

ARTICLE

“CARBGAME” (CARd & Board Games in Medical Education) as an innovative gamification tool for learning clinical enzymology in biochemistry for first year medical students

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Abstract

Gamification is emerging as an active learning innovation in medical education to enhance student engagement and promote life-long learning in a unique and collaborative environment. Clinical enzymology in biochemistry is one of the core topics in the medical curriculum. However, students face challenges in comprehension and retention of information. Hence, CARd & Board Games in Medical Education (CARBGAME) was introduced and evaluated for its effectiveness in enhancing learning, application, and retention of knowledge in clinical enzymology via gamification context. This mixed-method study involved 150 first-year undergraduate medical students. Before the game, students completed a pre-test in clinical enzymology. Later they were divided into 25 small groups to compete in the board game designed for enzymology in biochemistry. The students took turns throwing the dice and answering the questions on the game board to continue moving forward. The first team to reach 100 and solve the case-based question was deemed the winner. Following the board game, the students took up the post-test to compare the educational impact of the innovation. Also, the subsequent internal assessment scores were compared with previous batch who were not implemented with this intervention. Then students evaluated the effectiveness of CARBGAME—Clinical Enzymology using a 32-item questionnaire on 5-point Likert scale. The feedback obtained on a 10-point rating scale and for qualitative analysis, students' and faculty perceptions were recorded in small groups. CARBGAME received overwhelmingly positive feedback from both students and faculty. It was perceived well by students for being fun, relevant, consistent, motivating, collaborative, and promoting experiential learning. The game's low-stakes approach, effective feedback, and sense of accomplishment were highly appreciated, making it a valuable tool for education. A significant improvement in knowledge was recorded, from a mean score of 8.37 ± 1.126 on a 20-point scoring scale before the game to 16.53 ± 1.219 after with a *p*-value of 0.0001. The

comparison of the internal assessment scores between the intervention and non-intervention group of students also showed a significant improvement among those implemented with CARBGAME ($p < 0.0001$). The CARBGAME innovation has achieved the intended outcome of promoting active learning and enhanced performance in clinical enzymology. Highly positive responses from faculty and students also indicate the exigent need to introduce innovative components like games into curricula to achieve student engagement and promote a meaningful learning experience.

KEYWORDS

active learning, biochemistry, board game, cards, clinical enzymology, gamification, innovation, medical education

1 | INTRODUCTION

Over recent years, there have been revolutionary changes in the way medical education is approached, particularly after the COVID-19 pandemic.¹ Many pedagogical innovations to foster active, student-centered learning are emerging and games are one of the crucial components of this paradigm shift.² Learning with games offer active engagement, motivation, immediate feedback, critical thinking, collaboration, and real-world application. It enhances retention, provides a safe space for experimentation, and integrates multimedia for effective, enjoyable learning.³ Thus, games have the ability to ease the process of learning and make the learning experience joyful as well as meaningful.⁴

During early medical training, undergraduate students often find biochemistry a challenging topic.⁵ Particularly topics like clinical enzymology which has abstract concepts can be challenging to visualize and grasp. Clinical enzymology involves a shift from theoretical chemistry concepts to the practical application of enzymes in diagnosing and understanding diseases. This transition can be perplexing for students as they navigate the complex interplay between biochemical pathways and clinical manifestations. In addition to this, clinical enzymology demands a thorough understanding of enzymatic kinetics, which requires a grasp of intricate equations and concepts that may be challenging to those without a strong background in chemistry.⁶

Also, the sheer diversity of enzymes and their associated disorders, different types of inhibition and regulation mechanisms can overwhelm students, necessitating the memorization of numerous enzyme names, functions, associated pathologies and mechanisms.⁷ Furthermore, the integration of clinical enzymology into broader medical contexts, such as understanding the role of enzymes in various organ systems and diseases as

markers and therapeutic agents, demands critical thinking skills and the ability to connect biochemistry with clinical scenarios.⁶ These challenges cumulatively contribute to the complexity of learning clinical enzymology, thereby requiring dedicated effort and newer learning strategies to navigate these successfully and enhance the learning experiences of students.

