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Original Article

Biochemistry Section

Graph Constructors vs Graph Interpretors vs Non Graphers: A Search towards Better Cognitive Performers in Biochemistry among First Year Medical Undergraduates

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ABSTRACT

Introduction: Didactic lectures for medical undergraduates are usually presented with more text based factual contents with less room for visual representation. They contribute less for improved cognitive performance. Graphs are visually appealing for presentation of data and are a common means to illustrate data relationships. Graph literacy involves both graph creation and graph interpretation, benefits of which might well contribute to better cognitive performance.

Aim: To compare the cognitive performance of graph interpretors, graph creators and non graphers in biochemistry among 1st year medical undergraduates.

Materials and Methods: A Medical educational study with an analytical cross-sectional design was conducted during February 2023-March 2023. Total 150 students of both gender aged between 17-21 years, were included and divided equally with 50 subjects in each group (group I (non graphers), group II (graph creators), group III (graph interpretors). Lecture discussion was conducted on the topic of enzyme activity using textual contents for group I, Graph creation based teaching for group II and Graph interpretation based teaching for group III. Prior to lectures, priming session on graphing literacy using four stepped 20 point rubric based teaching was conducted for group II and III. Cognitive performance assessment was done at both lower and higher cognitive domain levels for all three groups. The scores obtained were analysed using one-way Analysis of Variance (ANOVA) and Chi-square test as tests for significance and odds ratio by logistic regression as test for outcome association.

Results: The mean age of the participants were 17.82±0.873 years for group I, 17.78±0.954 years for group II, 17.70±0.814 years for group III, along with gender ratio (female:male) distributed at 1.9:1, 1.7:1, 1.9:1 for group I, II and III, respectively. The results of the present study showed that the graphers {group II (graph creators) (12.24±1.02) and group III (graph interpretors) (11.06±1.03)} had significantly higher total cognitive performance scores compared to non graphers (group I) (9.34±1.64). Though the logistic regression model for graphing exposure to improved cognitive performance outcome showed no significant association with total cognitive performance, but statistically significant association was found at higher cognitive domain performance scores with positive B (2.819) (slope of regression coefficient) and odds of occurrence for higher cognitive performance increased by 16.75 times on graphing exposure when compared to non graphers.

Conclusion: The study concluded that graphs are superior over textual contents and graph creation is marginally but superior to graph interpretation in terms of comprehension and improving performance especially at higher cognitive levels.

Keywords: Eye gazing phenomenon, Rubric based teaching, Visual comprehension

INTRODUCTION

Didactic lectures for medical undergraduates are usually presented with more text based factual contents and with less room for visual representation. They do make students to grasp concepts, but rarely touch upon the evaluation and creation aspects of cognitive domain [1]. So there is always a constant search towards visual representation of textual contents. It not only draws attention but also has the potential to improve cognitive performance levels [1].

Graphs are visually appealing for presentation of data and are a common means to illustrate data relationships [2]. It makes easy for the learner to track trends of those data especially when they change over a time period [3]. Additionally, it provides opportunity towards pattern detection, draw conclusions, compare and contrast different influences, evaluate significances and even provide recommendations towards the data content. All these benefits slither through higher cognition levels with ease. Though commonly used in medical arena [4], graphs are still underutilised as a teaching learning strategy in medical schools.

Literacy towards graphing among individuals has been shown to generate more accurate interpretations [5]. Graphing literacy involves two different yet interconnected aspects of graph creation at one end and graph interpretation at other end of a continuous spectrum. In current scenario, only interpretation is being taught when any graph pops up in medical education, and that too most often is an incomplete teaching learning session. This should be no surprise, as both the expertise of medical teachers and prior knowledge of medical undergraduates towards graphing literacy is less [6].

To the author's knowledge, no research studies exist relating the comparative influence of graph creation and graph interpretation towards cognitive performance among medical undergraduates. On a tough note, even studies on graphing notably become rare in medical literature as graphs are still mythically considered as a distinct mathematical section. This drives the justification towards the basis and the need for the present study. The Study was designed to test the Null Hypothesis (H_0) statement that the graphing lecture has no role in improving the cognitive performance. While the cognitive performance getting improved after graphing lectures, being the Alternate Hypothesis (H_a) statement. The study was aimed at comparing the cognitive performance of graph interpretors, graph creators and non graphers in biochemistry among 1st year medical undergraduates.

