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Perception and effectiveness of a mechanistic approach to teaching metabolic cycles: A quantitative study among first-year MBBS students

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Abstract: *Background:* Metabolic cycles are a foundational but often challenging topic for novice medical students, frequently leading to reliance on rote memorization. Understanding the enzymatic and chemical basis (the "mechanistic approach") may improve comprehension and retention. *Objectives:* This study aimed to evaluate the perception and measure the potential immediate effectiveness of introducing a mechanistic teaching method (focused on enzymology, coenzymes, and chemical structure) for complex metabolic cycles among recently joined first-year MBBS students. *Methods:* This was a cross-sectional, quantitative questionnaire study with a supplementary qualitative component, conducted among n=141 first-year MBBS students using a 5-point Likert scale survey immediately after a mechanistic intervention lecture. *Result:* The mean scores for perceived difficulty ($\bar{x}_a$=3.64) and perceived effectiveness were ($\bar{x}_b$=3.63) moderate and nearly identical. The correlation between difficulty and effectiveness was statistically insignificant (r =-0.06). Qualitative comments reinforced the perceived benefit of structure and mnemonics (OTHLIL). *Conclusion:* The mechanistic approach to teaching metabolic cycles was positively perceived by first-year MBBS students. The method, by focusing on enzymology, chemistry, and coenzyme roles, appears to offer a promising, accessible alternative to enhance student learning in biochemistry.
Keywords: Biochemistry Education, Teaching Methods, Metabolic Pathways, Enzymes, Medical Students.

Introduction

Metabolic cycles, such as the urea cycle, glycolysis, and the tricarboxylic acid (TCA) cycle, form the foundational core of medical biochemistry. An in-depth understanding of these pathways is essential for grasping their integration, regulation, and subsequent application to clinical pathology and therapeutics [1-2]. However, novice medical students often perceive biochemistry, especially the intricate metabolic pathways, as one of the most challenging subjects in the preclinical curriculum [3-4].

The sheer number of substrates, products, and enzymes involved imposes a significant cognitive load, frequently leading students to rely on rote memorization for examination success [3, 5]. This superficial learning strategy often results in poor long-term retention and an inability to apply the knowledge in clinical contexts [3, 6].

The traditional didactic method of teaching metabolic pathways often prioritizes the simple flow of metabolites, inadvertently promoting a memorization-based approach over genuine conceptual understanding. To ensure students develop a deep, transferable understanding a mechanistic understanding it is crucial to explicitly link the steps of the pathway to the fundamental principles of enzymology (the 'how' of the reaction) and chemistry (the 'why' of the reaction) [7]. Assessing the educational value of this alternative pedagogical approach is necessary to inform curriculum design in medical education.

The mechanistic, enzyme-focused teaching approach will be positively perceived by the students, resulting in a high mean score for perceived study effectiveness ('b') despite a moderate to high initial perception of difficulty ('a'), indicating that the new method is viewed as a clear solution to the challenge of learning the pathways. The challenges in teaching and learning biochemistry are well-documented [3, 4]. Cognitive Load Theory suggests that the complex, interconnected nature of metabolic networks places a high demand on working memory, making it difficult for students to build coherent schemas. Effective pedagogical methods in biochemistry increasingly advocate for systems thinking and mechanistic reasoning over simple fact recall [8].

Understanding enzymology and coenzymes is highlighted as the crucial linking idea for mastering metabolism [9-11]. Enzymes, classified by the nature of the reaction they catalyze (e.g., OTHLIL classification), provide a predictable framework for understanding the chemical transformation at each step of a metabolic pathway. Furthermore, coenzymes, often derived from B-complex vitamins, act as essential carriers of functional groups or electrons, providing a crucial clinical correlation for the biochemical steps [9-10]. The need for detailed, specialized pedagogical approaches is not limited to basic principles; it extends to specific sub-domains, as demonstrated by studies that examine specialized educational strategies for teaching complex topics like metabolic profiles under varied physiological conditions [12].