In light of this, identifying the lacunae in traditional teaching methods to ignite student interest and promote active learning of concepts, the CARBGAME—(CARD & Board Games in Medical Education) was designed to ease the process of learning.⁸ The goal of implementing “CARBGAME” for clinical enzymology is to bridge the gap between theoretical knowledge and practical application by creating a dynamic learning environment where students can manipulate enzymatic reactions, simulate diagnostic scenarios, and make clinical decisions based on enzyme markers. Through this gamified approach, CARBGAME aims to simplify the understanding of intricate enzymology processes, encourage critical thinking, and facilitate a deeper connection between biochemistry and clinical practice.

2 | METHODS

This is a mixed-method study conducted during February 2023, involved 150 first-year undergraduate medical students pursuing MBBS (Bachelor of Medicine & Bachelor of Surgery) degree at the Panimalar Medical College Hospital & Research Institute, Chennai, Tamil Nadu, India. The study was approved by the Institutional Human Ethics Committee of the Panimalar Medical College Hospital & Research Institute (PMCH&RI/IHEC/059; Dated: 133 15.03.2022). All data were anonymously collected to ensure participants' confidentiality. Participation in the study was voluntary and written informed consent was

100  GAMETASTIC! You're Almost There Get your WINNING CARD!	99 In zero order kinetics amount of time to produce 3 moles of product is 7 minutes what will be the time required to produce same amount of product if enzyme concentration is decreased to 5?	98 Explain: Uncompetitive inhibition causes decrease in V max and Km	97  OOPS! BAD LUCK GO BACK BY 10 MOVES	96 Rationale for using asparaginase as an anti-cancer drug in adult leukemia?	95 Give 2 non-pathological conditions in which ALP is elevated	94  1 FADH2	93 FIND ME? I am an anti-coagulant. I can be used in Deep Vein Thrombosis MILACARODU	92 What is the effect on phosphofructo-kinase activity when abundant ATP is available?	91  NEXT THROW 1,3,5 – BACKWARD 2,4,6 – FORWARD
81 I am an isoenzyme of ALP, I am decreased significantly in Chronic Myeloid Leukemia	82  SAFE BOX	83 Why fluoride containing collection tubes are used for blood samples to estimate glucose?	84 Among lipase and amylase which enzyme estimation has greater significance in pancreatitis and why?	85  1 ATP	86 I am pyridoxal pyrophosphate: I function with coenzyme and help in transferring phosphate group. Find out the error	87  Next move only upon getting 6 on dice	88 Which enantiomeric form of thalidomide drug is more teratogenic?	89 In competitive inhibition, inhibitors are added to decrease the rate at which reaction proceeds: Justify if correct	90  1 NADH2
80 Which compound is the strong inhibitor of xanthine oxidase and what type of inhibition is it?	79  1 FADH2	78 The most common type of covalent modification?	77 Velocity at Km is _____	76 Which abnormal hemoglobin is manifested in Glucose 6 Phosphate Dehydrogenase deficient individuals?	75 Pseudo-cholinesterase is produced mainly by which cells	74 Prolonged use of Isoniazid results in?	73  1 NADH2	72 Marker for neuroendocrine tumours?	71 Where do allosteric regulators bind?
61  Repeat the same number on your last throw to move ahead	62 Which serum biomarker will you use to detect alcohol abuse?	63 The affinity of enzymes towards substrates is not decreased in which type of inhibition?	64  1 NADH2	65 Patient gives history of taking alcohol for 20 years but currently stopped. Which serum biomarker estimation is preferred to detect alcoholic liver disease?	66 Which enzyme activity is inactivated by phosphorylation that requires Mg ²⁺ as cofactor?	67  SAFE BOX	68  Which isoenzyme of ALP is of placental origin?	69 Solve: Enzyme concentration is tripled Vmax is tripled, then Resultant Km :- ?	70  1 ATP
60 Which biomarker is expressed in myocardial infarction as well as liver diseases?	59 Metal constituent of alkaline phosphatase	58 Is it possible to reverse the antibacterial activity of folic acid analogues? why?	57 Lipoprotein associated phospholipase A2 enzyme in serum is a predictor of which disease?	56  OOPS! BAD LUCK GO BACK BY 10 MOVES	55 Enzyme profile of a patient with alcohol anemia shows elevated levels of?	54 What is the AST/ALT ratio in severe hepatocellular damage?	53  1 FADH2	52 Find me? I am a metalloenzyme, my co-factor is IRON _E_ _ _ _ _ _ _ _ _	51  Next three moves only upon getting 1 on dice
41  SAFE BOX	42 We belong to class ligases, we require energy to catalyze biosynthetic reaction. What are we called? TEKSHATSEY	43  1 ATP	44 Normal value of LDH in serum	45 Name 2 drugs that cause hemolytic anemia	46 A: Reaction with enzyme B: Reaction without enzyme Which reaction has higher activation energy, why?	47  Nominate a person to answer next question	48 A child presents with symptoms of severe vitamin D deficiency, which serum biomarker is drastically elevated?	49 NEOSTIGMINE- is used against which disease?	50 I am also secreted by RBC, WBC and platelets. I survive in acidic pH. I am an important Tumor marker. Which of my isoenzymes is elevated in a disease in men?
40 Mechanism by which ALA synthase is regulated by heme concentration is called?	39 Which serum biomarker is the earliest to rise in myocardial infarction?	38 Regan isoenzyme is inhibited by which compound?	37 FIND ME? I am the cofactor of cytoplasmic isocitrate dehydrogenase	36  1 NADH2	35 Which is the most reliable cardiac biomarker and why?	34 Complete : Production of Prostaglandin from Arachidonic Acid is by enzyme A and A is inhibited by B	33 Accurate marker of Cholestasis in liver is?	32  OOPS! BAD LUCK GO BACK BY 10 MOVES	31  1 FADH2
21  Nominate a person to answer next question	22 Coenzyme required for alanine aminotransferase	23  1 FADH2	24 Which isoenzyme of Creatine Kinase is estimated in myocardial infarction and give its normal value	25 Enzyme that is elevated in parotitis is?	26 I am the major enzyme involved in alcohol metabolism, who is my cofactor?	27  1 ATP	28 Difluoro Methyl Ornithine is used in treatment of which disease?	29  SAFE BOX	30 List the types of cardiac troponins with expansion
20 Which is the fastest isoenzyme of LDH?	19 An cholesterol lowering agent that is the competitive inhibitor of rate limiting step of cholesterol biosynthesis is?	18 Which enzyme is deficient in emphysema	17 In presence of this metal ion, nucleotide phosphatase is inhibited	16  NEXT THROW 1,3,5 – BACKWARD 2,4,6 – FORWARD	15 List the isoenzymes of Creatine Kinase and state which has highest concentration in blood normally	14 Catalyst are substances that accelerate rate of chemical reaction but do not change the _____	13 Disulfiram is a non-competitive inhibitor of?	12  1 NADH2	11 Name 3 competitive drugs used for treatment of cancer
1 Enzymes that break the peptide bonds of proteins during digestion come under which class of enzymes?	2 I can lyse intravascular clot, I am extracted from bacteria	3  1 ATP	4 Isoenzymes are group of compounds that have _____ and _____	5 What is the non-protein part of the enzyme glyceraldehyde-3-phosphate-dehydrogenase?	6  SAFE BOX	7 Marker for congestive cardiac failure	8 All enzymes are proteins. Provide exception to this statement	9 Which enzyme is used in ELISA?	10 LDH1 & LDH2 – which isoenzyme is elevated in myocardial infarction?

