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The Implications of Case-based Learning (CBL) on Biochemistry Education: An Integrative Literature Review

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THE IMPLICATIONS OF CASE-BASED LEARNING (CBL) ON BIOCHEMISTRY EDUCATION: AN INTEGRATIVE LITERATURE REVIEW

by

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ABSTRACT

The COVID-19 has significantly impacted the world as we know it, especially in higher education institutions. In response to COVID-19, most colleges and universities were forced to close their doors to students and switch to online learning over Zoom. Although most students are adjusted well to this new mode of education, other students, such as individuals pursuing degrees in the sciences, have difficulty adapting to the online mode of instruction. Case-based learning (CBL) is considered one of the best strategies in teaching a course like Biochemistry in a large classroom setting. Implementing CBL in biochemistry education may increase student engagement in the curriculum. Students will connect the material they learned in class to their daily lives, promoting critical thinking. The purpose of this review was to determine the effects of CBL in biochemistry education. This integrative review will focus on the various CBL study that implored in a biochemistry class setting. The review aimed to determine the implication of CBL in teaching biochemistry and assess students' views regarding the CBL.

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INTRODUCTION

People all over the U.S. have been significantly affected by the COVID-19 pandemic, which has caused the deaths of millions of people across the nation. The number of infected people and deaths continues to increase globally, and no effective treatment has been determined to work against COVID-19. Almost every country placed restrictions to stop the spread of this virus from protecting the senior citizens and people with chronic diseases since they are considered high-risk groups. Furthermore, the young population has to abide by these restrictions and self-isolation to inhibit the dispersal of COVID-19.

As COVID-19 circumnavigates the globe, colleges and universities chose to restrict face-to-face lectures and laboratories as a tactic to slow the dispersal of this virus. Many professors are forced to work to deliver lectures and evaluate learning via online instruction. Simultaneously, higher education institutions are pushing faculty members to become better professors and provide higher levels of quality and value in an online classroom. Providing quality and value to a large class encompasses distinctive challenges. Consequently, the professors must determine efficient methods of instruction for large classes.

The American Society for Biochemistry and Molecular Biology (ASBMB) reported on the state of instruction in Biochemistry determined that higher education is driven by the course material and conveyed by lectures. These characteristics are associated with a surface approach to learning.[1] There are two main approaches to learning. The surface approach is associated with a low level of participation consisting of memorization and reproducing facts; however, the deep approach is associated with the high-level involvement, including internalizing content and making learning meaningful.[2] Many studies have determined a disadvantage of lecture-dominated teaching in stimulating critical thinking in most students.[3] Critical thinking is defined as the process of conceptualizing and analyzing the information gathered from an experience. Therefore, lecture-dominated syllabi may obstruct students from understanding scientific practice and innovations. However, active learning strategies are often seen as alternatives or supplements to lecture-based curriculum.[4]

The biochemistry found in most textbooks and teaching sessions describes pathways as a set of molecules without direct context to real-life applications such as diet and physical activity. Real-world contexts reveal students to perspectives from numerous sources and determine why people may want different results. Introducing the active learning strategy, CBL in a biochemistry course may improve student engagement with the material, aid students in relating the course to their daily lives, and promote critical thinking. Several studies have shown that the advantage of relating human nutrition to metabolic biochemistry understanding in active learning situations makes the curriculum more relevant to students' lives.[5] Students showed greater liking of the course, a more outstanding obligation of the need to study. Studies show that when the lecture integrates metabolic pathways and nutritional disorders, it shows that this presentation yielded better scores than a lecture-based course.[5] This study will analyze various resources to determine the effects of CBL on a biochemistry education.

PROBLEM STATEMENT

The problem statement for this thesis is to investigate the positive and negative aspects of implementing case-based learning in a biochemistry classroom.

PURPOSE

The purpose of this integrative review is to examine the effects of case-based learning on biochemistry education.

