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Original Article

Enhancing our ability to diagnose cardiac valve disease by applying a graphical educational game

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الملخص

أهداف البحث: هدفت هذه الدراسة إلى مقارنة لعبة تعليمية رسومية مصممة حديثا مع تمرين التعلم القائم على الحالة، وتعزيز القدرة على تطبيق معرفة فسيولوجيا دورة القلب لتشخيص أمراض الصمامات القلبية بين طلاب الطب قبل السريري.

طرق البحث: تم توزيع طلاب الطب في السنة الأولى في المرحلة الجامعية بشكل عشوائي إلى مجموعة "اللعبة الرسومية" (العدد = 42) ومجموعة "التعلم القائم على الحالة" (العدد = 37) في هذه الدراسة التدخلية. تضمنت مجموعة "اللعبة الرسومية" تظليل الرسوم البيانية لدورة القلب وحلقات الضغط والحجم بينما عملت مجموعة "التعلم القائم على الحالة" على حالتين من أمراض صمام القلب. تم اختبار الفهم النظري لدورة القلب بواسطة اختبار أسئلة متعددة الخيارات. بعد التعرض لفترة وجيزة لتسمع النفخة على نموذج محاكاة، تم تقييم مهارات تشخيص أمراض صمام القلب لدى المجموعتين باستخدام نموذج المحاكاة. تمت مقارنة متوسط درجات الاختبار النظري ومتوسط الدرجات في اختبار المحاكاة باستخدام تحليل مان ويتني الإحصائي. كما تم الحصول على منظور الطلاب حول "اللعبة الرسومية" وجلسة المحاكاة من خلال استبيان مقياس ليكرت المكون من 5 نقاط.

النتائج: حصلت مجموعة "اللعبة الرسومية" على متوسط درجات أعلى بشكل ملحوظ في الاختبار النظري واختبار المحاكاة مقارنة بالمجموعة الأخرى. وافق 91٪ من الطلاب على أن "اللعبة الرسومية" ساعدتهم على توضيح المفاهيم، ووافق 88٪ على أن المفاهيم التي تم فهمها من خلال "اللعبة الرسومية" ساعدت في تشخيص مرض الصمام على نموذج المحاكاة.

الاستنتاجات: استقبل الطلاب "اللعبة الرسومية" بشكل إيجابي وكان أكثر فائدة من "التعلم القائم على الحالة" في تعزيز تطبيق مفاهيم فسيولوجيا القلب وتحسين القدرة التشخيصية في بيئة إكلينيكية محاكاة.

الكلمات المفتاحية: التسمع؛ القياس التربوي؛ الكفاءة السريرية؛ أمراض صمام القلب؛ طلاب الطب؛ محاكاة

Abstract

Objectives: This study aimed to compare a newly designed graphical educational game (GEG) with a case-based learning (CBL) exercise and to enhance our ability to apply physiological knowledge of the cardiac cycle to diagnose cardiac valvular diseases among preclinical medical students.

Methods: In this interventional study, first-year undergraduate medical students were randomly assigned to a GEG group (n = 42) and a CBL group (n = 37). The GEG group involved shading cardiac cycle graphs and pressure–volume loops while the CBL group worked on two cases of cardiac valve diseases. A multiple-choice question (MCQ) test was then used to assess conceptual understanding of the cardiac cycle. After brief exposure to murmur auscultation on a simulator manikin, the groups were assessed in a simulator manikin test for their ability to diagnose cardiac valve disease. Median MCQ scores and mean scores in the simulator test were then compared using the Mann–Whitney U test. The student's perspectives of the GEG and simulation session were acquired on a 5-point Likert scale questionnaire.

Results: The GEG group had significantly higher median MCQ scores ($p < 0.001$) and mean simulator test scores ($p < 0.001$) when compared to the CBL group. Moreover, 91% of students agreed that the GEG helped them to

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clarify concepts, and 88% agreed that the concepts and knowledge gained through the GEG helped them to diagnose valve disease in the manikins.