FIGURE 1 CARBGAME: clinical enzymology game board: a 10 × 10 board with questions for learning clinical enzymology. CARBGAME, CARd & Board GAMES in Medical Education.

obtained from all the participants. Participants were allowed to withdraw from the study at any time.

2.1 | Designing of “CARBGAME”-clinical enzymology

The “CARBGAME,” a 10 × 10 game board with 100 boxes was designed. 70 blocks posed questions to the players on clinical enzymology and the remaining 30 were extras. The topics covered in clinical enzymology include: (i) enzyme structure and function, (ii) enzyme classification, (iii) enzyme kinetics, (iv) enzyme inhibition, (v) isoenzymes, (vi) enzyme regulation, (vii) enzyme disorders, (viii) enzyme assays, (xi) enzyme markers in disease diagnosis, and (x) therapeutic enzymes. Questions or instructions were provided in every box. Among the 70 boxes with questions, 11 boxes were represented with a red dot. These boxes mandated the answer to be given

only by the player who rolled the dice or has been nominated without discussing it with the team members. Among the 30 extra boxes, 5 safe boxes, 15 gift boxes, and 10 instructions boxes were created. Upon landing on safe boxes, the players need not answer any questions. 15 gift boxes were categorized into 5 ATP boxes, 5 FADH2 boxes and 5 NADH2 boxes that provided the players with 1, 2, and 3 bonus moves ahead respectively. Furthermore, there were 10 instruction boxes where players had to follow the instructions provided to proceed with the game. Each team was provided with 3 skipping star cards to skip any 3 questions during the game. Finally, upon reaching the 100th box, a winning card was provided with a case-based question. The first team to solve this case-based question was deemed the winner of CARBGAME-clinical enzymology. The board for CARBGAME-clinical enzymology is shown in Figure 1. The game material and instruction files are provided in the [Supporting information](#).

