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## KAIZEN AND 5S METHODOLOGY: EFFECTS ON BIOCHEMICAL KNOWLEDGE AND PEDAGOGICAL READINESS OF FUTURE BIOLOGY TEACHERS

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**Abstract.** The aim of the study was to evaluate the effectiveness of the Kaizen technology, supplemented by the 5S methodology. The study utilized a quasi-experimental design with pre- and post-testing and a control group. The sample comprised 120 undergraduate biology teacher trainees assigned to experimental and control groups. Data were collected using a biochemistry achievement test, a biochemistry knowledge organization scale, and a pedagogical readiness questionnaire. The results of the independent samples t-test showed that the scores on knowledge formation ( $t = 4.87$ ,  $p < 0.001$ ), conceptual understanding ( $t = 5.21$ ,  $p < 0.001$ ), and pedagogical readiness ( $t = 6.34$ ,  $p < 0.001$ ) were statistically significantly higher in the experimental group compared to the control group. The findings suggest that incremental learning, continuous feedback, reflective practice, and systemic organization are key strategies for promoting the development of cognitive and professional competencies of future biology teachers. The scientific value of this study lies in its substantiation of the effectiveness of integrating Kaizen technology and 5S methodology into the training of future biology teachers, thereby expanding existing approaches to organizing biochemistry education. The practical significance of this work lies in the potential use of the proposed learning model in developing educational programs, improving biochemistry teaching, and enhancing the professional development of future teachers.

**Keywords:** continuous improvement, education, methodology of 5S, Kaizen technology, biochemistry education, biology teacher education, biochemical knowledge formation, pedagogical readiness, conceptual understanding, reflective practice

### Introduction

The recent explosion of biological sciences has created the need to have well trained biology teachers who could explain complex molecular processes in coherent teachable forms.

Biochemistry is an enabling course of study that connects biological processes and molecular structures. Nonetheless, it remained the most problematic in the life of biology students as it is based on abstract concepts, symbolic representations, and a great number of terms.

Traditional approaches to teaching biochemistry follow the formula of putting much emphasis on the lectures and memorizing, which results in disjointed knowledge and absence of conceptual synthesis. The outcome of this disintegrated knowledge, in the case of future biology teachers, is a lack of translation of biochemical knowledge into the classroom. Consequently, the demand to introduce new instructional technologies that enable a systematic learning process and continuous improvement is growing. Kaizen technology, which was first implemented as a component of quality management systems, is concerned with incremental change via systematic process and introspection. Its adaptation to the teaching situations offers a promising approach to the issues of biochemistry education, both intellectual and pedagogical. The paper will explain the possibilities of applying Kaizen technology to create a biochemical knowledge system among future instructors of biology. Nevertheless, regardless of increased attention to the use of continuous improvement methods, empirical studies of how Kaizen and 5S practices are implemented in biochemistry teacher education in a systematic way are missing.

This research paper poses this gap by examining how the practice of the instruction of biochemistry teachers based on the concept of Kaizen can be useful. This research paper will explore the efficacy of the Kaizen technology supported by the 5S method in the development of the biochemical knowledge in future biology teachers

The study focuses on undergraduate students studying a biology teacher education course and analyzes the outcome of a course based on the use of Kaizen vs. one based on lectures. This study therefore examines the effectiveness of Kaizen technology supported by the 5S methodology in developing biochemical knowledge, conceptual understanding, and pedagogical readiness among future biology teachers.

### *Literature Review*

#### *Biochemistry Education Challenges*

The field of bio chemistry is generally referred to as one of the most intellectually demanding areas of the biological sciences, primarily due to its emphasis about explanations in terms of molecules and complicated chemical reactions that cannot be directly visualized.

It is a topic that requires students to integrate knowledge in chemistry, biology, and physics at a time, a very heavy cognitive load to students, particularly those students who do the subject as part of teacher education programs [1]. The major problem in biochemistry instruction is that the subject is mostly taught at an abstract level of understanding of the molecules in the form of structural formulas, reaction mechanisms, and symbolic representations, which at times do not directly relate to other biological knowledge previously held by students [2, 3].

Previous research has indicated that a number of students always have difficulties in making pertinent links between the biochemical processes and the macroscopic biological processes including metabolism, physiological regulation,

and cellular activities. Consequently, students often memorize isolated facts, enzymes, and pathways, lacking conceptual coherence.

This piecemeal approach to learning prevents the development of systematic knowledge of biochemistry and adversely affects the transfer of knowledge to real-life biological situations [4]. Biochemical content is dynamic and hierarchical, which is yet another major challenge.

Basic principles, including enzyme kinetics, metabolism, energy conversion, etc., require students to learn about cause-and-effect relationships and feedback at various levels within biological organization. In the absence of an organized instructional system, students tend to ignore these forms of interrelationships and end up developing false notions and shallow learning experiences.

The rapid pace of teaching biochemistry subjects, as per tradition, adds to these challenges, and little time is available to reflect on the material, consolidate it, and improve it over time [5]. Besides that, the teaching of biochemistry often relies on lecture-based approaches that emphasize content development rather than conceptual understanding. Such approaches have been said to be insufficient in addressing the diverse academic needs of the students and that in most instances, they ignore the advanced learning capacities of students such as the capacity to analyze, synthesize, and apply.