Conclusion: The GEG was positively received by students and was more useful than the CBL in enhancing the application of cardiac physiology concepts and improving diagnostic ability in a simulated clinical setting.

Keywords: Application of basic sciences; Diagnosing cardiac valve disease; Game-based learning; Medical education; Simulation

Introduction

Cardiac auscultation is still recognised as a high fidelity and cost-effective method for the diagnosis of cardiac valve diseases.[1] Medical students need to achieve competency in auscultating murmurs and identifying cardiac valve diseases. Previous studies have highlighted the need to improve this ability. Repeated exposure to pre-recorded murmurs on a computer or simulator can lead to improvements in diagnostic ability. The diagnosis of cardiac valve disease is possible if a student understands the dynamic events that occur in a heart with valve disease and correlates it with auscultated murmurs. This is a process-driven approach that had been shown to be superior to the memorisation and pattern recognition approach to diagnosing valve diseases.[1]

Clinical correlation exercises are used to teach students the process-driven approach for clinical problem solving. By experiencing these exercises, students can learn to apply physiological and pathophysiological principles while performing specific clinical tasks. Clinical correlation exercises can enhance conceptual understanding of basic sciences and enhance student performance in clinical sciences.[2−10]

Case-based learning (CBL) is a clinical correlation exercise in which students are guided by facilitators and learn to apply basic science knowledge to authentic clinical scenarios. There is evidence that CBL helps to develop deeper conceptual understanding, analytical thinking, and reflective judgment; these skills are essential for diagnostic reasoning. CBL helps to prepare students for future clinical training.[11−16]

Visualising murmurs within the cardiac cycle improves diagnostic ability by cardiac auscultation.[1,3,9] Educational games provide an engaging illustration of concepts and rely on the learning approach of problem solving through teamwork.[17] Educational games are based on the principles of generality. They work on universal problem-solving principles and come with a predefined set of instructions and learning goals. Graphical educational games (GEGs) create situations that challenge the learner to find solutions that have applications in the real world. GEGs are simple, entertaining, and have a eureka factor.[17] In contrast to CBL, educational games emphasise domain-independent critical thinking and abstract reasoning.[18] Educational games have been used to teach the cardiac cycle and membrane potential changes to preclinical students.[17,19] One previous study used puzzles to improve the recognition of abnormal ECG patterns.[20]

Here, we designed a graphical educational game (GEG) to teach preclinical students how to apply the principles of cardiac cycle physiology to diagnose cardiac valve diseases.[21] This was conceived as an improvisation to a previous CBL activity that was used for the same purpose in an earlier academic year. There is no documented evidence of CBL or GEG being used to improve diagnostic ability for cardiac valve disease.

This study aimed to compare a newly designed GEG with a CBL exercise and to enhance the ability of preclinical medical students to apply physiological knowledge of the cardiac cycle to diagnose cardiac valvular diseases.

Materials and Methods

Setting

This interventional study involved a cohort of first-year undergraduate medical students who had completed six months of preclinical education in anatomy, physiology, and biochemistry. All students had joined medical training after completing their higher secondary education. Prior to intervention, the students received two didactic lectures on cardiac cycle physiology using predefined learning objectives. Students were taught to analyse pressure−volume loops and the factors contributing to turbulent blood flow after which they were briefly introduced to different cardiac valve diseases. During a practical class, students learnt to perform an examination of the cardiovascular system in healthy volunteers. Students were already familiar with the format of CBL as they had undergone CBL sessions in other physiological topics prior to this study. Students had not undergone any clinical rotations until the time the interventions were conducted.