This focus on specialized instructional design underscores the general academic movement toward methods that promote functional, applied knowledge. Active learning strategies, such as role-play and computer simulations [13], which promote this conceptual, integrated, and systems-driven understanding, have shown improved learning outcomes compared to traditional lectures [8,14-15]. Studies focusing on innovative strategies, such as use of Case-Based Learning (CBL), have also been employed to improve analytical thinking in MBBS students [16]. This study builds upon this literature by quantifying the immediate student perception of a direct, explicit mechanistic teaching intervention in an Indian medical college setting.

Aim: To evaluate first-year MBBS students' perceptions regarding the difficulty of learning complex metabolic pathways using conventional study methods and the perceived immediate effectiveness of a mechanistic teaching approach.

Objectives:

1. To assess students' perceived difficulty in learning complex metabolic pathways using conventional study methods.
2. To evaluate the perceived immediate effectiveness of a mechanistic teaching approach focusing on enzymology, coenzymes, and chemical principles.
3. To examine the relationship between perceived difficulty and perceived effectiveness of the teaching approach.
4. To explore qualitative student feedback on the perceived benefits of mechanistic learning strategies.

Material and Methods

Study Design and Setting: This was a descriptive, cross-sectional, quantitative questionnaire based study with a supplementary qualitative component (free-text comments).

Setting: Department of Biochemistry, Al-Ameen Medical College, Vijayapura.

Study Period: The study was conducted during the initial orientation phase for the first-year MBBS students (October-November 2024).

Participants: The actual sample size (n) was 141 students (94% response rate).

Ethical Approval and Consent: A brief synopsis and the proposed study were submitted to and reviewed by the Institutional Ethics Committee (IEC) of Alameen Medical College, Vijayapura. Informed written consent was taken from all participating students prior to the distribution of the survey, ensuring voluntary participation and anonymity of responses.

Sample Size Calculation: The study population (N) consisted of 150 first-year MBBS students. As this was a descriptive cross-sectional study aiming to estimate the prevalence or perception of an effect, the sample size was calculated using the formula for finite populations. The initial minimum sample size required for an infinite population (n_o) was calculated using the formula:

$$n_o = \frac{Z^2 x\ p(1-p)}{e^2}$$

Where: Z = 1.96 (for a 95% Confidence Level), p = 0.50, and e = 0.04.

$$n_o = \frac{(1.96)^2 \text{ x } 0.5(0.5)}{(0.04)^2} = 600.25$$

This n_o is then adjusted using the Finite Population Correction (FPC) formula:

$$n = \frac{n_o}{1 + (n_o - 1) / N}$$

$$n = \frac{600.25}{1 + (600.25-1)/150} = 120.17$$

The calculated minimum required sample size was n=121. The actual sample size achieved (n=141) significantly exceeds the calculated minimum required sample size, maximizing the statistical power and internal validity for the study cohort (a near-census participation of 94%).

Inclusion Criteria:

1. Currently enrolled first-year MBBS student at Al-Ameen Medical College.
2. Attended the specific teaching session on metabolic cycles using the mechanistic approach.
3. Provided informed written consent to participate in the immediate post-session survey.

Exclusion Criteria:

1. Students not attending the intervention session.
2. Students unwilling to provide consent.
3. Students with incomplete survey data.

Teaching Intervention and Data Collection Procedure: The intervention was a 40-minute Class-Conducted (CC) lecture delivered by the principal author in a standard lecture hall setting.

1. *Preparation of Teaching Material (Power Point Class):* The presentation focused on Enzyme Classification (OTHLIL), Coenzyme/ Vitamin Roles (e.g., B-complex vitamins), and Chemical Structures, explicitly linking these mechanistic components to the steps of the metabolic cycles (e.g., Urea cycle, Glycine metabolism).
2. *Instruction Delivery:* The session emphasized looking for the enzyme class and the coenzyme/vitamin at each reaction step, presenting the concept as a'key' (enzymology) to 'unlock' the complex 'door' (metabolic cycle).
3. *Post-Class Survey Administration:* Immediately after the session, hard-copy questionnaires were administered.