These problems are vital to the future biology educators whose conceptual knowledge of the subject fails to help them to present more intricate biochemical concepts or distinguish what they are teaching students in secondary grades [6]. Moreover, the exams in biochemistry classes are usually oriented towards the assessment by recall, which encourages superficial learning instead of conceptual learning. The culture of assessment was also limiting long-term retention and discouraged consideration of the learning practices.

Consequently, students are able to undertake biochemistry courses without confidence and good pedagogical preparation [7]. Taken altogether, these issues make one conclude that innovative teaching techniques need to be created that will reduce the cognitive load, enrich the conceptual integration, and add to the continuous knowledge development.

#### *Systematic Knowledge Formation in Teacher Education*

One of the main points that have been emphasized throughout the existing literature on teacher education is the fact that systematic knowledge building is the necessary tool to prepare future educators with effective professional delivery.

Systematic knowledge, unlike fragmented or procedural learning, is an organization and interrelationship of concepts by which teachers can master subject matter on a profound level, flexibly use that knowledge and be able to explain it to learners. It is also important that the skills of the ability to systematize and synthesize complex scientific knowledge will be particularly important to future biology teachers as this has a direct effect on the quality of teaching and student performance [8].

The structured knowledge systems help the teachers to see the relationship among concepts; the teachers identify the underlying principles and devise consistent descriptions of the relationship between the theoretical knowledge

and classroom practices. According to research in science education, pre-service teachers with good conceptual frameworks are better placed to predict student misconceptions, choose suitable instructional methods, and adapt content to different learning contexts [9].

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The conceptual coherence is also associated with the formation of systematic knowledge in teacher education programs closely. Conceptual coherence assists the teachers of the future to consider scientific knowledge not as individual facts or subjects but. It may be particularly important in such areas as biochemistry, where its interpretation needs an appreciation of the interactions between molecular structures, biochemical reactions, and biology. In the absence of this coherence, pre-service teachers might not be able to deliver the content in a logical and meaningful way at the school level.

Additionally, systematic knowledge formation enables pedagogical transfer, the process of converting disciplinary knowledge into teachable material. The transfer of effective pedagogy should entail simplifying the complex, without compromising scientific accuracy on the part of teachers. Research shows that pre-service teachers who possess well-organized systems of knowledge are better placed to succeed in designing teaching materials, describing abstract ideas, and working with students in inquiry-based learning [11].

Although it is an important part, systematic knowledge formation is not always well addressed in conventional teacher education programs that may focus on content coverage rather than conceptual integration. Consequently, prospective teachers might have factual knowledge but may not be able to organize and implement it properly. It should be noted that this limitation has been of great importance in motivating instructional methods that directly aid the gradual development of systematic knowledge frameworks through learning, reflection, and constant enhancement.

Pedagogical technologies, with a focus on gradual knowledge building and systematization, are especially useful in this regard. Techniques such as Kaizen technology that focus on constant transformations and progressive learning are near the objectives of systematic knowledge creation in teacher training. These strategies can be integrated into the learning of biochemistry to enhance performance of future biology teachers in terms of subject knowledge and pedagogy.

*Kaizen Technology as a Pedagogical Framework  
Methodical and gradual transformations.*

Kaizen was developed within the organizational and quality management

climate, which is geared towards continuous improvement of the process. The collective Kaizen technology is founded on minor, continuous, and controlled incrementalism as opposed to radical or expedited transformation.

In the recent years, this philosophy has found wider application in the education sector where it has been recognized as an effective model of enhancing the effectiveness of learning and the quality of instruction.

Kaizen technology promotes a learner-centered concept in the learning environment where students are actively involved in learning processes. Instruction based on Kaizen will not turn the learners into passive receivers of information, that is why they are expected to engage in the same process of self-evaluation, introspection and self-reflection. The interaction will build a feeling of ownership towards the realization of learning outcomes and leads to the development of self-regulated learning skills which are important in terms of academic success and professional growth throughout the lifetime.

One of the main aspects of Kaizen technology in education is its consideration of reflective practice. Students are advised to analyze their learning strategies, identify those that need improvement, and make gradual changes to gain knowledge. This reflection cycle aligns with current theories of learning that emphasize metacognition in profound learning. By reflecting on and refining the same learning material, learners can build increasingly coherent and sustainable knowledge structures [12].

Another aspect of Kaizen technology is its focus on responsibility for learning outcomes at both the individual and collective levels. The peer interaction and mutual accountability, facilitated by collaborative learning activities and shared reflection processes, create a learning environment that appreciates continuous improvement. These environments have been proven to help boost motivation, persistence and involvement, especially in intellectually challenging subjects. Empirical investigations in various pedagogical environments have demonstrated that Kaizen based teaching models have a positive influence on the motivation of students, their achievement, and their satisfaction with learning.

Learning is improved by the Kaizen technology through minimizing the cognitive load through breaking down complex information into small learning components and concentrating on continuous improvement that helps in sustaining long-term involvement. This particularly applies in science education where the students are likely to be faced with abstract and conceptually challenging material. In teacher education, Kaizen technology can play a twofold role.

It not only enhances subject-matter learning but also serves as a model of an instructional philosophy that teacher candidates can follow in their professional practice. Through Kaizen-based learning, future biology educators gain an appreciation for continuous improvement as a primary pedagogical value, which can be applied to the organization of instruction and classroom management practices [13].