Description of the interventions

Separate groups received GEG and CBL to learn how knowledge of the cardiac cycle could be used to analyse murmurs and diagnose valve diseases. On the day of the intervention, students were randomly assigned to the GEG or CBL groups. Stratified random sampling was used to control for the difference in the baseline internal assessment scores between groups. Each intervention was followed by two types of assessments, a paper based MCQ test and a test on a simulator manikin. A simulation session was carried out prior to the simulator test. The CBL intervention was conducted in small group teaching halls where the seating was modified to facilitate group discussion. For both groups, the GEG MCQ test, simulation manikin exposure, and simulator tests, were conducted in various rooms within the simulation laboratory. All interventions and assessments were completed on the same day.

Each GEG group consisted of four to five students. A faculty instructor was assigned to manage and facilitate each group. Students had to follow specific instructions described in a worksheet. To solve the GEG, the students had to shade cardiac cycle graphs and pressure—volume loops (also presented in the worksheet) using coloured pens. The students had to discuss the tasks with their group members before arriving at a consensus. When a group completed the GEG, one member from the group had to match their worksheet with a standard pre-coloured graph that was available with the facilitator. If there was no match, the rest of the group members would get another chance to solve their mistakes. The first group to achieve a perfect match was judged to be the winner of the task. However, the remaining groups were required to complete the task, and a maximum of 60 min was allotted for the entire session.

The CBL group received a session lasting approximately 60 min. The students were presented with two cases, one of mitral stenosis and the other aortic regurgitation. Each case featured the patient's particulars, presentation, relevant history, physical examination, and investigation findings, including mention of murmur timing. Cases were accompanied by graphs of the normal cardiac cycle and abnormal cycles arising from valve disease. The accompanying questions directed students to infer the valve disease by analysing the abnormal pressure profiles and correlating these with the timing of the murmur mentioned in the case. Although only one type of disease (either stenosis or regurgitation) was presented in each case, the accompanying questions encouraged students to contrast the features seen in the case with the likely features that would be present in the other type of valve disease. Discussion groups consisted of four to five students, each facilitated by a faculty member.

Both types of interventions were designed to help students restructure learned information and to help them use physiological concepts to diagnose valve disease. Students were not allowed to access other learning resources and had no access to the internet.

MCQ test

Individually, students had to answer 8 single best-response questions over a specified duration. The questions were designed to test conceptual knowledge of cardiac cycle physiology in relation to cardiac murmurs and valve diseases. Each correct response was assigned a score of one, with no negative marking.

Simulation session

Prior to the simulator test, students underwent a simulator session where they were taught to auscultate the first and second heart sounds, and palpate the carotid pulse on the manikin. Students also auscultated systolic and diastolic murmurs under the guidance of a faculty instructor. Gaining reasonable proficiency in this clinical skill was essential before receiving the simulator test.

The simulation laboratory has an accommodation capacity of 120 and two manikins were available for training. Students, called in groups of ten, were given 15 min of exposure to simulation. The manikin used was the Laerdal ALS simulator (Medical resources India, Chennai, India).

Assessment with the simulator test

Students had to complete two similar tasks on separate manikins which were operated by different faculty assessors. The two tasks had to be completed within a specified time. In each task, students went through a clinical case of valve disease in which the name of the affected valve (mitral *vs* aortic) was specified. The case description was vague in that a diagnosis would not be possible until the murmur was auscultated on the manikin. The student had to then diagnose the valve condition as stenosis or regurgitation and write the response in an answer sheet. Students were expected to rationalise the responses based on previous learning and articulate them on paper. This was necessary to test the application of physiological principles in making the diagnosis.

The simulator test responses were evaluated by examiners who were not a part of this study and hence were unaware of the student grouping. The assessments were validated by a second evaluator to ensure reliability. Each written response was designated as correct and was given one point only when the appropriate rationalisation accompanied the correct diagnosis. This meant a correct diagnosis but with an incorrect or absent rationalisation did not get a point. Each student would thus get a total score of either zero, one or two, depending on the number of task responses the student got correct.

The timing of the murmur initially mentioned by the student before making the diagnosis was also noted. This was scored separately as zero, 1 or 2 depending on the number of tasks in which the murmur timing was correctly identified.