BACKGROUND

Active Learning

The active learning interventions varied widely in intensity and application. They integrated tactics as distinct as group problem-solving, worksheets or tutorials completed during class, personal response systems, and studio or workshop course designs.[6] A colossal amount of evidence reveals that schemes that promote student interactions and cognitively engage students with content lead to learning and positive outcomes for students in science courses. [6]Many educational and governmental bodies have called for and supported the adoption of these student-centered strategies throughout the undergraduate science curriculum.[6] Furthermore, providing evidence that active learning can improve undergraduate science education.

Case-Based Learning (CBL)

CBL is concerned with bridging the gap between theory and practice, between declarative and operational knowledge, and can apply to most professional training.[2] Students can use case-based learning can be used to exemplify particular issues. It can be used throughout a course to address the whole syllabus, the cases being designated so that the content areas that are to be addressed are represented and sequenced in the rationality of the build-up of knowledge.[2] The use of real-life case scenarios in teaching makes learning more applicable and relevant to students, and when CBL involves group work, it can enhance communication skills.[7] Also, CBL is a student-involved process encouraging students to take accountability for their learning. In doing, so students develop the critical thinking and transferable skills, including life-long learning needed outside of academia.[8] Taken as a whole, CBL is an evidence-based instructional method shown to enable students to problem-solve via gathering and applying pertinent information, retaining relevant knowledge, and improving communication skills.[4]

In some disciplines, a case study is a perfect way of observing how students can apply their knowledge and professional skills. Case studies may need to be highly formal and carried out under supervision or carried out individually. Assessing the case study is essentially all-inclusive, but researchers can use aspects both for formative feedback and for collective assessment.[3]

In CBL, students are expected to solve detailed questions that can be open-ended and require articulate explanations to problems.[9] A study comparing long-term content retention among students who were taught using a conventional lecturing method vs. an active learning method, the study showed that the performance on the retention exam related to "recognition" and "recall" questions decreased as a function of time in both groups. However, retention rates were still higher for the recognition questions, particularly among the students in the active learning group.[8] Correspondingly, students exposed to active learning performed better on the "meaningful" questions rather than "memorization" questions on retention exams than students taught using only lectures.[9] Furthermore, CBL has shown promise across several content-rich science disciplines concerning knowledge retention. Hence, a focus of ongoing work is to elucidate better how this pedagogy benefits learning in biochemistry courses.[10] The hands-on approach of the case-study method of problem-solving allows students to learn by reading a textbook or listening to a lecture. In solving a case study, students acquire analysis and application skills, which is the objective of most courses. The use of a realistic situation also illustrates the relevance of foundational science coursework to society.[4] Overall, CBL is an instructional technique that is both student-centered and based on group work and can benefit students in several ways. However, there is a gap in knowledge concerning knowledge retention in the teaching of biochemistry.[8] To that effect, it is hypothesized that CBL will improve the academic performance of students enrolled in biochemistry

There are numerous reports on the use of case studies in large classes. Active learning has been used in teaching models where students and instructors interact online. Students were presented with various online resources like discussions via Zoom and discussion boards. Supporting resources that provide the framework for case processing can be transferrable to online platforms. The directed case framework used in this article can be implemented in large classes, and the access to web-based resources as described above can assist students during case processing.[6] For instance, the learning issues or questions can be provided to students in the class for an initial discussion, and their group responses can be posted online.

In CBL, students are engaged in inquiry, and material is presented based on their significance. Students must become investigators, collect relevant information, and recognize fundamental concepts, incorporate previous knowledge, make informed decisions, and have group discussions to determine the best solutions to an issue.[8] CBL does not necessitate much investment of resources. There may be no need to train a facilitator to lead small group discussions, and cases can be assimilated into lectures within an extensive range of class sizes. Furthermore, CBL has been shown to improve experimental knowledge, increase collaboration, and develop critical-thinking skills.