*Application of K*

The context for introducing Kaizen principles into the teaching of science is a paradigm shift in instructional design that focuses on continuous improvement, incremental learning, and reflective practice.

This is contrary to the traditional methods of teaching where it is focused on the rate in which the content will be covered. On the contrary, the Kaizen-based methods focus on small steps that can be easily followed to enable learners to acquire knowledge that can be transferred to more complex scientific ideas. It is particularly suitable in a gradual style in those fields where the abstract molecular structures, intricate metabolic pathways and the multi-step reaction mechanisms are likely to be confusing to the learners in their entire form.

It has been studied that application of the Kaizen principles in science classes can enhance the problem-solving ability of the students. Analytical and logical reasoning skills which are fundamental in explaining biochemical phenomena are obtainable through the breakdown of complex tasks into small attainable goals.

The incremental tasks challenge the students to think hard about the material and respond accordingly to rethink their learning strategies. This is a process of assessment, reflection and improvement that is compatible with the modern constructivist perspectives on learning, that emphasize the active construction of knowledge, based on experience and reflection [14].

The other significant benefit of Kaizen-based instruction in a science classroom is that it allows learning in a group. The majority of Kaizen models include teamwork where learners discuss problems, brainstorm and test solutions.

This implies that such collaborative activities do not only enhance communication and teamwork skills, but also promote peer-mediated knowledge creation so that students are able to develop more than one perspective of complex scientific ideas. The collaborative Kaizen exercises allow learners to put the experimental data in perspective, to simulate the biochemical processes, and to draw conceptual maps jointly, thus allowing the learners to understand more clearly the interactions between molecular systems.

Kaizen principles also help in developing critical thinking and metacognition. This is because of the loop of feedback that is inherent with the Kaizen-based teaching method that enables learners to put to test their reasoning, uncover and solve misconceptions, and get their conceptual structures in order.

This reflective practice improves higher order thinking skills such as analysis, synthesis, and evaluation that is required in studying difficult subjects such as biochemistry. It has been found out that students who are exposed to Kaizen related work are in a better position to use them in new scenarios; a characteristic of a high degree of learning and cognitive adaptability [15].

In addition, the systematic nature of the Kaizen assignments allows working with complicated scientific content. When complex biochemical pathways are broken down into smaller learning units and regular, specific feedback is provided, Kaizen-based instruction reduces cognitive overload without decreasing student motivation and persistence.

This is the opposite of the classical lecture-based models, in which abstract content often leads to shallow learning and lower retention due to rapid delivery. The practice of Kaizen, as applied to biology, can be helpful for future teachers in the field. It not only enhances their command of biochemistry but also serves as a model of effective teaching methods that they can subsequently use in their classes.

Through a structured, incremental, and reflective learning process, pre-service teachers appreciate the value of evidence-based pedagogical methods that enhance deep learning, problem-solving, and critical thinking among future learners.

In sum, the relevance of the Kaizen principles in science education provides an overall understanding of the complete approach to the cognitive and pedagogical issues of a complex discipline like biochemistry.

The conceptual knowledge, critical thinking and professional readiness can be cultivated using kaizen-based teaching, ongoing feedback, designing tasks in small increments, and reflection, which are encouraged through teamwork. It is an invaluable training technique of future teachers of biology.

#### *Educational Adaptation of the 5S Methodology*

Although the 5S methodology was originally used in industrial and organizational leadership to facilitate effectiveness in workplaces, its application in learning institutions has proved to be successful in aspects like promoting learning, organizational performance, discipline and knowledge memory. The 5S model, which comprises of “Sort”, “Set in Order”, “Shine”, “Standardize” and “Sustain”, is a guide in systematizing learning content and materials and in the encouragement of disciplined learning behaviors, in the learning of cognitively challenging subjects such as biochemistry.

The “sorting” phase focuses on prioritization of the useful material in learning and elimination of unwanted content which ensures that students do not feel overwhelmed with the process of learning, but rather concentrate on the essential concepts in biochemistry. Although the study [7] and [13] reveal enhanced conceptual clarity, it does not include the effect of the same on long-term competence in knowledge retention or pedagogical preparedness, which reveals a gap that the current research intends to cover.

The second one is the “set in order” stage that deals with the rational arrangement of learning resources and learning activities. To illustrate, in the instruction in biochemistry, basic ideas like molecular structures, the kinetics of enzymes and metabolic pathways can be introduced in a gradual manner to enable slow comprehension. Such a methodology makes sure that each new idea is based on the previous knowledge and enhances the short-term and long-term memory.

The third component is “shine”, as it aims at establishing a clean, well-organized, and distraction-free learning environment. This can be in the form of physical and electronic classroom set-ups, well-marked laboratory material, well organized lecture notes and the systematized computer-based learning. Alongside the strengthening of concentration and attention, the stage of the “Shine” gives

the learners a chance to rehearse and take a reflection on what they have learnt, and it solidifies the learning process by periodically polishing knowledge.

The fourth, “standardize” involves coming up with routines, procedure and learning practices that may be used throughout the teaching sessions. The reason is that in teaching education, standardization is employed to make sure that upcoming biology educators embrace ideal practices in personal learning and classroom management. Following the routines of the studies, task sequences, and reflection, learners develop a range of habits that facilitate the improved organization of the knowledge, its understanding and applying the concepts in the teaching context.