Feedback

A survey was conducted one week after the intervention using an anonymous online five-point Likert scale questionnaire form consisting of seven items that enquired about the process of GEG and simulation and were administered to the group that took the GEG.

Development of resources for the sessions

The cases used for the CBL, the GEG, the MCQs with simulator test questions, and the feedback form, were designed and curated by three separate groups, each consisting of two faculty members each. All faculty members were subject experts in physiology and had undergone training in the use of simulators. MCQs were chosen from a pool of questions that had previously undergone item analysis and had been validated by faculty. The content created and curated by each group was reviewed and validated by the remaining groups. The same faculty groups facilitated the

GEG and CBL interventions, conducted the MCQ test, and delivered feedback forms.

Statistical analysis

Statistical analyses were performed with SPSS version 19 (IBM Corporation Armonk, NY, USA). The Student's t-test was used to identify baseline differences in academic performance between the two intervention groups. For this, we considered the cumulative score from all continuous assessments conducted in physiology before the current study. The tests include two team-based learning sessions, one theory sessional exam that had MCQ, short- and long-answer questions, and one practical sessional exam which was objectively structured.

For the assessments carried out after the intervention, we calculated median and interquartile ranges for the MCQ scores and mean scores with standard deviation (SD) for the simulator test. The Kolmogorov−Smirnov test showed that the data did not follow a normal distribution. Hence, non-parametric statistics were employed. The Mann−Whitney U test was used to compare the median MCQ scores and the mean scores in the simulator test between two independent groups. A p-value < 0.05 was considered statistically significant.

Results

A total of 79 students, including both genders, participated in this study (Figure 1). The mean age of the participants was 19 years. There were no significant differences between the groups with regards to baseline scores ($p = 0.2$), thus implying that the groups were comparable.

The median scores for the MCQ test in the GEG group were significantly higher (Table 1) than in the CBL group ($p < 0.001$). The GEG group had a significantly higher mean score in the simulator test when compared to the CBL group ($p < 0.001$) when diagnosing valve disease. However, there was significant difference between the two groups with regards to the ability to identify murmur timing ($p = 0.09$) (Table 2).

All 42 students who participated in the GEG (Figure 2) responded to all items in the questionnaire. Approximately 91% of students agreed that the GEG task allowed them to clarify previously learned theoretical concepts relating to cardiac cycle physiology. Most students agreed (88.1%) that the concepts learned through the GEG were applicable for the diagnosis of valve disease; 64.2% believed that they had learned new concepts that they were unaware of before solving the GEG (Table 3).