Case-Based Learning in Biochemistry Education

Despite its strong connections to nutrition, the biochemistry found in most textbooks and lecture describes mechanisms as a set of molecules and not in direct context to diet. Presenting nutritional components in a CBL-based biochemistry course may increase student involvement with the material, enhancing its significance to students' lives and promoting vital cognitive skills. Some evidence shows that this novel approach yields positive academic outcomes, particularly in teaching macronutrient metabolism.[8] Numerous research studies have described the benefits of linking human nutrition to metabolic biochemistry understanding in active learning settings that make the material relatable to students' lives. Other professors teaching biochemistry have developed cases based on physical activity or non-nutritional experimental situations. For instance, issues dealing with alcoholism in young adults to introduce body fluid homeostasis, low carbohydrate/ketogenic diet, and the fat substitute Olestra discuss lipid structure. [11]

Familiarizing this model to undergraduate biochemistry courses outside of medicine presents specific challenges. Students in undergraduate biochemistry continue into varied science majors, so curricula are content-driven instead of focusing on open-ended clinical diagnoses. It may be unrealistic to expect a fair investment of instructor's time at the group level in a vast class context. Most publications on undergraduate case studies refer to the instructor's role as a facilitator at the whole class level. In CBL, the instructor presents the case to the class and generally does not interact intensively with each group during case processing. Instead, the instructor may facilitate consensus with the class as a whole to generate an integrated solution after each group has worked on their own.

METHODOLOGY

A literature review of the implications of CBL on biochemistry education conducted with key terms combined to including "biochemistry," "case-based learning," and "education." The search results consisted of a total of 129 sources. The sources were analyzed and narrowed down to 25 articles that seemed most relevant to the purpose of this review. The sources were retrieved from UCF Library Quick Search and Google Scholars using the search terms. The data was organized into tables that synthesized the many positive and negative aspects of implementing CBL in biochemistry education. Inclusion criteria for the search results included articles were that must have been published in English and focused on case-based learning in Biochemistry education. Each paper was evaluated and individually critiqued for relevance to the topic and application to CBL in biochemistry education. Subsequently, all the critiques were synthesized, and key data was extracted. Consistent and inconsistent findings were noted, along with gaps in the knowledge. Recommendations for future research were identified. Implications for biochemistry education were included, along with the limitations of this review.

RESULTS

Cornely (1998) used CBL with nutrition elements in her study at Providence College.[12] The student responses to the case-study exercise have been positive in the study. In an evaluation at the end of the semester, students were presented with a series of 30 statements concerning the course.[12] They were requested to answer whether they agreed, strongly agreed, disagreed, strongly disagreed, or were neutral about the statement.[12] In response to the statement "The case study was a valuable exercise," 45% of the 51 students in the class strongly agreed, 31% agreed, 18% were neutral, and 6% disagreed.[4] On the contrary, in response to the statement "The homework assignments were a valuable exercise," 18% of the students strongly agreed, 45% agreed, 23% were neutral, and 14% disagreed.[12] Thus, the case study exercise has the effect of involving students who would not otherwise be engaged.[12]

Davis followed a similar approach incorporating CBL as a supplement to lectures to integrate metabolic pathways and nutritional disorders.[7] They reported that this format yielded better scores than a lecture-based course. Including case studies into the Nutritional Biochemistry curriculum at Georgia Southern University allowed students to learn in a more active environment.[7] They gained knowledge of metabolic diseases and made connections between the disorders and the metabolic pathways discussed in class. To further evaluate the effectiveness of this method, exam scores were examined.[7] During the 2001 Spring semester, the Nutritional Biochemistry course was composed of 20 students, and no case studies were utilized that involved metabolic pathways.[7] In contrast, the 2002 spring semester Nutritional Biochemistry course was composed of 26 students, and two case studies were presented that focused on metabolism and the connections between several metabolic pathways.[7] Initially, final exam scores were examined since this exam is comprehensive and cumulative, including all metabolic pathways.[7] When an increase was noticed in the section where case studies focusing on metabolism were used, the regular exam that mainly focused on metabolic pathways and their connections was also examined.[7]

Table 1. The Comparison of Exam Scores[7]

	2001 Spring Class	2002 Spring Class
Final Exam Averages	71 ± 2.31* %	76 ± 2.16* %
Final Exam Score Range	46% - 95%	55% - 94%
Exam #4 Averages	77 ± 2.31* %	80 ± 2.61* %
Test #4 Score Range	48% - 98%	61% - 98%

* 95% Confidence Limit.