Finally, “sustain” is aimed at sustaining and enhancing the learning system. This, in relation to biochemistry teaching, would entail a continuous evaluation of the conceptual knowledge, regular practice and continuous learning strategy enhancement. The retention of 5S approach would incorporate systematic learning habits, which would foster the capacity to self-regulate, be disciplined, and make an individual a lifelong learner among the future biology teachers.

Empirical studies have demonstrated that the 5S approach when applied in education can result in the measurable learning outcomes. Students are more engaged and their knowledge is better and better organized and conceptually retained. The 5S method supplements incremental learning, constant feedback, and reflective practice and when applied together with instructional technologies like Kaizen, offers a complete way of effective science education [8, 10].

Although both studies [8] and [10] prove that the 5S approach positively influences the involvement of learners, the knowledge organization, and retention of concepts, study [10] incorporates Kaizen as a method to provide a holistic approach. The two studies, nevertheless, concentrate on short-term quantitative results and fail to analyze long-term results and pedagogical preparedness, which is why the current research is necessary.

The 5S framework is able to promote the cognitive and pedagogical readiness, i.e., creating clarity, discipline, and constant improvement, and the ultimate goal being the systematic construction of knowledge that is part of the teacher education program.

#### *Research Questions*

1. What is the effect of Kaizen technology in developing a systematic body of biochemical knowledge in future biology teachers?
2. How does the conceptual knowledge of biochemistry in students change after teaching under Kaizen-based instruction?
3. How far do Kaizen principles and the 5S methodology offer pedagogical preparedness in the teaching of biochemistry?

#### *Theoretical Justification of the Hypotheses*

The proposed hypotheses are developed on theoretical grounds of constructivist learning theory and uninterrupted improvement models primarily, Kaizen and 5S approach. The constructivist learning theory focuses on the idea that knowledge is created and conceptual cognition builds up through active interaction, contemplation, and organized learning settings.

In this view, systematic organization, learner involvement, and repetitive feedback instructional strategies, like those used in Kaizen based instruction, would be likely to affect the process of biochemical knowledge building and conceptual learning among students. Moreover, continuous improvement models theorize teaching as a dynamic process whereby minor advancements contribute to making instruction more efficient and professionally ready.

Theoretical connection of the introduction of Kaizen principles and the 5S methodology into the teacher education contexts, in its turn, is associated with the positive changes in the pedagogical preparedness in terms of reflective practice, process optimization, and instructional coherence. These theoretical assumptions, therefore, lead to logical derivation of hypotheses that can be empirically tested as part of the proposed research.

#### *Hypotheses*

- H<sub>01</sub>: The biochemical knowledge formation in students taught by Kaizen technology and traditional instructional techniques does not differ statistically;
- H<sub>02</sub>: There is no significant impact of Kaizen based instruction on conceptual knowledge of biochemistry in students;
- H<sub>03</sub>: The implementation of the Kaizen principles and 5S methodology does not have great impact on the pedagogical preparedness of the future biology teacher.

### **Materials and methods**

#### *Research Design*

A quasi-experimental pre-test–post-test control-group design was employed to examine the effectiveness of Kaizen technology supported by the 5S methodology in biochemistry education.

The study involved two groups: an experimental group (n = 60) receiving Kaizen-based instruction incorporating incremental learning tasks, continuous feedback, reflective practice, and 5S-based organization of learning activities, and a control group (n = 60) receiving conventional lecture-based instruction. The same biochemistry content and instructional duration were maintained for both groups, while the instructional approach differed between the experimental and control conditions.

A pre-test was administered before the intervention to establish baseline performance, followed by the instructional intervention and a post-test administered under comparable conditions. Because the study was conducted in an educational setting, [state whether intact classes were used or whether participants were randomly allocated to the two groups.

#### *Participants*

The sample comprised 120 undergraduate students enrolled in a biology teacher education program at a public university.

Participants were divided equally into an experimental group (n = 60) and a control group (n = 60). The experimental group received Kaizen-based instruction supported by the 5S methodology, whereas the control group received conventional lecture-based instruction.

Participants were comparable in academic level, age, prior biochemistry knowledge, and academic performance at baseline. Participants were selected and Eligibility required students to be enrolled in the relevant biology teacher education/biochemistry course during the study period.

#### *Instructional Intervention*

The experimental group received biochemistry instruction based on Kaizen principles and supported by the 5S methodology.

The intervention was conducted over few weeks and comprised instructional sessions, with each session lasting approximately. The same biochemistry curriculum content was taught to both groups. However, the experimental group learned through incremental tasks, continuous feedback, reflective activities, and systematic organization of learning materials, whereas the control group received conventional lecture-based instruction.

In each Kaizen-based lesson, complex biochemical concepts were divided into manageable learning units. The control group received conventional lecture-based instruction covering the same biochemistry topics and for the same instructional duration as the experimental group. Instruction primarily involved teacher-led explanations, presentation of biochemical concepts, classroom questioning, and routine learning activities.

The control group did not receive the structured Kaizen learning cycle or the 5S-based organization, reflection, and continuous-improvement procedures used in the experimental group. Students completed the learning tasks sequentially, received feedback on their performance, identified areas requiring improvement, and revised their responses or learning strategies. Short reflective activities were incorporated to encourage students to monitor their understanding and identify subsequent learning goals.