MATERIALS AND METHODS

This medical educational study with analytical cross-sectional design was conducted during February 2023-March 2023 in the Department of Biochemistry, Melmaruvathur Adhiparasakthi Institute of Medical Sciences and Research, Melmaruvathur, Tamil Nadu, India. Study was approved by the Ethics Committee of the institute {Ref No. :MAPIMS/IEC/52/2023} and informed consent from all study participants were obtained before actual conduct of the study.

Inclusion criteria: All Phase-I Medical undergraduates of the institute aged between 17-21 years, irrespective of gender were included in the study.

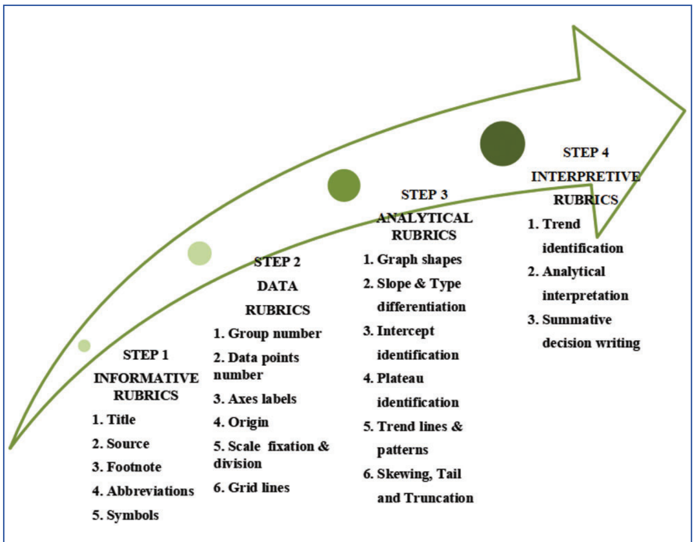
Exclusion criteria: Phase-I Medical undergraduates who were unwilling to participate in the study were excluded from the study.

Sample size calculation: The study involves three groups with group I involving non graphers, group II involving graph creators and group III involving graph interpretors. The total participant number was 150 with 50 participants being allocated into each group based on simple random sampling.

Data Collection

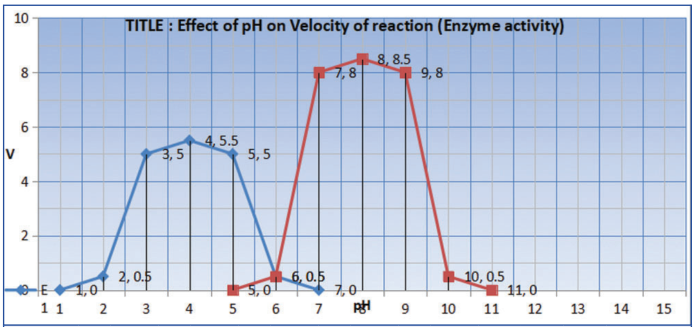
Lecture session: The lecture session was conducted on the biochemistry topic of Enzyme activity for one hour duration on the same day by three different lecturers for each group. Addressing the effect of possible lecturer variation bias, the basic contents for the lecture delivery were made similar using standard reference text book [7] as per group allocation needs. The session objectives included were the role of seven different factors at varying concentrations affecting enzyme action involving textual and graphical contents depending on the groups. The factors included were substrate concentration, enzyme concentration, product concentration, pH of the medium, temperature of the medium, enzyme activators and enzyme inhibitors.

There was a 20 minute priming session on graphing literacy for group II (graph creators) through steps of graph creation and for group III (graph interpretors) through steps of graph interpretation. The priming session involves four stepped (informative, data, analytical, interpretive) 20 point rubric based teaching as depicted in [Table/Fig-1] on various aspects of graph attributes, designed specifically for this study based on the previous study by Angra A and Gardner SM [8]. The various attributes includes graph types, quadrant definition, graph titling, graph footnote, graph abbreviations, symbols, cartesian coordinate, abscissa, ordinates, labels, label scales, origin, grid lines, data source, group number, data points number, slope and types, pattern shapes, plateauing, intercept, trend lines and patterns, skew, tail and truncation. There was no priming session related to graphing for group I (non graphers).



