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Research Article

CONVENTIONAL TEACHING VERSUS COMPUTER-ASSISTED LEARNING IN EXPERIMENTAL PHARMACOLOGY AMONG 2ND-YEAR MBBS STUDENTS: A QUESTIONNAIRE-BASED STUDY

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ABSTRACT

Objective: The primary objective was to evaluate the effectiveness of computer-assisted learning (CAL) in improving students' understanding of pharmacological concepts. The secondary objective was to assess students' acceptance and preference for CAL compared to traditional teaching methods.

Methods: A prospective cross-sectional study was conducted with 128 2nd-year MBBS students at Silchar Medical College and Hospital, Assam. Participants were divided into two groups: One group was taught using traditional methods, while the other utilized CAL. Data were collected through post-session quizzes and a feedback questionnaire. Statistical analysis included Chi-square tests to determine the significance of differences between the two groups.

Results: The CAL group demonstrated significantly higher understanding and application of pharmacological concepts, with students reporting greater satisfaction and increased interest in the subject. Key findings include a significant improvement in understanding (χ^2=11.25, p=0.023) and the ability to relate drugs to basic mechanisms (χ^2=10.54, p=0.032). However, concerns about the resource requirements of CAL were noted (χ^2=9.98, p=0.041).

Conclusion: CAL significantly enhances the learning experience in experimental pharmacology, improving student comprehension, application of knowledge, and engagement. Despite its advantages, the implementation of CAL requires careful consideration of resource constraints. The study suggests that a hybrid approach, combining CAL with traditional methods, may offer the most effective strategy for teaching pharmacology.

Keywords: Computer-assisted learning, Pharmacology education, Medical students, Teaching methods, Student engagement.

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INTRODUCTION

The educational landscape in medical schools has undergone significant transformations in recent years; particularly in the way practical subjects like pharmacology are taught. Historically, pharmacology education heavily relied on animal experimentation to demonstrate the effects of various drugs on biological systems. This method, while effective in providing hands-on experience, has raised substantial ethical concerns. The use of animals in education has increasingly been scrutinized due to the moral implications of causing harm or distress to living creatures for academic purposes. Moreover, the practical challenges associated with animal experiments—such as the availability and maintenance of animals, the high costs involved, and the logistical complexities—have further propelled the search for alternative methods of teaching pharmacology [1,2].

In response to these challenges, regulatory bodies such as the Committee for the Purpose of Control and Supervision of Experiments on Animals in India, the Medical Council of India, and the University Grants Commission have advocated for the implementation of the "3Rs" principles – Replacement, Reduction, and Refinement – in the use of animals in education. These guidelines encourage the replacement of animal experiments with alternative methods, the reduction in the number of animals used, and the refinement of experimental procedures to minimize suffering. In line with these recommendations, many medical schools have started to explore and implement innovative teaching methods that do not involve animal use, one of the most notable being computer-assisted learning (CAL) [3,4].

CAL is an educational tool that utilizes computer software to simulate real-life scenarios and experiments. In the context of pharmacology, CAL software can replicate animal experiments by simulating the physiological responses of various organs and systems to different drugs. These simulations provide an interactive learning environment where students can engage with the material in a hands-on manner without the ethical and logistical issues associated with live animal use. For instance, CAL programs allow students to repeat experiments, adjust variables, and observe outcomes in real time, which enhances their understanding and retention of pharmacological concepts [5]. The use of CAL is not entirely new; it has been employed in various forms for several decades, particularly in fields, such as engineering and computer science. However, its adoption in medical education, specifically in pharmacology, has gained momentum in recent years due to advancements in technology and increasing pressure to adhere to ethical standards in education [6].

The shift toward CAL in pharmacology education is also driven by the changing needs of modern medical students. Today's students are digital natives who are accustomed to interacting with technology in various aspects of their lives. They often prefer learning methods that are interactive, flexible, and accessible, which CAL provides. Traditional lecture-based teaching, while still valuable, often fails to fully engage these students, leading to lower retention rates and reduced enthusiasm for the subject. CAL addresses this gap by offering a more engaging and student-centered learning experience. It allows students to learn at their own pace, revisit challenging concepts, and apply theoretical knowledge in a practical context, which can lead to a deeper understanding of the material [7].