#### *Instruments*

Information about the data and evaluation of the effectiveness of the Kaizen-based instruction was collected with the help of three tests, i.e., Biochemistry Achievement Test, Biochemical Knowledge Organization Scale, and Pedagogical Readiness Questionnaire.

The Biochemistry Achievement Test was used to assess understanding of the fundamentals of biochemistry and the ability to apply that knowledge to solve problems. The Biochemical Knowledge Organization Scale was used to measure the systematic organization and integration of biochemical knowledge, as well as the extent to which learners were able to develop coherent conceptual structures.

The Pedagogical Readiness Questionnaire assessed participants' readiness to apply knowledge of biochemical principles to effective teaching practice. The subject-matter experts had previously tested the instruments in terms of content relevance and the instruments had acceptable reliability coefficients that guaranteed the validity and consistency of data obtained.

#### *Ethical Considerations*

The study received ethical approval from the institutional review board. Before participation, all students were informed about the purpose, procedures, and potential risks of the study and provided informed consent.

Participation was voluntary, and participants were informed of their right to withdraw from the study at any time without academic penalty. All collected data were treated confidentially, and identifying information was not disclosed in the reporting of the findings.

Results

H<sub>01</sub>: The difference in the biochemical knowledge formation between the students who are taught by using Kaizen technology and those taught by the use of traditional instructional technology does not differ significantly. As it can be seen in Table 1, the difference between the two groups is statistically significant ( $t(118) = 4.87, p < 0.001$ ), as experimental group has shown significantly higher levels of acquisition of biochemical knowledge as compared to the control group.

Table 1. Independent-samples t-test for biochemical knowledge formation

| Group        | N  | Mean  | SD   | t    | p       |
|--------------|----|-------|------|------|---------|
| Experimental | 60 | 78.45 | 6.32 | 4.87 | 0.0001* |
| Control      | 60 | 70.12 | 7.15 |      |         |

Note.  $p < 0.05$

This observation reveals that those learners who attended the Kaizen-based teaching gained coherent and more well-structured conceptualizations of biochemical concepts than did learners who attended traditional lecture-based teaching methods.

Consequently, Hypothesis H<sub>01</sub> is rejected, providing empirical support for the effectiveness of the Kaizen methodology in facilitating the structured formation of biochemical knowledge among pre-service biology teachers. These tendencies are visually summarized in Figure 1.

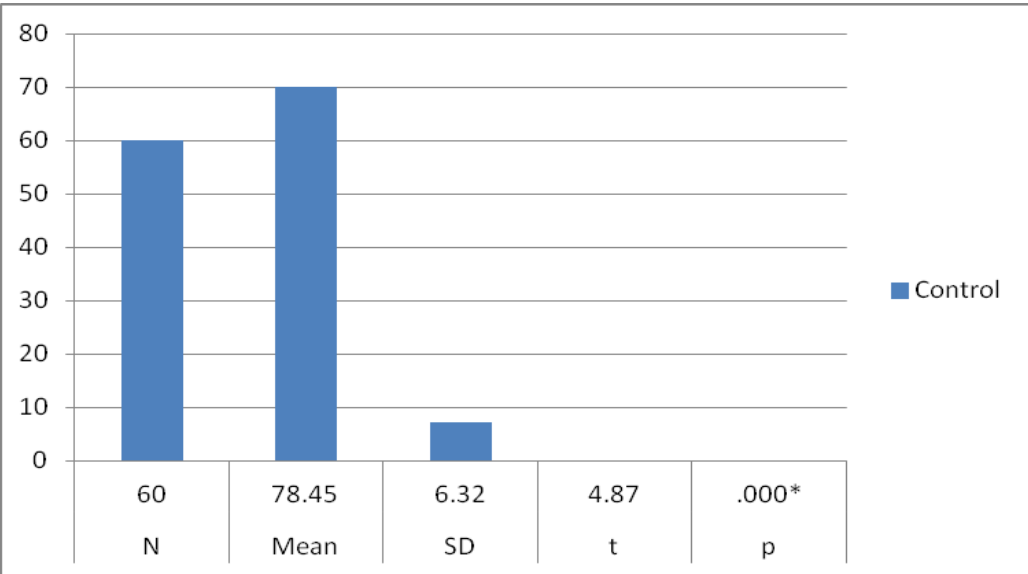


Figure 1 - Research design of the quasi-experimental study using Kaizen-based instruction and the 5S methodology

*Interpretation:*

The significant improvement in the experimental group indicates that incremental learning, structured tasks, and regular feedback are the main characteristics of Kaizen technology, which facilitate a deeper understanding of the goal, more effective incorporation of concepts, and improved retention of biochemistry knowledge.

This is consistent with the available literature that holds that cognitive organization and academic performance in advanced fields of science would be enhanced through systematic and reflective instructional approaches.

H<sub>02</sub>: There is no significant difference between the conceptual understanding of biochemistry in students taught using Kaizen.

An independent-samples t-test was conducted to evaluate how Kaizen-based teaching-based instruction influences the conceptual knowledge students have of biochemistry and the results are summarized in Table 2.