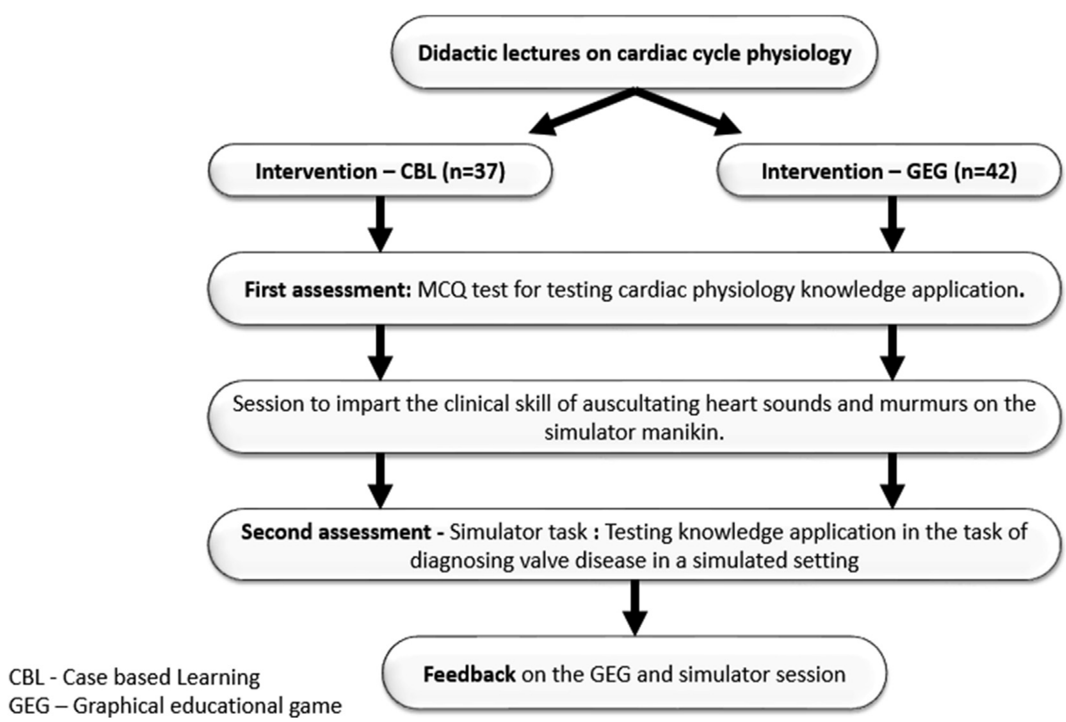
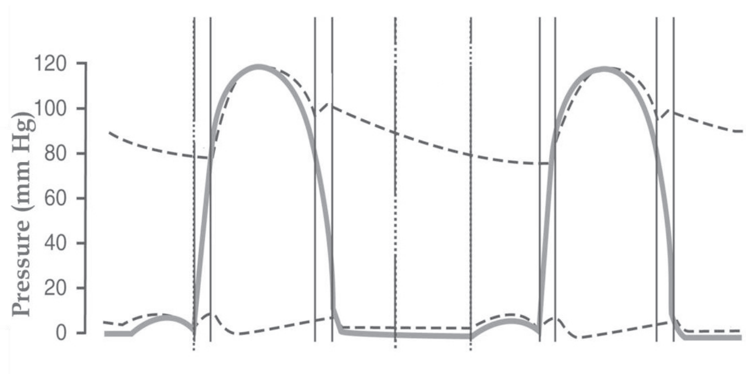


Figure 1: Study design flow chart.

Learning objective: Timing the valve events in a cardiac cycle by analyzing graphs and pressure-volume loops and use this understanding to learn to diagnose 4 specific valve diseases from their respective murmur timings.



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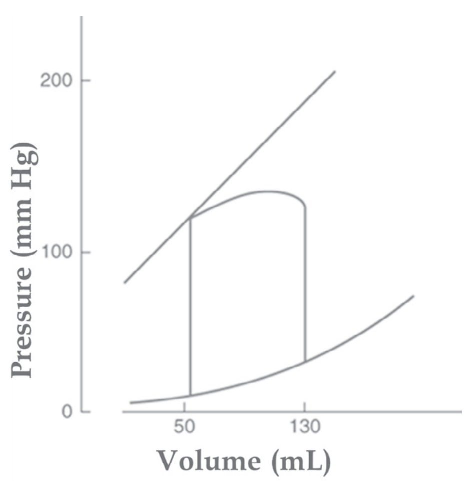

Label the first and second heart sounds in the above four images.

Now draw vertical bars to represent first and second heart sounds in the dotted line drawn below the cardiac cycle graphs. Label ventricular systole and diastole in the same representation. Identify the heart sound that corresponds to the carotid pulse.

Figure 2: Worksheet for GEG.

The statements below mention different valve states. Choose four different colours to shade the boxes placed before the statements. (choose colours sequentially following the order in which the pens are serially numbered 1, 2, 3 and 4)

☐ The phase where the aortic valve is open.

☐ The phase where the mitral valve is open.

☐ The phase where the aortic valve is closed.

☐ The phase where the mitral valve is closed.

Now proceed to shade appropriate portions of the cardiac cycle graph and pressure-volume loop that correspond to the statements mentioned above. Choose matching colours that correspond to shades used for the respective boxes.