2.2 | Conduct of “CARBGAME”-clinical enzymology

Before the game, a pre-test with 20 multiple-choice questions with 10 knowledge-based and 10 application-based questions was conducted. Later students were briefed about the game instructions and all queries were clarified. 150 students were divided into 25 small groups with 6 players in each team. A faculty was allotted for every team. Each team was provided with the game board, cards, and dice. Players had to throw a one on the dice to begin. Later, players took turns throwing the dice in the same order throughout the game. As the players provided correct answers to the questions, they proceeded forward on the game board. They were allowed to discuss with the team members except for questions on the boxes with a red dot. Answers given in the first attempt were considered final. If wrong answers were provided, players went back by 5 moves on the board and continued the game. In case the players landed on the same block which they didn't answer, in the next turn, they attempted again to find the right answer, used a skipping star or continued going back by 5 moves. The first team to reach the 100th box and solve the case-based question was the winner of CARBGAME-clinical enzymology. The estimated time to complete this game was 60 minutes. At the end of the gaming session, all the students took up the post-test to compare their level of knowledge improvement.

2.3 | Evaluation of CARBGAME

The pre- and post-test analysis was done to evaluate the educational impact of CARBGAME. Also, after the game, all students recorded their perceptions about CARBGAME for clinical enzymology using a 32-item questionnaire on a 5-point Likert scale. Their feedback regarding CARBGAME was also obtained using a 5-item questionnaire on a 10-point rating scale. For qualitative analysis, small group interviews were conducted to obtain students' and faculty views and opinions about CARBGAME. Content analysis was performed and the responses were segregated into different themes. In addition to this, for a more objective evaluation, the effectiveness of CARBGAME was compared with traditional teaching methods. The subsequent internal assessment scores of students implemented with CARBGAME and previous batch of students who followed traditional teaching on the same topic was compared. This also served as an analysis for evaluating the game's potential to enhance retention of concepts and application of

knowledge over a period of time and not just immediately after the game.

2.4 | Data analysis

The questionnaire was categorized into six domains: domain 1: design of CARBGAME, domain 2: gaming environment in CARBGAME, domain 3: motivation while playing CARBGAME, domain 4: learning experience with CARBGAME, domain 5: assessment & feedback in CARBGAME and domain 6: play & learn with peers. A descriptive analysis was conducted on the continuous variable, reporting the mean and standard deviation (SD). To compare differences in the continuous variables, the *t*-test and Analysis of variance (ANOVA) were used. For non-normally distributed data, the Mann-Whitney U test and the Kruskal-Wallis test were applied. All statistical analyses were performed using Statistical Package for Social Science (SPSS, version 17) for Microsoft Windows, SPSS Inc. USA, with a significance level set at $p < 0.05$. Qualitative data from open-ended questions and one-to-one interviews were recorded to understand the students' and faculties' responses.

3 | RESULTS

This game was designed for 150 first-year medical students. 93.7% of the participants were equal to or less than the age of 20 while 6.3% were greater than 20 years of age. 68.5% were female participants while 31.5% were males. The educational impact of the innovation was assessed by comparing the pre- and post-test scores on clinical enzymology that comprised 20 Multiple Choice Questions. There was a highly significant improvement in knowledge from a pre-test score of 8.37 ± 1.126 (mean \pm SD) to a post-test score of 16.53 ± 1.219 (mean \pm SD) with a *p*-value of 0.0001.

The 32-item questionnaire for the perceptions of students towards the effectiveness of CARBGAME gamification tool recorded on a 5-point Likert scale revealed highly favorable responses across six distinct domains, offering valuable insights into its effectiveness and impact. Learners appreciated the game's alignment with their knowledge and skills (94.6%), tailored gameplay (83.8%), and consistent rules (96.4%), contributing to an engaging learning environment (99.1%). The game's design sparked curiosity (98.2%) and active discovery (96.4%), encouraging social interaction (91.9%) and collaboration (98.2%). CARBGAME effectively motivated learners (96.4%), making the learning of enzymology

TABLE 1 Students' perceptions towards CARBGAME—clinical enzymology.