Table 2. Independent-samples t-test for conceptual understanding of biochemistry

| Group        | N  | Mean | SD   | t    | p       |
|--------------|----|------|------|------|---------|
| Experimental | 60 | 4.12 | 0.48 | 5.21 | 0.0001* |
| Control      | 60 | 3.45 | 0.52 |      |         |

Note.  $p < 0.05$

The results indicate that the two groups are not statistically similar ( $t(118) = 5.21$ ,  $p < 0.001$ ), and the experimental one possesses a better conceptual understanding of biochemical principles.

Based on this, H<sub>02</sub> is rejected, meaning that the conceptual learning on biochemistry among students is positively influenced by Kaizen-based teaching (Figure 2).

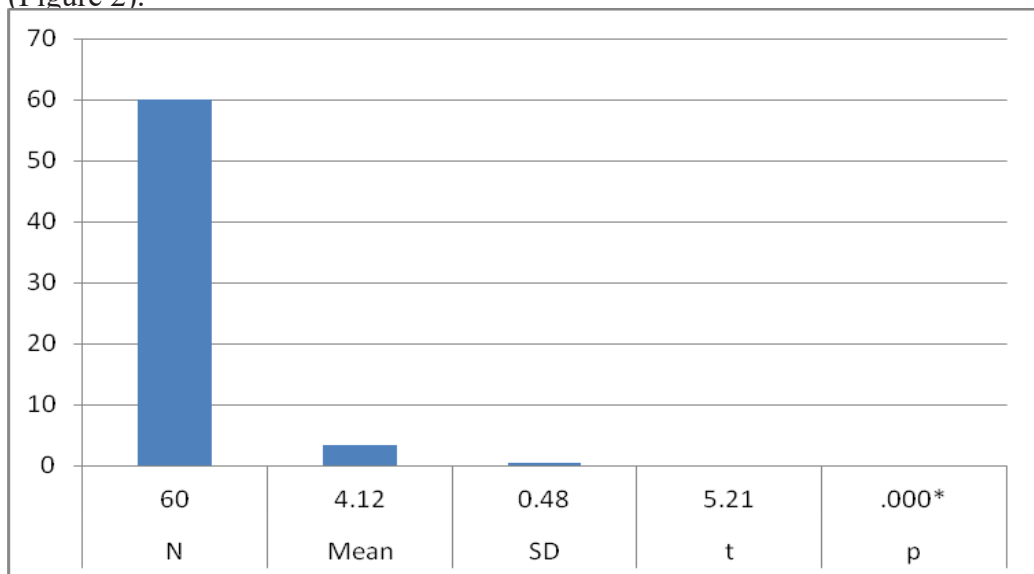


Figure 2 - Model of Kaizen-based instructional intervention in biochemistry teacher education

*Interpretation:*  
The results indicate that deep learning and cognitive integration can be supplemented by the structured, step-by-step, and reflective learning environment that Kaizen technology creates.

The students in the experimental group had more opportunities to relate abstract biochemical ideas to the underlying biological phenomena, which supports the idea that Kaizen-based strategies encourage meaningful conceptual learning rather than rote learning.

H<sub>03</sub>: There is no statistically significant impact of implementation of Kaizen and the 5S methodology on pedagogical preparedness of future biology educators.

Independent-samples t-test was used to evaluate the effect of the Kaizen principles and the 5S methodology on pedagogical preparedness and the following results were obtained and displayed in Table 3.

Table 3. Independent-samples t-test for pedagogical readiness

| Group        | N  | Mean  | SD   | t    | p       |
|--------------|----|-------|------|------|---------|
| Experimental | 60 | 85.36 | 5.12 | 6.34 | 0.0001* |
| Control      | 60 | 76.48 | 6.08 |      |         |

*Note.*  $p < 0.05$   
The results reveal that the statistical significance between the two groups is significant ( $t(118) = 6.34$ ,  $p < 0.001$ ), which means that participants in the Kaizen + 5S group were more pedagogical prepared.

Consequently, H<sub>03</sub> is refuted, indicating that the combination of Kaizen principles and the 5S methodology has a positive effect on the readiness of future biology educators to teach biochemistry efficiently (Figure 3).

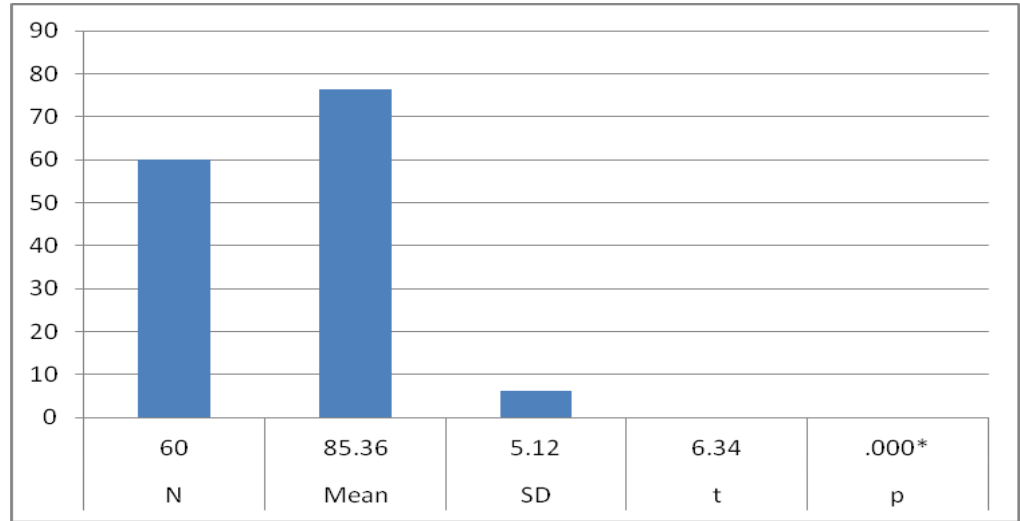


Figure 3 - Conceptual framework of systematic biochemical knowledge formation and pedagogical readiness based on Kaizen and 5S principles