Now that you have completed shading the graphs and loops, write a statement that best describes the malfunction, in each of the below-mentioned valve diseases.

☐ Mitral stenosis ……………………………………………………………..

☐ Aortic stenosis………………………………………………………………

☐ Mitral regurgitation……………………………………………………….

☐ Aortic regurgitation………………………………………………………

Is it possible to deduce in which phase of the cardiac cycle, the valve malfunctions are likely to be manifested?

Try colour-coding the boxes for the valve diseases mentioned above. Use colours that you think correspond to the colour of the shaded cardiac cycle phases where the valve malfunction is likely to be manifested.

Do you think these phases would also correspond to the timing of the murmurs produced by each of the mentioned valve diseases? Discuss.

It should be clear to you at the end of this exercise as to which valve diseases produce systolic and which of them produce diastolic murmurs.

Get feedback from your faculty instructor.

To correct errors in shading, use original colours, but shade with dotted lines adjacent to the initial shading.

Now proceed to the manikin and auscultate the following: Normal heart sounds, systolic murmurs, diastolic murmurs

Use the worksheet to correlate the auscultated murmurs with the cardiac cycle phases in which it is heard.

Try to deduce the likely valve disease that could produce each of the auscultated murmurs.

Figure 2: (*continued*).

Table 1: Comparison of post-test MCQ scores between the GEG and CBL groups.

Group	N	Median (Q1, Q3)	U statistic	p-value
CBL	37	8 (7, 11)	289	<0.001[a]
GEG	42	13 (11, 15)		

Results of the Mann−Whitney U test that compared medians of MCQ test scores. The maximum score that a student could get was 18. CBL, case-based learning; GEG, graphical educational game; Q1 and Q3, first and third quartiles; N, student number.
[a] Statistically significant.

Table 2: Comparison of group performance in the simulator test: the diagnosis of valve disease and the identification of murmur timing.

Group	N	Diagnosing valve disease Mean score (SD)	Identifying murmur timing Mean score (SD)
CBL	37	0.11 (0.45)	0.72 (1.01)
GEG	42	0.68 (0.82)	1.18 (0.75)
p-value		<0.001[a]	0.09

Results of the Mann−Whitney U test comparing the mean scores in diagnosis of valve disease. The maximum score that a student could get in each task was 2. CBL, case-based learning; GEG, graphical educational game; SD, standard deviation.
[a] Statistically significant.

Table 3: Student responses to the questionnaire relating to GEG and the simulation session.

	Questionnaire item	Strongly agree N (%)	Agree N (%)	Cannot say N (%)	Disagree N (%)	Strongly disagree N (%)
1	The graphical game task clarified previously learned theoretical concepts in cardiac cycle physiology.	12 (28.5)	26 (61.9)	2 (4.8)	1 (2.4)	1 (2.4)
2	While using the worksheet, I gained knowledge of completely new concepts that I was unaware of previously	7 (16.6)	20 (47.6)	9 (21.4)	5 (12)	1 (2.4)
3	The task with the worksheet helped me build concepts that I could apply to analyse murmurs and diagnose valve diseases on the manikin.	6 (14.3)	31 (73.8)	3 (7.1)	(1) 2.4	(1) 2.4
4	The entire session with the worksheet and the simulator suited my method of learning.	11 (26.2)	25 (59.5)	4 (9.5)	1 (2.4)	1 (2.4)
5	The sounds on the manikin were clear and discerning enough on auscultation.	7 (16.6)	21 (50)	6 (14.3)	5 (12)	3 (7.1)
6	I got sufficient time for hands-on training on the Simulator manikin.	6 (14.3)	26 (61.9)	3 (7.1)	5 (12)	2 (4.8)
7	Working with the graphical game along with the simulator helped me realize the clinical relevance of cardiac cycle physiology.	14 (33.3)	22 (52.4)	3 (7.1)	2 (4.8)	1 (2.4)

Feedback was given by all students who underwent the GEG (N = 42). Responses were scored on a 5-point Likert scale, where 5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, and 1 = strongly disagree. Cronbach's alpha coefficient value was 0.75. N, number of responses for each statement.