[Table/Fig-1]: Four stepped 20 point rubric based graphing content protocol (used for discussion during priming session on graphing literacy for group II and III).

The priming session was followed by 20 minute content delivery which involved text based powerpoint presentation on the topic for group I (non graphers), graph creation on the topic using graph coordinates based on 20 point graph rubrics discussed on individual factors for group II (graph creators), graph interpretation on the topic using 20 point rubrics based stepped interpretation from a given graph as depicted in [Table/Fig-2] on individual factors for group III (graph interpretors).



Data points table (pH, Velocity) for E1 and E2															
pH	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
E 1 (V)	0	0.5	5	5.5	5	0.5	0	-	-	-	-	-	-	-	-
E 2 (V)	-	-	-	-	0	0.5	8	8.5	8	0.5	0	-	-	-	-

[Table/Fig-2]: A model graph with all attributes used for interpretation showing effect of pH on enzyme activity at varying concentrations.
pH Graph: Groups: E1 (Enzyme1): Blue colour coded; E2 (Enzyme2): Red colour coded; Axes labels: X axis: pH of medium (no unit); Y axis: V (Velocity of reaction expressed in U (µmol/min)); Data labels (pH, Velocity) with drop lines: Black colour coded; Scale division: X axis: pH (1 Gridline: 1 unit pH) Y axis: V (1 Gridline: 2 µmol/min); Major Gridlines (both horizontal and vertical) are in bold

Assessment: Assessment was done immediately after the sessions for all three groups by Multiple Choice Questions (MCQs). Questionnaire included 14 questions on the topic (seven MCQs were on lower cognitive domain levels (remember, understand, apply) [1] and seven MCQs were on higher cognitive domain levels (analyse, evaluate, create)) [1] prepared using standard reference textbook [7] by subject experts. The questionnaire relevance for the appropriateness of the questions in differentiating lower and higher cognitive domain levels on a scale (0-irrelevant to 10-highly relevant) was validated for content appropriateness using validity framework [9] by individual subject experts of the institution. Reliability analysis for relevance using Cronbach's Alpha=0.728 {95% CI (0.173-0.968)} were good and acceptable. Assessment scoring involves the total attainable maximum cognitive score at 14 (with seven maximum for both lower and higher cognitive domain scores). Scoring outcome was defined with >50% score being considered as pass and <50% score being considered as fail at all cognitive domain levels.

STATISTICAL ANALYSIS

The data were tabulated and analysed using Chi-square test, one-way ANOVA as tests for significance and logistic regression model for odds ratio calculation through statistical software Statistical Package for the Social Sciences (SPSS) version 18.0.

RESULTS

In the present study, female participants outnumbered male participants however gender ratio distribution showed no significant difference among all the three groups as shown in [Table/Fig-3].

Among all the three groups, graph creators (group II) scored highest mean total cognitive score (12.24±1.02), graph interpretors (group III) scored lesser (11.06±1.03) than them, followed by non graphers (group I) who scored lowest mean total cognitive score (9.34±1.64), with statistically significant difference noted among them as shown in [Table/Fig-4].

The logistic regression analysis has not shown any significant association of graphing exposure on improvement in total cognitive performance outcome, although a positive B slope (2.819) was

Demographic characteristic	Group I	Group II	Group III	Test statistics	p-value
Age (years)	17.82±0.873	17.78±0.954	17.70±0.814	F=0.240	0.787 NS
Female {N(%)}	33 (66)	32 (64)	33 (66)	χ^2=0.059	0.971 NS
Male {N(%)]	17(34)	18 (36)	17 (34)		
Sex ratio (Female:Male)	1.9:1	1.7:1	1.9:1		

[Table/Fig-3]: Demographic characteristics of all participating groups {group I (n=50), group II (n=50), group III (n=50)}. p-value ≤0.05 is significant. NS: Not significant. Quantitative variables between three groups were compared using one-way ANOVA test (F value) and Qualitative variables using Pearson Chi-square test (χ^2).