*Interpretation:*

The results indicate that an incremental learning approach based on Kaizen and 5S organizational strategies improves the organization of instruction, the order of content, and classroom preparedness.

Educators of biology in the future who have been exposed to this strategy are better placed to organize lessons, teach complex biochemical topics clearly, and engage in reflective practice in teaching.

This substantiates the fact that the development of pedagogical competence in teacher education programs requires constant advancement and systematic organization.

**Discussion**

The current research examined how applying Kaizen technology, using the 5S approach, can be used to develop a systematic view of biochemical, conceptual, and pedagogical preparedness among future teachers in the field of biology.

The findings indicate that the application of Kaizen-based learning has a significant effect on each of the three aspects of learning, which proves the applicability of the concepts of continuous improvement in teacher education. The first hypothesis involved the levels of biochemical knowledge development in response to the teaching that is based on Kaizen.

The results demonstrated that mean scores in the post-test in the experimental group were by far greater as compared to the control group, and that systematic, incremental learning was practical in fostering the systematic generation of knowledge.

These findings agree with the research on the importance of structured knowledge base in science education, particularly in cognitive demanding science such as biochemistry. Kaizen technology assists the efficient internalization of concepts; biochemistry concepts, by decomposing the concepts, giving feedback, creating concept connectivity, and urging the students to internalize the concepts.

Hypothesis number two was used to test the effectiveness of the Kaizen teaching on the concept grasp of biochemistry by the students. The experimental group proved to be superior to the rest, i.e. incremental task design, reflective practice, and continuous feedback are beneficial in the deep learning as opposed to the superficial memorizing.

This observation agrees with other researchers who have demonstrated that pedagogical approaches, which are Kaizen-driven, are effective in developing greater cognitive ability, critical thinking, and knowledge transfer. When applied to teacher education, deeper conceptual understanding would allow future professionals in the field of biology education to explain abstract biochemical phenomena to students in a simple, coherent and pedagogically meaningful manner.

The third hypothesis studied the effect of the Kaizen and 5S principles on pedagogical preparedness. The results showed that the experimental group was significantly equipped to teach biochemistry, design lesson material and apply reflective pedagogical strategies.

This confirms that the 5S methodology which is a structured organizational approach enhances learning discipline, clarity of content and retention of knowledge. These strategies are in accordance with the philosophy of continuous improvement based on the philosophy of Kaizen, and it is responsible to learn the principles of biochemical concepts and also acquire the tricks of teaching which are vital to the professional development of upcoming teachers.

Taken together, the research shows that the combination of Kaizen principles, incremental tasks, and systematic organizational approaches in teacher education programs produces a whole-person approach to learning. This kind of environment can reduce cognitive problems, facilitate conceptual coherence, and enhance pedagogical competence.

These results support the need to abandon the traditional lecture-based approach to teaching and adopt more active, structured, and reflective learning methods. In addition, the findings have practical implications for science teacher education. Kaizen-based teaching methods should be introduced into biochemistry courses, as they can help students be more motivated, engaged, and confident, and lead them to model those methods in their future classrooms.

Teacher education programs can equip future biology teachers to approach complex content and support their students' learning outcomes by developing habits of continuous improvement, reflective practice, and systematic knowledge organization. Finally, the paper contributes to the research on the innovative pedagogical models of teaching science by showing the possibility of enhancing the cognitive and professional outcomes by use of Kaizen technology and the 5S method.

The findings underscore the value of applying a learning strategy which incorporates incremental learning, the use of reflective feedback and systematic organization in developing a well prepared conceptually and pedagogically competent biology teacher by curriculum developers and instructors.

## Conclusion

This research gives extensive support that the instruction based on Kaizen and incorporating incremental tasks, ongoing feedback, self-reflection, and the 5S approach has a powerful effect on improving biochemical knowledge, conceptual understanding, and pedagogical preparedness in the future biology educators.

The reflective and systematic approach of Kaizen and the systematic arrangement with the use of 5S approach makes learners actively build their knowledge, create coherent conceptual frameworks, and implement their learning in pedagogical settings.

*Theoretical contributions.* The results expand on the constructivist theory of learning and models of continuous improvement by showing that the combination of structured, progressive, and reflective models of instruction is beneficial to deeper learning and professional readiness in teacher training.

The study demonstrates the potential of the combination of process-oriented instructional design with active learning strategies to promote cognitive complexity

and conceptual integration that can be effectively used by future studies on science education as a solid theoretical foundation.

*Practical implications.* Adding to the teacher training programs with the Kaizen and 5S principles is a systematic, evidence-based method of professional development. Teachers who have been trained according to this model are able to convert the complicated biochemical concepts into pedagogically viable and approachable classroom teaching.