A slight but noticeable increase in performance is shown in Table 1 for the 2002 Spring Class (CBL Class).[7] Other exam scores were examined to determine if the 2002 Spring Class performed better overall than the 2001 Spring Class, and no correlation was observed.[7] The final averages for both classes were within two percentage points of each other.

Hermes-Lima et al. found that student discussions on clinical applications like obesity, diabetes, and iron metabolism increased biochemistry integration and application.[13] The topics included anorexia, energy requirements for a triathlete, vitamin D deficiency, and dietary implications of cystic fibrosis.[13] Students also showed greater satisfaction with the course, a greater appreciation of the need to study, and a better appreciation of nutrition as an integrated topic.[13] This study aimed to determine the value of a system of seminars on clinically related biochemistry topics for undergraduate students in medicine and nutrition at the University of Brasília, Brazil.[13] The average performance grades for the seminars in the first semester of 1998 were significantly lower than those for the following semesters, indicating some degree of success with the new system.[13] They conducted, utilizing questionnaires, an evaluation of each student seminar about the overall biochemistry learning experience connected to the clinical expectations of the students.[13] Moreover, when asked whether the seminars were relevant to a more clinical approach to biochemistry and whether the oral presentations could be viewed as valuable tools for the understanding of biochemistry, 96% (n = 188) and 80.6% (n = 150) of the students, respectively, answered, "yes." [13]

Joshi et al. carried out a study in the Department of Biochemistry, government medical college, Aurangabad, after obtaining institutional ethical approval.[9] Sixty students, including males and females, were randomly selected from the first-year medical class.[9] Then, these participants were randomly divided into batches A and B of thirty each. For these participants, a clinical biochemistry topic was selected.[9] All the sixty participants were evaluated with a pre-test in multiple-choice questions with one best possible answer related to the topic chosen.[9] This score evaluates all participants and is the pre-test score for batch A and batch B.

Table 2. The comparison of scores obtained after CBL method and lecture method[9]

	Post CBL Score of batch A	Post lecture Score of batch B	P value
MCQ evaluation	9.32 ± 2.04	6.28±1.77	<0.0001*

* Extremely statistically significant

Table 2 shows a comparison between post-CBL and post-lecture scores. In the study, there was a significant improvement in scores in post-test after CBL than in post-test after lecture method.[9] These results are supported by other studies which show increased test scores post-CBL session. Regarding the perception of the students, no one thought that the CBL session was not helpful. The majority of students (73%) opined that CBL helped understand the topic; sessions motivated them to learn and arouse interest in clinical biochemistry topics.[9] 69% of the students marked "strongly agree" on the importance of the role of facilitator.[9] Majority of students thought that the case discussion helped them in critical thinking and to link basic knowledge with applied. The majority of students (77%) opined that CBL would help them diagnose in the future, and 83% of students opined that sessions helped them interpret the results better.[9] Most importantly, 90% of the students felt CBL be better than the lecture method in understanding clinical biochemistry topic.[9]

Kulak, V., Newton, G., & Sharma, R. used the revised two-factor study process questionnaire, a retention test, final exam grades, and other demographic information to statistically compare academic outcomes of students subjected to either CBL or non-CBL active learning techniques.[8] They showed that students exposed to CBL in a second-year course performed significantly better on a retention test conducted nine months after the final exam. There was a positive correlation between a deep learning approach and higher retention scores.[8] The primary research question of the present study was to determine whether the use of CBL in an undergraduate biochemistry course would improve the retention of crucial concepts.[8] There were statistically significant improvements in the retention scores of the CBL class compared to the non-CBL class, and the DA score significantly predicted retention scores in the CBL condition; however, this resulted in a moderate correlation.[8]