Perceptions	Strongly agree (%)	Agree (%)	Neither agree nor disagree (%)	Disagree (%)	Strongly disagree (%)
Domain 1: design of CARBGAME					
The questions on enzyme card & board game was related to my knowledge and skills.	41.4	53.2	5.4	0.0	0.0
The level of the enzyme card & board game is tailored on the basis of the player's abilities.	33.3	50.5	13.5	2.7	0.0
There was consistency in the rules while playing the enzyme card & board game using the CARBGAME tool.	39.6	56.8	3.6	0.0	0.0
Understanding the rules and functioning of the enzyme card & board game were easy.	62.2	36.0	1.8	0.0	0.0
The complexity of the game was not harder than the learning content of the game.	40.5	45.9	11.7	1.8	0.0
The enzyme card & board game was well-designed with rewards and surprises that motivated me to engage more in the game.	51.4	41.4	5.4	0.9	0.9
The enzyme card & board game is sustainable and can be easily reused at any time and place.	40.5	49.5	6.3	3.6	0.0
Domain 2: gaming environment in CARBGAME					
The card & board game created a fun-filled and engaging environment to learn enzymology.	73.9	25.2	0.9	0.0	0.0
The enzyme card & board game created curiosity and sense of exploration.	66.7	31.5	0.9	0.9	0.0
The enzyme card & board game engages the player in active discovery.	52.3	44.1	3.6	0.0	0.0
The enzyme card & board game is often multiplayer or social.	54.1	42.3	3.6	0.0	0.0
The enzyme card & board game can be completed within a fair time frame.	36.0	49.5	11.7	2.7	0.0
During the enzyme card & board game the players are engaged in pursuing a goal.	46.8	48.6	3.6	0.9	0.0
Domain 3: motivation while playing CARBGAME					
The enzyme card & board game has evoked motivation to learn.	58.6	37.8	2.7	0.9	0.0
The CARBGAME tool has ignited my interest towards learning enzymology in biochemistry.	60.4	35.1	2.7	1.8	0.0
The enzyme card & board game is a meaningful way of learning using CARBGAME as an innovative gamification tool.	56.8	42.3	0.9	0.0	0.0
The enzyme card & board game has made my learning experiential.	48.6	48.6	2.7	0.0	0.0
Domain 4: learning experience with CARBGAME					
The enzyme card & board game fosters the ability to transfer learning from the game context to a real context.	45.9	49.5	4.5	0.0	0.0
The enzyme card & board game created a non-threatening environment to learn.	49.5	48.6	1.8	0.0	0.0
The enzyme card & board game provides an opportunity to try, make mistakes and learn with minimal penalty.	58.6	39.6	0.9	0.9	0.0
I was able to recall what I have studied by playing the enzyme card & board game by using the CARBGAME as an innovative gamification tool.	56.8	39.6	3.6	0.0	0.0
The enzyme card & board game reinforced my learning through repetition of information in lectures and textbook.	48.6	47.7	3.6	0.0	0.0

(Continues)

TABLE 1 (Continued)

Perceptions	Strongly agree (%)	Agree (%)	Neither agree nor disagree (%)	Disagree (%)	Strongly disagree (%)
Domain 5: assessment & feedback in CARBGAME					
The enzyme card & board game has ensured immediate and effective feedback for learner development.	40.5	55.0	4.5	0.0	0.0
During the enzyme card & board game the player can assess the acquired knowledge or skill with other players.	54.1	45.0	0.9	0.0	0.0
The enzyme card & board game served as a platform to test my knowledge rather than mere representation of facts.	52.3	45.0	1.8	0.9	0.0
Immediate and contextualized feedback is supplied during the enzyme card & board game session.	35.1	55.0	9.0	0.9	0.0
Domain 6: play & learn with peers					
The enzyme card & board game has improved my social interaction skills.	54.1	37.8	6.3	0.9	0.9
The competition in the enzyme card & board game has encouraged me to perform better.	53.2	39.6	5.4	1.8	0.0
The enzyme card & board game has facilitated collaborative learning.	54.1	44.1	1.8	0.0	0.0
During the enzyme card & board game players are gradually challenged because they cannot move freely among the game levels.	36.9	49.5	10.8	2.7	0.0
Solving the enzyme card & board game required integration of knowledge and skills from all types of learners.	53.2	42.3	4.5	0.0	0.0
Completing the enzyme card & board game using CARBGAME as an innovative gamification tool has created satisfaction and sense of accomplishment in me.	55.0	41.4	2.7	0.9	0.0