Data Collection Instrument: A structured survey was used, consisting of two core, self-developed items scored on a 5-point Likert Scale (1 = Strongly Disagree/Very Poor to 5 = Strongly Agree/Very Good), based on the method described by Likert [17].

- *Item 'a' (Perceived Difficulty):* "Learning and memorizing metabolic pathways is difficult." (Gauged baseline perceived challenge).
- *Item 'b' (Perceived Effectiveness):* "My current study methods are effective for learning metabolic pathways, especially after this mechanistic session." (Measured immediate perceived efficacy of the new approach).
- The survey also included space for free-text qualitative comments.

Data Analysis: Statistical analysis was performed using SPSS statistical software (IBM SPSS Statistics version 28, IBM Corp., Armonk, NY, USA,). A significance level of $p<0.05$ was established.

1. *Descriptive Statistics:* Mean ($\bar{x}$) Median, Mode, and Standard Deviation (σ) were calculated for the Likert scale responses.
2. *Inferential Statistics:* A Pearson correlation coefficient (r) analysis was performed to assess the linear relationship between perceived difficulty ('a') and perceived effectiveness ('b').
3. *Qualitative Analysis:* Free-text responses were transcribed, reviewed, and categorized to interpret the specific benefits perceived by students.

Results

Data were collected from a total of 141 first-year MBBS students, representing a response rate of 94%. All 141 students who attended the mechanistic teaching session completed the questionnaire and were included in the final analysis. No incomplete responses were recorded.

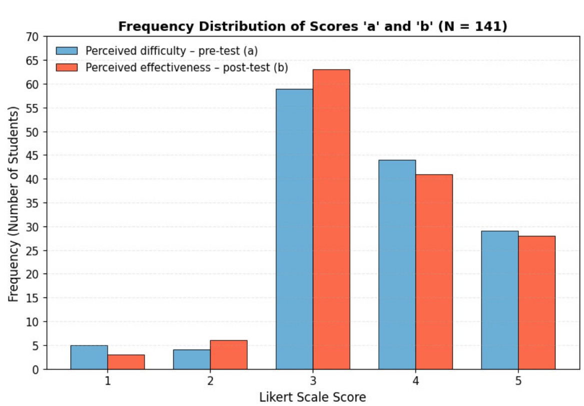
Descriptive Statistics: The descriptive statistics for perceived difficulty (score 'a') and perceived effectiveness (score 'b') are presented in Table 1.

Table-1: Summary of Descriptive Statistics (N=141)

Statistic	Score 'a' (Perceived Difficulty)	Score 'b' (Perceived Efficacy)
Count (N)	141	141
Mean ($\bar{x}$)	3.64	3.63
Median	4.00	4.00
Mode	3	3
Standard Deviation(σ)	1.05	1.03
Minimum Score	1	1
Maximum Score	5	5

The mean perceived difficulty score was 3.64, while the mean perceived effectiveness score was 3.63. The median score for both variables was 4.00, and the mode was 3. The standard deviation was 1.05 for perceived difficulty and 1.03 for perceived effectiveness, indicating moderate variability in student responses.

Fig-1: Showing the frequency distribution of scores 'a' and 'b' among first-year MBBS students (N = 141). Score 'a' represents perceived difficulty and score 'b' represents perceived effectiveness.



As shown in Figure 1, the majority of students selected Likert scale scores of 3 and 4 for both perceived difficulty and perceived effectiveness, while comparatively fewer responses were observed at the lower end of the scale.

Correlation Analysis: Pearson's correlation analysis was performed to assess the relationship between perceived difficulty and perceived effectiveness.

Table-2: Correlation Analysis (Scores 'a' vs. Scores 'b')

Measure	Value	Interpretation
Correlation Coefficient (r)	= -0.06	Very Weak Negative Correlation
Coefficient of Determination (r^2)	= 0.0036	Only 0.36% of the variance in efficacy ('b') is explained by difficulty ('a').