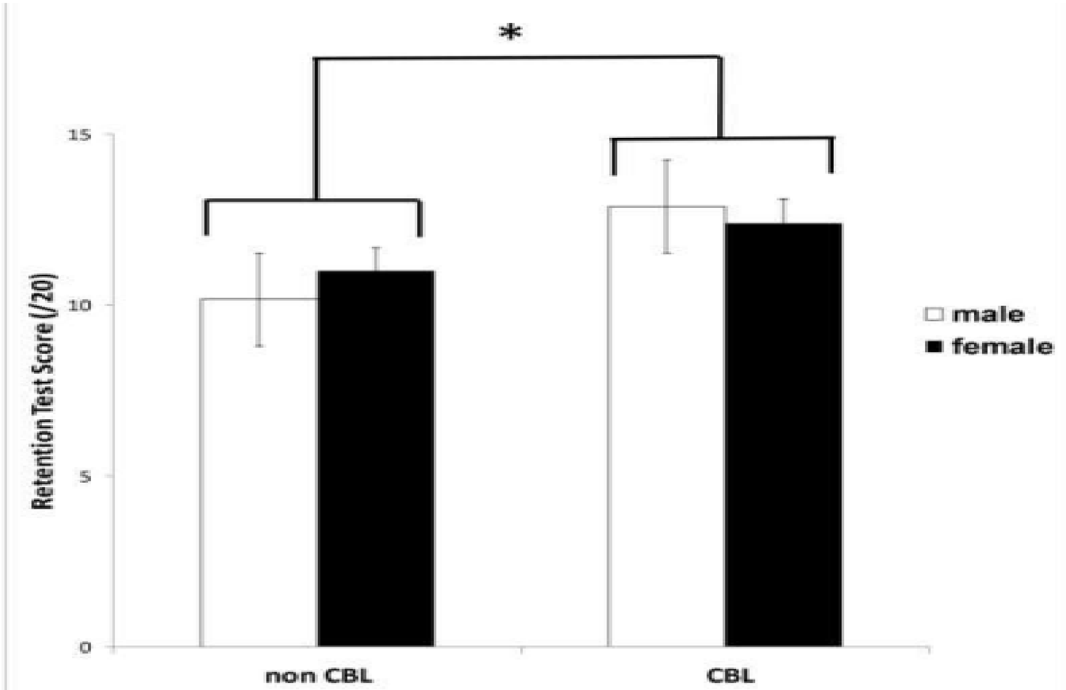

Figure 1. Teaching condition and retention scores relationship significance for non-CBL and CBL pooled groups[8]

The CBL group performed significantly better on the retention test than the non-CBL group as measured by independent sample t-tests in each pooled condition, as shown in Figure 1.[8] When retention test scores were analyzed as a function of treatment condition and gender, gender was non-significant.[8] There was no correlation between teaching treatment and gender on retention scores.

Millard designed a series of cases based on popular television medical dramas where characters were patients at the E.R. suffering from drug overuse; the issues aimed to teach enzyme inhibition and lipid metabolism. [14] Although there is no quantitative data to suggest that using television dramas is more successful than written cases based on the medical literature, student evaluations, even chemistry majors with no intention to pursue medicine, they often comment favorably about this approach.[14] Students generally find biochemistry to be the most rigorous course they have ever taken. Many students report back from medical school and graduate school that they find themselves exceptionally well prepared.[14] They often cite the difficulty of the case studies as being key to their preparation.[14]

Nair et al. studied a group of 100 students that were divided into two groups as the control group and the study group.[15] A total of 50 students were introduced to case-based learning, which formed the test group, and 50 students who attended lectures formed the control group.[15] A very significant improvement was observed among the students after the CBL sessions, which can be observed in Table 3 (below). A 4-point Likert scale questionnaire which contained eight questions was administered to the students to know their perception of the usefulness of the CBL.[15]

Table 3: Result of Evaluation Test[15]

	Before intervention	After intervention	p value
Test	20.42±11.6	36.5±11	$p<0.0001$
Control	16±10.5	26.6±13	$p<0.0001$

$p<0.0001$=very significant.