Scores	Group I (non graphers)	Group II (graph creators)	Group III (graph interpretors)	F statistic*	p-value
Mean score at lower cognitive domain level (max: 7)	5.10±1.05	6.10±0.83	5.54±0.78	15.46	<0.001†
Mean score at higher cognitive domain level (max: 7)	4.24±1.00	6.14±0.80	5.52±0.70	65.33	<0.001†
Mean total cognitive domain score (max: 14)	9.34±1.64	12.24±1.02	11.06±1.03	65.91	<0.001†

[Table/Fig-4]: Mean cognitive score comparisons of all three groups {group I (Non graphers), group II (graph creators), group III (graph interpretors)} at lower, higher and total cognitive domain levels along with F statistic and p-value.
*F statistic and p-value calculated using one-way ANOVA for three mean comparisons. †: p≤0.05 is considered significant; NS: Not significant

noted with odds of occurrence at improving performance score increased by 16.75 times at higher cognitive domain levels among the participants [Table/Fig-5].

Outcome odds ratio for result (pass/fail)	Variables	Risk estimate				95% Confidence interval	
		B	SE	Sig	Exp (B)	Lower	Upper
For lower cognitive domain scores	Graphing exposure	1.462	1.27	0.250 NS	4.316	0.358	52.023
	Age	-1.116	0.793	0.159 NS	0.328	0.069	1.550
	Sex	-18.456	4827.57	0.997 NS	0.000	0.000	-
For higher cognitive domain scores	Graphing exposure	2.819	1.088	0.010†	16.757	1.988	141.278
	Age	0.326	0.498	0.513 NS	1.386	0.522	3.676
	Sex	0.202	0.786	0.797 NS	1.224	0.262	5.712
For total cognitive domain scores	Graphing exposure	19.208	4019.14	0.996 NS	2.198	0.000	-
	Age	-0.022	0.503	0.965 NS	0.978	0.365	2.622
	Sex	-0.038	0.928	0.967 NS	0.963	0.156	5.933

[Table/Fig-5]: Logistic regresssion model for exposure outcome association between predictor independent variable (graphing exposure, age, gender) and the outcome dependent variable (50% cognitive score) among participants.
B: Regression coefficient; SE: Standard error; Sig: p-value, p≤0.05 is considered significant; Exp (B): Odds ratio; CI: Confidence interval; NS: Not significant; †: OR>1

DISCUSSION

Both the text based and graph based lecture discussions has its own advantages and limitations. The results of the present study has shown that the graphers {group II (12.24±1.02) and group III (11.06±1.03)} had significantly higher total cognitive performance scores compared to non graphers (9.34±1.64). It further adds that significant mean difference was found at both lower and higher cognitive domain performance levels between them. This was in accordance with studies like Huestegge L and Pötzsch TH that showed graphical contents to have faster comprehension with better focus and interpretive accuracy when compared to textual contents and in sharp contrast to studies like Parrott R et al., that proved comprehension superiority to textual contents [10,11].

The reasons for lower cognitive performance among textual contents are multiple and varied. Text based discussions are monotonous, time consuming and not so visually appealing [12]. They are one way top to bottom discussion approach and its retaining accuracy slowly dips with expanding content volume. Inter relationships between the contents fade away with passing time. Furthermore, all initial content memories get lost in the midway when the final contents are to be comprehended with passing time.

On the contrary graphical contents are non monotonous and add visual appeal as a single shot image comprehension. The shapes used in graphs evoke positive affect [13]. They are time saving and has potential for adaptable different approaches including top to bottom, bottom to top, and random screening for possible questions and answers. Addressing the drawback of visual clutter arising from different approaches, the present study has added rubric based conventions to graphing that adds directional linearity to the graphical comprehension in a systematic structured way. Additionally, Inter relationships of the contents are never lost with graphs.