The correlation coefficient (r) was –0.06, indicating a very weak negative correlation between the two variables. The coefficient of determination (r^2) was 0.0036, showing that less than 1% of the variance in perceived effectiveness was explained by perceived difficulty. The correlation was not statistically significant (Table-2).

Fig-2: Scatter plot showing the relationship between perceived difficulty (score 'a') and perceived effectiveness (score 'b') among first-year MBBS students (N = 141).

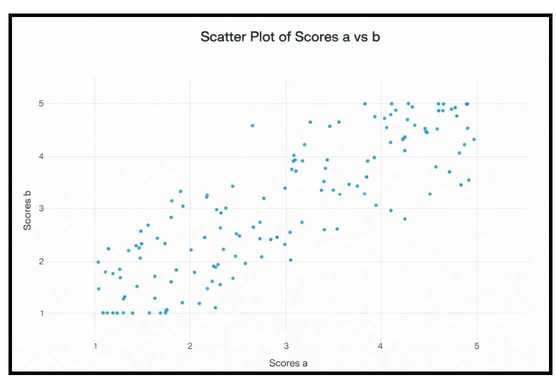


Figure 2 shows the scatter plot illustrating the relationship between perceived difficulty (score 'a') and perceived effectiveness (score 'b') among first-year MBBS students (N =

141). The distribution of data points does not demonstrate a clear linear trend, indicating minimal association between the two variables. Pearson's correlation analysis revealed a very weak negative correlation between perceived difficulty and perceived effectiveness ($r = -0.06$), which was not statistically significant. This suggests that students' perceived effectiveness of the learning method was largely independent of the level of difficulty they reported.

Qualitative Comments: The analysis of free-text comments provided specific insights:

- *Clarity and Structure:* Students reported improved clarity and organization in learning, with comments such as *"Got an idea how to study metabolic pathways"* and *"Finally understood the logic behind the steps, not just the names"*.
- *Aids to Memorization:* Several students highlighted the usefulness of mnemonics, noting that *"With mnemonics, it was quite easier to remember"* (referencing OTHLIL).
- *Integration of Concepts:* Students emphasized the benefit of integrating enzymology with related topics, as reflected in comments such as *"Integration of enzymology, vitamins, and minerals helped facilitate deeper conceptual understanding"*.

Discussion

The present study explored first-year MBBS students' perceptions of a mechanistic approach to learning complex metabolic pathways. Although metabolic pathways were generally perceived as difficult, students reported a favourable perception regarding the effectiveness of the mechanistic teaching approach. This indicates that perceived difficulty did not act as a barrier to recognizing the educational value of instruction that emphasized enzymatic logic, coenzyme involvement, and underlying chemical principles.

The absence of a statistically significant correlation between perceived difficulty and perceived effectiveness suggests that students' appraisal of the teaching method was largely independent of the level of challenge they experienced. Such an observation can be interpreted in the context of instructional approaches that emphasize structured organization of complex information and schema-based learning, which may support learners in managing cognitively demanding content more effectively [8-9].

Qualitative feedback further reinforced these findings. Students frequently reported improved conceptual clarity, better organization of information, and enhanced recall when metabolic pathways were taught using mechanistic explanations, enzymology-based mnemonics, and explicit cognitive strategies. These learner responses are consistent with pedagogical approaches that emphasize structured understanding, use of cognitive strategies, and meaningful learning in biochemistry education [18-19].

Overall, the findings highlight the importance of instructional design in shaping student learning experiences in conceptually demanding areas such as metabolic biochemistry. A mechanistic, enzyme-focused teaching approach appears to facilitate meaningful learning even when students perceive the subject matter as challenging.

Conclusion

In conclusion, this study demonstrates that a mechanistic approach to teaching metabolic cycles is perceived as effective by first-year MBBS students, despite the inherent difficulty of the subject. By focusing on enzymology, coenzyme chemistry, and reaction logic, the approach aligns with the study aim of improving conceptual understanding of metabolic pathways. These findings suggest that mechanistic teaching strategies may offer a useful alternative to traditional memorization based methods in undergraduate medical biochemistry education.

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