis, L. V., Luganska, O. V., Palamarek, K. V., & Bredikhina, Y. L. (2020). Electrochemical Determination of Sudan Dyes and Two Manner to Realize it: a Theoretical Investigation. *Letters in Applied NanoBioScience*, *9*(4), 1451–1458.

Ufua, D. E., Itai, M., Kumar, A., & Al-Faryan, M. A. S. (2024). Achieving operational resilience through kaizen practice: a case in a commercial livestock farm in Nigeria. *The TQM Journal*, *36*(4), 1092–1112.

Umarova, Z. (2024). Developing the Professional Competence of Future Chemistry Teachers through Digital Technologies: A Case Study of Kazakhstan. *International Journal of Information and Education Technology*, *14*(8), 1119–1126.

UNESCO. (2023). *Global Education Monitoring Report 2023: Technology in education: A tool on whose terms?* GEM Report UNESCO.

Villanueva, P. J., Sugiyama, T., Villanueva, B. M., Rodriguez, H. I., Arciénaga, A., & Cherian, I. (2024). Using Engineering Methods (Kaizen and Micromovements Science) to Improve and Provide Evidence Regarding Microsurgical Hand Skills. *World Neurosurgery*, *189*, e380–e390.

Volodarets, S., Chernousova, N., Peleshenko, H., Maslak, H., Savchenko, A., & Netronina, O. (2022). Using e-learning tools in biochemistry teaching for undergraduate medical students in multicultural environment in Ukraine during <scp>COVID</scp> -19 crisis. *Biochemistry and Molecular Biology Education*, *50*(3), 290–295.

Walker, J., Heudebert, J. P., Patel, M., Cleveland, J. D., Westfall, A. O., Dempsey, D. M., Guzman, A., Zinski, A., Agarwal, M., Long, D., Willig, J., & Lee, R. (2022). Leveraging Technology and Gamification to Engage Learners in a Microbiology Curriculum in Undergraduate Medical Education. *Medical Science Educator*, *32*(3), 649–655.

Wallo, A., Martin, J., Sparrhoff, G., & Kock, H. (2022). Balancing "Critique for Improvement" With "Critique for Emancipation" in Management Learning and Education. *Journal of Management Education*, *46*(3), 506–530.

Wessner, C. W., & Howell, T. R. (2020). *Educating and Training a High-Tech Workforce* (pp. 217–276).

Yin, R. K. (2013). *Case study research and applications: Design and methods*. SAGE Publications.

Zhong, X. (2025). *Applications Research of PDCA Cycle Management in College Japanese Teaching* (pp. 702–711).