98% of the students reported that they found the CBL sessions to be a fascinating method of gaining knowledge.[15] 84% of them felt that they exposed them to an experience of logical application of the knowledge, which was acquired in cracking cases, which would be of great help in the future also.[15] Case-Based Learning (CBL) was used, and it is effective in the medical curriculum for a better understanding of Biochemistry among the medical students.[15]

Patil et al. conduct a study that included 148 students of the first-year student[16] The traditional lecture was given to all 148 students, and the pre-test was completed by giving ten multiple-choice questions.[16] Then, the 148 students were divided into two groups, the test group, and the control group. A 4-point Likert scale questionnaire which contained ten questions, was administered to the students to know their perception of the usefulness of the CBL. It was observed that 97% of students enjoyed the new teaching method and developed an interest in the subject.[16] It was also observed that the intervention group's perception was significantly improved compared with pre-and post-test multiple-choice questions. The study also observed that analytical thinking ability was highly increased in Group 1 than that of Group 2.[16] CBL was determined to be a very effective technique. It helps improve not only students' perception but also analytical thinking ability in this study.[16]

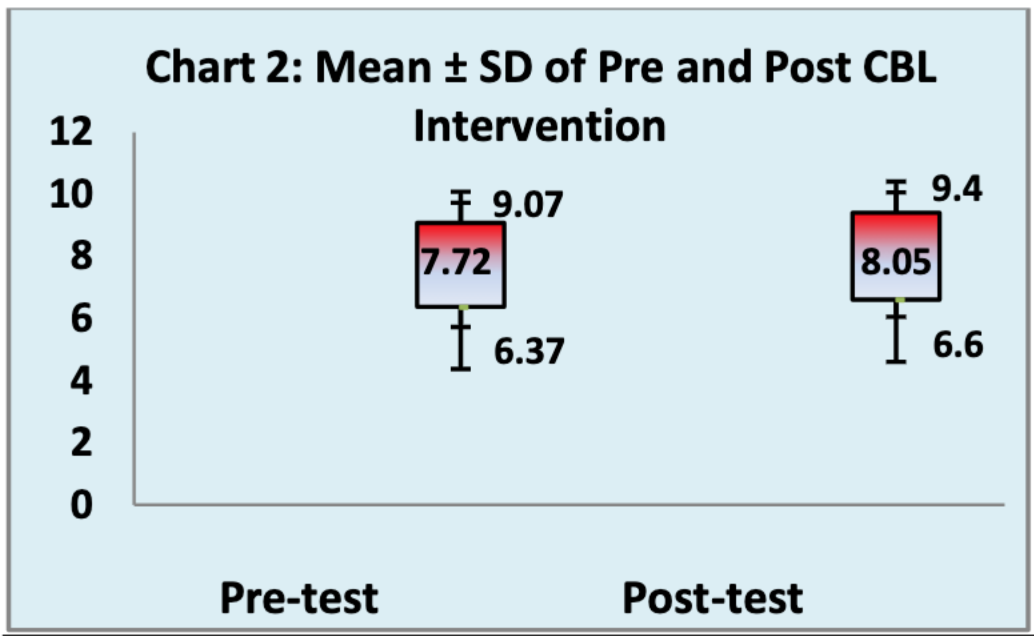

Figure 2: The Mean ± S.D. of Pre and Post CBL Intervention[16]

At the same time, students' perception was assessed using Pre-tests and Post-tests in Figure 2 (above). It was observed that the post-test score (8.05±1.45) was increased than that of the pre-test score (7.72±1.35).

Salgar conducted a study to determine the perception of students to various aspects of case-based learning.[17] The present study was conducted in a batch of 125 first-year students at

Rural Medical College of Pravara Institute of Medical Sciences, Loni. All the participants were included in the test group, and no control group was formed.[17] The modules prepared for the case-based learning session were based on common medical problems. For each module, three sessions were conducted.[17]

Table 4. Students' response to case-based learning[17]