Discussion

In the present study, we compared a GEG with a CBL targeted to achieve the same goal. Analysis demonstrated that the GEG group exhibited better ability to analyse physiological principles to diagnose cardiac valve disease in a simulated clinical setting.

The GEG group performed better in the MCQ test than the CBL group. Our results are similar to those from a study by Cardozo et al. that used a cardiac cycle game. In this previous study, the students in the game group performed better than the control group in terms of the assessment exercise.[17] Both the CBL and GEG are active collaborative learning exercises that aim to achieve higher levels of learning.[13,22] The better ability of the GEG group to solve application-based MCQ tests in the present study indicated the more favourable influence of the GEG. Higher levels of learning can translate to an enhanced ability to apply knowledge to novel and authentic situations which can help to explain the better performance of the GEG group in the simulator task, at least in part.[4]

An ability to integrate and apply different types of knowledge to arrive at a diagnosis is an essential element of clinical reasoning. A basic level of clinical reasoning appropriate to preclinical students was assessed in the simulator tasks. Clinical reasoning involves a combination of strategies ranging from analytical deductive reasoning, inferential pattern recognition, to abductive reasoning that includes analogy-based reasoning.[23,24]

In this study, the approach to using clinical reasoning for the purpose of diagnosis was taught differently in the GEG and CBL. CBL used a backdrop of two complementary cases, each relevant to a particular valve. Students had to progress from understanding the abnormal function of the particular valve mentioned in the case to learning the resultant abnormal cardiac mechanics that determines murmur timing. In the simulator task, students had to work this process in reverse. After auscultating the cardiac murmur, they had to arrive at a diagnosis by making a choice from several possible valve diseases. Studies suggest that explicitly stating the method to connect clinical information with basic sciences for clinical problem solving can improve diagnostic accuracy.[25] The CBL, by its very nature, did not explicitly teach the process of making a diagnosis beginning from a clinical sign. In contrast to the CBL, the GEG while lacking a clinical case, provided a broader contextual framework for learning that had an attached clinical relevance.[18] This stimulated domain-independent critical thinking skills. Solving the GEG, students could understand the domain-independent principle that changes in chamber volume (cardiac systole *vs* diastole) during the cardiac cycle create pressure gradients that cause unidirectional closing and opening of the intervening healthy valves, thus resulting in blood flow between chambers. Students could then understand how a particular valve dysfunction can generate abnormal blood flow patterns, guided by pressure gradients, thus causing a murmur to occur at a specific time point in the cardiac cycle.[21] With this, students had a clear conceptual framework for determining what murmur timing to expect from which type of valve disease. This concept could be used in the simulator task.[21,26] Such illustration of concepts where students can visualize murmurs within the cardiac cycle can lead to improved diagnostic ability by cardiac auscultation.[1,3,9,21,26] Analogy-based approaches to reasoning and the focus on learning underlying the principles employed by the GEG might be more favourable for diagnosing valve disease than the hypothesis-driven reasoning approaches learnt in CBL.[4]

GEG provided a dynamic learning environment for students to reinforce old concepts, and to build, interpret, and actively experiment with new ones.[17,18,20,22,27,28] In total, 88.1% of students in the present study agreed that the GEG helped them to build a concept that was applicable for the analysis of murmurs and the diagnosis of valve disease. Game based learning environments incite fun and curiosity in students. In a recent study which used a digital puzzle for cardiac cycle physiology, the students justified the usefulness of the game-based activity as it was dynamic, playful and allowed interaction with colleagues.[29] The challenge of solving the GEG intrinsically motivates students to learn.[17] Working out the GEG using various viewpoints while receiving a formative evaluation of their critical thinking skills through peer discussion helped the students gain problem-solving skills in the simulation task.[18,26,30]

In the present study, 76% of students agreed that they had sufficient time on the manikin and sounds were clearly auscultated. We deliberately made certain adjustments in the manikin, such as turning up the volume of the heart sounds to the highest level and fixing the heart rate at 70 beats/min for the easy discernment of sounds. By combining the GEG and the simulation, most of the students could appreciate the clinical relevance of the basic science topic, as indicated in the student feedback.