Abbreviation: CARBGAME, CARd & Board GAMES in Medical Education.

experiential (97.2%) and meaningful (99.1%). It facilitated the transfer of learning to real-world contexts (95.4%) and offered immediate feedback for development (95.5%). The tool's collaborative aspects were evident in both self-assessment (97.3%), peer assessment (99.1%) and social interaction (91.9%), promoting healthy competition (92.8%) and a sense of accomplishment (96.4%). Overall, the CARBGAME gamification tool demonstrated its value in enhancing the enzymology learning experience through engagement, motivation, and collaborative learning opportunities. Table 1 provides a detailed representation of students' perceptions towards CARBGAME for clinical enzymology. Tables 2 and 3 show the feedback rating and qualitative responses from students and faculty towards the effectiveness of CARBGAME for clinical enzymology.

Furthermore, the comparative analysis of the subsequent internal assessment scores of the present batch of students implemented with CARBGAME and the

previous batch of students who followed traditional teaching on the same topic revealed a statistically significant improvement in academic performance of the intervention group compared with control group. The overall scores for internal assessment was 100 which included long answer questions, short answer questions and multiple choice questions. The mean score of the non-intervention batch of students was 52.12 ± 4.6 and for the intervention batch, it improved to 67.30 ± 5.4 with a *p*-value of 0.0001. Both the internal assessment question papers were reviewed for same level of difficulty and diversity in questions to ensure a fair comparison.

4 | DISCUSSION

This study assessed the impact of the CARBGAME innovation on clinical enzymology among first-year medical students. Notably, the game exhibited a significant

TABLE 2 Students' feedback – CARBGAME – Clinical Enzymology.

Feedback item	Rating									
	1	2	3	4	5	6	7	8	9	10
How helpful was the CARBGAME gamification tool in terms of development of critical thinking in clinical enzymology?	0%	0%	0%	0.93%	3.74%	2.80%	6.54%	12.15%	18.69%	55.14%
How helpful was the CARBGAME gamification tool in terms of future application of knowledge in clinical enzymology?	0%	0%	0%	0.93%	0.93%	2.80%	13.08%	11.21%	16.82%	54.21%
How helpful was the CARBGAME gamification tool in terms of sharing knowledge related to clinical enzymology in your group?	0%	0.94%	0%	0%	0%	1.89%	9.43%	16.04%	14.15%	57.55%
How helpful was the CARBGAME gamification tool in terms of self-assessment of your learning gaps in clinical enzymology?	0.93%	0%	0%	0%	0%	1.87%	10.28%	10.28%	18.69%	57.94%
How helpful was the CARBGAME gamification tool in terms of arousing interest in active learning of clinical enzymology?	0%	0.94%	0%	0%	0%	0.94%	6.60%	8.49%	15.09%	67.92%

Abbreviation: CARBGAME, CARd & Board GAMES in Medical Education.

TABLE 3 Feedback from students and faculties towards CARBGAME—clinical enzymology.

Students' responses	Faculty responses
"I thoroughly enjoyed playing CARBGAME" "Never knew learning could be made this interesting" "CARBGAME is most useful to learn easily evaporating concepts" "Enzymology was hard initially but now it is very interesting" "It has so much clinical applications that makes CARBGAME very special" "While learning with CARBGAME you don't get burdened" "If CARBGAME was not there, enzymology would have been so dry and difficult to learn"	"CARBAGME is a new method that I have encountered. It is certainly one of the most creative ways to enhance learning" "CARBGAME innovation in biochemistry is a very effective and impactful learning tool" "Even I have faced difficulty in studying enzymology chapter, but CARBGAME seems to ease the learning process" "CARBGAME for clinical enzymology is certainly an innovative and highly effective tool to learn biochemistry" "CARBGAME has served its purpose of engaging students into active learning of clinical enzymology which they would have not done in traditional classroom or using textbooks"

Abbreviation: CARBGAME, CARd & Board GAMES in Medical Education.

improvement in knowledge levels and received favorable feedback for its customized gameplay, motivational aspects, and collaborative learning features. The game's

ability to enhance enzymology education through active engagement, critical thinking, and interest towards learning in a non-threatening environment were apparent.