Q. No	Question	Agreed (%)	Neutral Response (%)	Disagreed (%)
1.	CBL is more useful in understanding particular topic as compared to didactic lecture.	112 (89.6)	04 (3.2)	09 (7.2)
2.	CBL can be conducted along with lectures.	89 (71.2)	00	36 (28.8)
3.	Clinical scenario given in CBL was interesting.	121 (96.8)	01(0.8)	03 (2.4)
4.	CBL session was interactive.	116 (92.8)	03 (2.4)	06 (4.8)
5.	CBL module is helpful in development of critical thinking.	117 (93.6)	04 (3.2)	04 (3.2)
6.	CBL is important for independent learning and developing communication skills.	123 (98.4)	00	02 (1.6)
7.	Role of facilitator in CBL is important.	124 (99.2)	01 (0.8)	00
8.	CBL can be recommended for future batches	119 (95.2)	00	06 (4.8)
9.	CBL will be help to perform better in formative as well as summative examinations.	121 (96.8)	01 (0.8%)	03 (2.4)
10.	CBL is useful in terms of future application of knowledge in medicine.	116 (92.8)	04 (3.2)	05 (4)

At the end of the session, students' perception regarding case-based learning as enhancing learning was assessed by a close-ended questionnaire obtained from each participant. The majority of students felt that case-based learning is more helpful in understanding biochemistry than lectures. A total of 112 (89.6%) students agreed that CBL sessions are more useful in understanding biochemistry than didactic lectures.[17] 89 (71.2%) participants suggested that CBL can be conducted along with lectures.[17] Most of the participating students indicated that the CBL module is helpful in the development of critical thinking and can be recommended for future batches.[17] 98.4% of students perceived that the CBL module was practical in self-directed learning and developing communication skills.[17] A total of 96.8% expressed the view that CBL is very useful in clearing the concept of the particular topic, which is not cleared during regular theory classes. Therefore CBL will help them to perform better information as well as summative examinations.[17] The role of facilitator in the CBL session was reported to be important by 99.2% of participants.[17] Majority of the students enjoyed CBL sessions as it was very interactive and allowed them to participate actively in the learning process which is not possible in didactic lectures.[17] 98.4% of students perceived that the case-based learning module was helpful in independent learning and developing communication skills.[17] The role of facilitator in case-based learning sessions was reported to be important by 99.2% of participants.[17] The study supports that case-based learning can be used as an innovative teaching method for increased retention of knowledge.[17]

DISCUSSION

It is strongly encouraged that instructors interested in active learning collaborate with the teaching community via online journals. For students familiar with working independently on assignments, the case-study exercise provides the opportunity to work collaboratively with their peers. During the case-study activities, the students need to be actively engaged in proposing solutions. In a course such as biochemistry, where it is all too usual for students to feel completely overwhelmed by the utter size of the material, an exercise like the one described here allows them to sort through a large amount of data and begin to make meaningful connections between topics. The activity requires the students to articulate, both verbally and in writing, the solution to the problem, and they must present convincing evidence to support their conclusion.

This study presents a review of CBL and the potential implications of its use in biochemistry education. Each author explains the teaching logic behind their case along with purposes. It also provides concise and transparent steps to help alleviate some of the challenges in case design. In turn, its contribution may facilitate implementing cases as academic aids and as research tools. Furthermore, the authors hope to initiate a discussion on case preparation standards for science teaching. This is important because most authors reporting on CBL use do not disclose how their cases were developed. Thistlethwaite et al. raise the point that there is no research examining the process by which cases are prepared and presented.[20] Additionally, it is possible that a lack of detailed guidance and consensus on case preparation is preventing instructors from considering CBL as a teaching aid.[18]

Current evidence on CBL comes from diverse research questions and varied sample sizes, student demographics, and course levels. For the most part, published results do not disclose the level of difficulty of the implemented cases. These variations make comparisons and the generation of new evidence difficult. So far, evidence from systematic reviews and meta-analyses on CBL indicates that student motivation and satisfaction with these pedagogies are positive. There are strong indicators that: students enjoy CBL, students perceive CBL as an enhancement to their learning, and teachers enjoy teaching with CBL because it engages students. This means that most reports focus on outcomes largely dependent on overall experience indicators. However, reported experiences are often based on anecdotes or student interviews. Although such feedback is very informative, there is a need to corroborate such findings with statistically sound research instruments such as validated student and teacher questionnaires.[5] The potential benefits of CBL seem to be many; however, its successful implementation in science education and its effects on learning approaches remains largely unquantified.