In total, 85.7% of students felt the GEG we used, along with the simulation, suited their method of learning. In a previous study by Cardozo et al. (2016), which used a cardiac cycle puzzle, 96% of students agreed that the puzzle helped to visualize the process, thus making it easier to understand the topic and thereby improving learning.[17] Although the GEG and CBL were guided enquiry-based approaches to learning, the GEG was more structured; there was a prescribed procedure to solve and the end goal was clearly defined.[31] In contrast, for the CBL, even though students received faculty feedback, they had to devise their own methods to solve a problem that had several possible outcomes.[13,32] For novice preclinical medical students, having recently transitioned from predominantly didactic teaching formats, using a more structured inquiry-based approach to teach the process of diagnosing cardiac valve disease by cardiac auscultation may be more beneficial.[33,34]

In the present study, valve disease diagnosis on the simulator was meant as a test of clinical reasoning. However, diagnostic ability was also influenced by the ability to initially identify the timing of the murmur correctly. This is an auscultatory discerning ability rather than a clinical reasoning skill. Comparative analysis revealed a significant difference in the ability to identify murmur timings correctly for the two groups, thus eliminating it as a confounding factor influencing the ability to diagnose valve disease (Table 3).

The students scored higher when identifying the murmur when compared to diagnosing valve disease. Many of the students who identified the timing of murmurs correctly, especially in the CBL group, were either unable to diagnose the valve disease correctly or were unable to follow up the correct diagnosis with an appropriate rationalization.

The GEG activity we used was simple to implement and utilized a universal problem-solving principle that required a solution that had real world applications. This strategy emphasized domain-independent critical thinking. This also had a eureka factor afforded to the student when a correct match was obtained between the student drawn image and the predesigned image.[17,35] Future studies should focus on studying the benefits of the GEG in improving ability to diagnose cardiac valve disease in real patients.

Limitations

Small group discussions are known to enhance learning.[14,36] In this study, we were unable to quantify specific differences in the extent of group discussion between the two interventions and the extent of group discussions provided for each of the learning experiences when compared to the delivery format of the content itself. For the CBL, an effort was made to simplify the clinical cases and construct them with specific learning objectives so as to direct student attention more to the clinical signs of murmur timing and its relevance to diagnosis. Despite this, the greater cognitive load associated with solving two separate cases in CBL *versus* gaining the same information with a single GEG may have influenced the results of this study.[37] The students were exposed to GEG-based pedagogy for the first time in their current curriculum, and the novelty of the pedagogical intervention might have influenced student engagement in learning material.

Conclusion

GEG was positively received by students and was more useful than the CBL in terms of enhancing the application of cardiac physiology concepts and improving ability to diagnose cardiac valvular diseases in a simulated clinical setting.

Source of funding

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Conflict of interest

The authors have no conflict of interest to declare.

Ethical approval

The study was approved by Kasturba Medical College and Kasturba Hospital Institutional Ethics committee (IEC 89/2019) on the 13 February 2019. This study was performed in line with the principles of the Declaration of Helsinki.

Authors contributions

DP: Conceptualization, Methodology, Resources, Supervision Project Administration, Investigation, Data acquisition, Formal Analysis, Writing Original Draft – Reviewing & Editing; CAS: Conceptualization, Methodology, Data acquisition, Reviewing & Editing; KRN: Conceptualization, Methodology, Data acquisition, Reviewing & Editing; KMP: Conceptualization, Methodology, Data acquisition, Reviewing & Editing; All authors have critically reviewed and approved the final draft and are responsible for the content and similarity index of the manuscript.

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