Further, graphs have been shown to be multidimensionally superior to texts including effective content communication, precise conceptual learning, induction of behavioural change among learners along with faster cognitive processing and faster inference making times [14]. The priming session for graphers in the present study might have enhanced the repetition effects on cognitive learning which the non graphers lacked.

Graphing literacy involves two different yet interconnected paths of graph creation and graph interpretation. There is a dearth of research studies in this regard especially in medical field. So the egg and chicken birth debate continues as to which needs to be taught first for medical undergraduates in medical schools.

Among the graphers, the present study has shown more cognitive weightage towards graph creators {group II (12.24±1.02)} who have better cognitive performance scores compared to graph interpretors {group III (11.06±1.03)}. While few studies like Wang ZH et al., lays emphasis more on graph interpretation, there are few other studies like Uzun MS and Nazansezen A laying emphasis on graph creation, supporting the claim of the present study [15,16]. Though the logistic regression model for graphing exposure to improved cognitive performance outcome showed no significant association with total cognitive performance, but statistically significant association was found at higher cognitive domain performance scores with positive B (2.819) (slope of regression coefficient) with odds of occurrence for higher cognitive performance increased by 16.75 times on graphing exposure when compared to non graphers. The justification to this improved cognitive performance claim among graph creators are multifocal each cumulatively adding to better graphical comprehension.

On the data front, graph creators could have better data context in terms of changes over time and meaningful correlations as semiotic path of contents seems to flow like an incremental wave. Whereas graph interpretors have semiotic path of contents downpoured in one shot image as a tide which deny them the ease of flow of data context. These data contexts and semiotic systems have been shown to affect graph comprehension [17]. Being in the process of creation, creators also has additional advantage of ease of translation from absolute to percent scale and better localisation of graph specifiers.

On the image front, graph interpretors are more prone for distraction under visual clutter while creators have to deal with less of it. On the flip side, final images from graph creators group are error prone as they are self-made when compared to error free image among graph interpretors. But the present study has addressed this drawback by making corrections to standardised final images of the learners among graph creators.

On analysis front, the graph rubric based priming session has possibly eliminated the bias from graph schema knowledge for both the groups. But graph creators could have dual visualisations of the contents with both creative and exploratory data visualisations while graph interpretors have only exploratory data visualisations. Furthermore, graph creators are involved in all phases of graph comprehension from visual image creation to conceptual image translation while graph interpretors are focused more on just conceptual image translation.

On an individual front, the internal representation of the graph, its data and so its interpretation involves a complex set of cognitive skills that could certainly differ among different individuals and can be highly biased.

On cognitive domain front, though basic graph rubrics for both graph creators and graph interpreters were similar, graph creators had an opportunity to start from nothing to end up with whole picture while graph interpretors started from whole picture and just decoded it. This makes the creators group acquire more competencies as they touch on cognitive domain peaks of synthesis and creation of new things which includes the various aspects of graph framework, specifiers, shape creation, trend identification and so on.

On neurocognitive front, both the graph creators and graph interpretors recruit multiple senses involvement with eye gazing phenomenon, effect towards the contents [18]. But in addition, graph creators also has the potential to activate multiple neuro circuits of cognition [19] including reading, comprehension, attention, memory, focus, construction, perception, decoding and execution when compared to graph interpretors. All these sums up and puts graph creators on the cognitive performance front runners ahead of others in data comprehension.

Limitation(s)

Technical limitations include lack of crossover influences that were not made between graphers and non graphers, and also between graph constructors and graph interpretors that could have additionally ascertained the inferences of the study.

CONCLUSION(S)

The study concludes that graphs are superior over textual contents and graph creation is marginally but superior to graph interpretation in terms of comprehension and improving performance especially at higher cognitive levels among medical graduates. Graph superiority can be related to its visual appeal, faster comprehension and cognitive processing, high interpretive accuracy and behavioural change effects. Graph creation additionally creates opportunity for gaining multiple competencies and activates multiple neurocognitive circuits. This highlights the importance of inclusion of graphing literacy among teaching learning strategies in medical education. This will strengthen not only students' performance levels but also upgrade teachers graphing expertise too. On a caution note, further studies are needed in future to extrapolate the evidences obtained across all phases and all subjects of medical curriculum.

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