The attention is moving away from lecture-dominated curricula into active learning has generated numerous strategies and conceptual frameworks available across disciplines. Currently, there is no agreement that a single teaching method is superior to others. Different ways bring in advantages and disadvantages that have not yet been measured to allow for unbiased comparison. Lundeberg and Yadav pointed out that measurement is not as precise in pedagogical research as in the sciences.[19] Quantitative measurement may limit methodology and research questions, so evidence comparison is generated slowly.[19] Overall, this context creates several difficulties.

First, CBL may facilitate a direct and active cognitive experience in the learner, but its long-term effects are yet to be measured.[5] Subsequent, there is also a lack of comprehensive research on the effectiveness of CBL over other active learning techniques or traditional lectures.[5] Additionally, evidence is absent regarding the degree of success of CBL at teaching content.

These problems may hinder the willingness of instructors to embrace change and to introduce CBL in their courses. This change implies a new intellectual pattern versus the one promoted by traditional lectures: a shift from relying on memorization alone to embracing the effort to examine, integrate, and assess scientific content.

Cornely portrayed using a current event as a vehicle to teach biochemical principles as a highly effective method for introducing the students to essential mechanisms in biochemistry.[11] At the same time, student interest was heightened because the content centered on a "story" that they could relate to in their own lives.[11] Also, the use of a case study that involves an element of conflict allows students to address the results of scientific inquiry on society.[11]

Case-based learning may, however, lead to excessive workloads for both teacher and student.[3] While these tasks improved the quality of performance, the students complained of excessive workload, which underlines the need for care in designing these sorts of assessments.[3]

Overall, case studies in a biochemistry course encourage students to actively participate in the learning of biochemistry rather than serving as passive recipients of large amounts of factual data. For students who have difficulty seeing the connections between their courses and their career aspirations, the case-study exercise allows them to see that knowledge of biochemical concepts and analytical problem-solving skills are essential to a clinical problem.[4]

Therefore, the implementation of CBL is aimed at facilitating learning of content and problem-solving, critical thinking, and communication skills in biochemistry education. To fully accomplish these goals, instructors need to become proficient in both writing and teaching with cases, which exposes the need for students to become comfortable using the case study approach. Further reviews and primary research are needed to be done on how these elements interplay are necessary.

These findings challenge institutions and science disciplines to reflect on practices and policies. Specifically, institutions should revise their tenure, promotion, and merit-recognition policies to incentivize and reward the implementation of evidence-based instructional practices for all academic ranks.[20] Preferably, implementing these practices would be an expectation for advancement and tenure to be factored into annual merit decisions.[20] These policy changes would require institutions and professional organizations to provide practical pedagogical training for the current and future professoriate, similar to the level provided for research.[20] Further, these policy changes cannot be meaningfully implemented without research-based guidelines for measuring effective teaching practices. Funding agencies should prioritize the development of such approaches.

CBL has a long history of use in various disciplines, so although research findings in a single field may not be generalizable, the research contributes to the general understanding of the impact of CBL pedagogy.[5] It could serve as a framework for similar research in other disciplines. The use of case studies in biochemistry education and demonstrated that using cases in this context conferred positive academic outcomes, including preventing a shift towards surface learning and improving academic performance, particularly at the level of introductory knowledge. CBL provides students with diverse experiences in the classroom, including problem-solving, knowledge co-construction, communication, and group collaboration.[5] Through these activities, students can explore and develop new knowledge and acquire relevant skills that have application both in the classroom and beyond. Several notable research gaps are addressed as we move away from lecture-dominated teaching towards using more active and student-centered approaches. Collaboration between researchers is essential, including cooperation between researchers teaching in the same degree programs and across programs and institutions. It is only through the accumulation of a network of evidence that a comprehensive understanding of the short-term and long-term impact of case-based learning on education and academic performance will emerge.

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