Moreover, the given method promotes the culture of continuous improvement, reflective practice, and gradual acquisition of skills and, thus, improves the overall quality of teaching and learning in pre-service education.

*Future research directions.* Future studies ought to examine the long-term consequences of Kaizen-based instruction in various scientific fields and learning environments, determine how it can be extended and modified to various institutional contexts, and determine the relationship with other components of teacher competencies, such as instructional creativity, classroom management, and student engagement.

Additional studies could also be done to compare the efficiency of the Kaizen-based methods to other active learning and improvement frameworks to develop the best practices in pre-service teacher education.

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## **КАЙДЗЕН ЖӘНЕ 5S ӘДІСТЕМЕЛЕРІ: БОЛАШАҚ БИОЛОГИЯ МҰҒАЛІМДЕРІНІҢ БИОХИМИЯЛЫҚ БІЛІМІ МЕН ПЕДАГОГИКАЛЫҚ ДАЙЫНДЫҒЫНА ӘСЕРІ**

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**Аңдатпа.** Зерттеудің мақсаты 5S әдіснамасымен толықтырылған Кайдзен технологиясының тиімділігін бағалау болды. Зерттеуде алдын

ала және кейінгі тестілеу және бақылау тобы бар квазиэксперименталды дизайн қолданылды. Іріктеме эксперименттік және бақылау топтарына тағайындалған 120 биология пәнінің мұғалімі, бакалавриат студенттерінен тұрды. Деректер биохимия жетістіктерін тексеру, биохимия білімін ұйымдастыру шкаласы және педагогикалық дайындық сауалнамасы арқылы жиналды. Тәуелсіз үлгілердің t-тестінің нәтижелері білімді қалыптастыру ( $t = 4,87, p < 0,001$ ), тұжырымдамалық түсіну ( $t = 5,21, p < 0,001$ ) және педагогикалық дайындық ( $t = 6,34, p < 0,001$ ) бойынша баллдардың эксперименттік топта бақылау тобымен салыстырғанда статистикалық тұрғыдан айтарлықтай жоғары екенін көрсетті. Зерттеу нәтижелері болашақ биология мұғалімдерінің когнитивтік және кәсіби құзыреттіліктерін дамытуға ықпал ететін негізгі стратегиялар болып табылатынын көрсетеді. Бұл зерттеудің ғылыми құндылығы болашақ биология мұғалімдерін даярлауға Кайдзен технологиясы мен 5S әдіснамасын енгізудің тиімділігін негіздеуінде, осылайша биохимия білімін ұйымдастырудың қолданыстағы тәсілдерін кеңейтуінде жатыр. Бұл жұмыстың практикалық маңыздылығы ұсынылған оқыту моделін білім беру бағдарламаларын әзірлеуде, биохимияны оқытуды жетілдіруде және болашақ мұғалімдердің кәсіби дамуын арттыруда пайдалану мүмкіндігінде жатыр.

**Тірек сөздер:** үздіксіз жетілдіру, білім беру, 5S әдіснамасы, Кайдзен технологиясы, биохимия білімі, биология мұғалімдерін даярлау, биохимиялық білімді қалыптастыру, педагогикалық дайындық, тұжырымдамалық түсіну, рефлексивті тәжірибе

## **МЕТОДЫ KAIZEN И 5S: ИХ ВЛИЯНИЕ НА БИОХИМИЧЕСКИЕ ЗНАНИЯ И ПЕДАГОГИЧЕСКУЮ ГОТОВНОСТЬ БУДУЩИХ УЧИТЕЛЕЙ БИОЛОГИИ**

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**Аннотация.** Целью исследования была оценка эффективности технологии Кайдзен, дополненной методологией 5S. В исследовании использовался квазиэкспериментальный дизайн с предварительным и последующим тестированием, а также контрольная группа. В выборку вошли 120 студентов-педагогов, обучающихся по программе подготовки учителей биологии, которые были распределены в экспериментальную и контрольную группы. Данные были собраны с помощью теста на успеваемость по биохимии, шкалы организации знаний по биохимии и анкеты педагогической готовности. Результаты t-критерия для независимых выборок показали, что баллы по формированию знаний ( $t = 4,87, p < 0,001$ ), концептуальному пониманию ( $t = 5,21, p < 0,001$ ) и педагогической готовности ( $t = 6,34, p < 0,001$ ) были статистически значимо выше в экспериментальной группе по сравнению с контрольной группой. Полученные результаты

свидетельствуют о том, что поэтапное обучение, непрерывная обратная связь, рефлексивная практика и системная организация являются ключевыми стратегиями для содействия развитию когнитивных и профессиональных компетенций будущих учителей биологии. Научная ценность данного исследования заключается в подтверждении эффективности интеграции технологии Кайдзен и методологии 5S в подготовку будущих учителей биологии, что расширяет существующие подходы к организации обучения биохимии. Практическая значимость данной работы состоит в потенциальном использовании предложенной модели обучения для разработки образовательных программ, улучшения преподавания биохимии и повышения квалификации будущих учителей.

**Ключевые слова:** непрерывное совершенствование, образование, методология 5S, технология Кайдзен, биохимическое образование, подготовка учителей биологии, формирование биохимических знаний, педагогическая готовность, концептуальное понимание, рефлексивная практика

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