CARBGAME for clinical enzymology has significantly improved the knowledge of students with a *p*-value of 0.0001 in assessments comparing performances before and after the game as well as between intervention and control group. Thus, CARBGAME supports the assertion that games are effective pedagogical tools to enhance knowledge. These findings are similar to a board game innovation in physiology education, which demonstrated that when compared with instructional methods learning was dramatically improved while using a stimulating board game about the physiology of muscle function.⁹ Also, the key features of CARBGAME innovation was its ability to enhance memory and promote interest, curiosity and creativity while learning. All these are supported by gaming innovations in medical education, which stated that fun-filled educational games serve as an effective teaching and learning tool for anatomy and physiology by encouraging significant learning as well as creativity, attention, and memory, among students.^{10,11}

Another striking feature of CARBGAME for clinical enzymology is that 99.1% of the learners have agreed that the game created an engaging learning environment and it was a good opportunity for peer assessment. Engaging learning environments have been linked to improved student motivation, retention, and overall learning

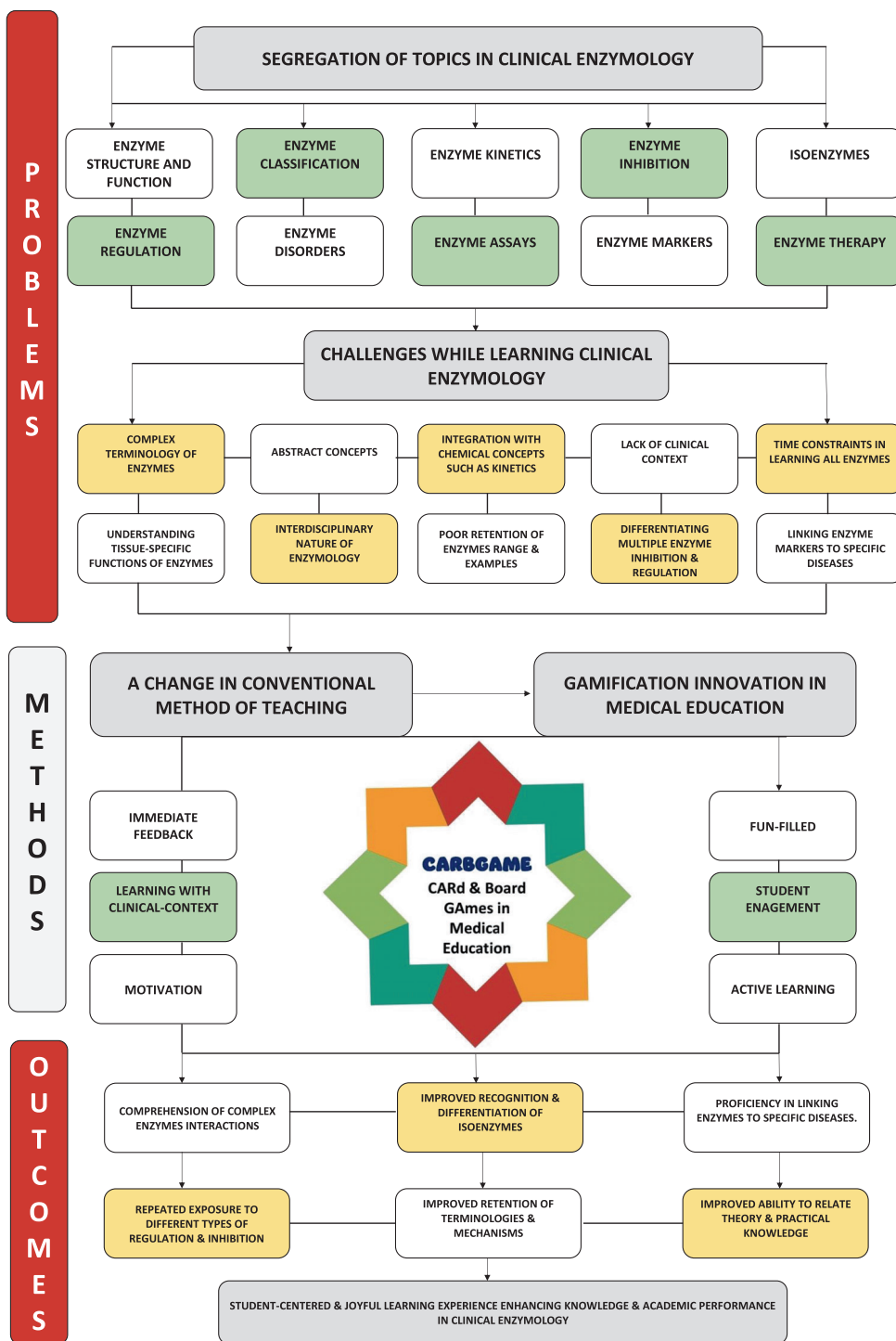


FIGURE 2 The conceptual framework for CARBGAME—clinical enzymology. Conceptual framework describing the problems in learning clinical enzymology and proposing CARBGAME as effective method to overcome the challenges and attain the outcomes. CARBGAME, CARd & Board Games in Medical Education.

outcomes.¹² According to educational literature, when learners find educational experiences engaging, they are more likely to actively participate, which fosters deeper understanding and retention of concepts.^{13,14} Moreover, incorporating peer assessment aligns with contemporary pedagogical trends that emphasize collaborative and interactive learning.^{15,16} Research has shown that peer assessment not only enhances critical thinking and communication skills but also provides learners with diverse

perspectives and feedback, enriching the learning experience.^{17,18} This alignment is further supported by studies indicating that peer assessment promotes self-regulated learning and the development of metacognitive skills.^{19,20}

Many gamification and game-based innovations have been introduced in medical education.²¹ They provide an interactive platform to grasp complex concepts, making abstract topics more tangible. Through gamification, learners engage actively, fostering deeper

understanding and knowledge retention.^{22,23} These principles have also been optimally proven in this CARBGAME innovation. Particularly in biochemistry, where students often feel overwhelmed by numerous terminologies and complex metabolic pathways, the introduction of games has significantly aroused interest towards learning and enhanced students' performance. Aligning with the findings of this study, numerous game-based innovations in biochemistry also emphasize that implementing games in biochemistry education serves as a powerful tool to conquer complexity, engage learners, and bridge the gap between theory and real-world applications.^{24–27} However, this innovation is unique in its design of combining both cards and board in a creative manner offering a realistic gaming platform for students to effectively collaborate and learn.

4.1 | CARBGAME—Future directions

Looking ahead, the success of CARBGAME opens avenues for further innovation in medical education. Future directions may involve the development of a broader range of educational games and interactive tools that address various medical disciplines, catering to diverse learning styles. Additionally, incorporating artificial intelligence and virtual reality technologies could provide even more immersive and realistic learning experiences. As educators continue to explore novel approaches inspired by CARBGAME's achievements, a dynamic and adaptable medical education landscape could emerge, better preparing students to navigate the challenges of healthcare with competence and confidence.

4.2 | Limitations of the study

This study is subjected to certain limitations. The innovation was implemented for first-year medical students only from one institution. Thus, before extrapolating these results to a wider audience, it is important to verify the results of this innovation with larger groups of students.

4.3 | Conceptual framework

Figure 2 presents a conceptual framework outlining prevalent issues linked with traditional teaching approaches in learning clinical enzymology. To address these concerns, CARBGAME—an approach that employs CARD & Board Games in Medical Education was introduced. This innovative solution aims to mitigate these challenges and

deepen students' understanding of clinical enzymology concepts in biochemistry. Furthermore, it facilitates the practical application of acquired knowledge within clinical scenarios for better understanding and academic performance.

5 | CONCLUSION

CARBGAME's undeniable success in enhancing active learning and performance within clinical enzymology highlights its potential to reshape medical education. The enthusiastic response from faculty and students underscores the urgency to introduce innovative components like games into the curriculum, creating a more engaging and meaningful learning experience. This achievement serves as a compelling call to adapt and evolve, fostering a dynamic educational landscape that equips future healthcare professionals with the skills and enthusiasm needed to excel in their field.

AUTHOR CONTRIBUTIONS

K. M. S.: Conceptualization; methodology; software; validation; formal analysis; investigation; resources; data curation; writing—original draft preparation; writing—review and editing; visualization; supervision; project administration.

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CONFLICT OF INTEREST STATEMENT

The author declares no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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