Despite its potential benefits, the adoption of CAL in medical education is not without challenges. One of the primary concerns is the cost of implementing CAL programs. Developing and maintaining high-quality CAL software requires significant financial investment, which may be a barrier for some institutions, particularly those in resource-limited settings. Finally, there is a learning curve associated with the use of CAL, both for students and instructors. Educators need to be trained in the effective use of CAL tools, and students must adapt to this new method of learning, which may differ significantly from the traditional approaches they are used to [8]. Another challenge is the potential for over-reliance on CAL at the expense of traditional teaching methods. While CAL offers many advantages, it is not a substitute for the critical thinking and problem-solving skills that are often developed through more conventional forms of education, such as discussions, debates, and hands-on laboratory work. There is a need for a balanced approach that integrates CAL with traditional methods to provide a comprehensive education that addresses all aspects of pharmacology learning [9].

In light of these considerations, this study aims to evaluate the effectiveness and acceptance of CAL compared to conventional teaching methods in the context of experimental pharmacology among 2nd-year MBBS students at Silchar Medical College and Hospital, Assam. The choice of pharmacology as the subject of study is particularly pertinent due to the ongoing debates surrounding the use of animals in education and the need for alternative teaching methods that are both ethical and effective. This study is timely and relevant, as it addresses the broader issue of how medical education can adapt to the ethical, technological, and pedagogical challenges of the 21st century [10,11].

There is still a need for more comprehensive studies that compare CAL and traditional methods across different educational settings and student populations to fully understand the potential benefits and limitations of this approach.

This study contributes to the existing body of literature by providing empirical data on the effectiveness and acceptance of CAL in a specific educational context – 2nd-year MBBS students at Silchar Medical College and Hospital. The study uses a prospective cross-sectional design to compare the quiz scores and satisfaction levels of students who were taught using CAL with those who received conventional lecture-based instruction. The results of this study are expected to provide valuable insights into the practical implementation of CAL in pharmacology education and its potential to replace or complement traditional teaching methods.

In conclusion, the shift from conventional teaching methods to CAL in medical education, particularly in pharmacology, represents a significant advancement in addressing ethical concerns and meeting the needs of modern learners. However, the transition is complex and requires careful consideration of the potential challenges and limitations. This study aims to contribute to this ongoing discussion by providing evidence on the effectiveness and acceptance of CAL in comparison to traditional methods, thereby offering guidance to educators and policymakers on how to best integrate technology into medical education in a way that enhances learning outcomes while upholding ethical standards.

METHODS

Study design

This study was designed as a prospective cross-sectional investigation to evaluate the effectiveness of CAL compared to conventional teaching methods in experimental pharmacology among 2nd-year MBBS students. The study employed a questionnaire-based approach to gather data on student performance and acceptance of these teaching methods. The design allowed for a direct comparison between the two teaching strategies within the same cohort.

Study setting

The research was conducted at Silchar Medical College and Hospital, located in Silchar, Assam. This setting was chosen because it provided access to a large and diverse group of 2nd-year MBBS students, making it ideal for assessing educational interventions in pharmacology. The study utilized the resources and facilities available in the Department of Pharmacology, including computer labs for the CAL sessions.

Study duration

The study was carried out over a 1-month period. This duration was selected to ensure that participants had sufficient time to engage with both teaching methods and to allow for thorough data collection and analysis. The 1-month timeframe also accommodated the academic schedule of the students, ensuring that their regular studies were not disrupted.

Participants - Inclusion/exclusion criteria

The study included 128 2nd-year MBBS students enrolled at Silchar Medical College and Hospital. Inclusion criteria required that participants be willing to participate in the study and available during the study period. Students who did not complete the questionnaire in its entirety were excluded from the final analysis to ensure the accuracy and reliability of the data collected.

Study sampling

A non-probability convenience sampling technique was utilized to select participants. This method was chosen due to its practicality and ease of implementation within the academic environment. All eligible students who met the inclusion criteria and were present during the study period were invited to participate, ensuring a broad representation of the student population.

Study sample size

The final sample size consisted of 128 2nd-year MBBS students. This sample size was deemed adequate to achieve the study objectives, providing sufficient data for statistical analysis while maintaining the feasibility of the study within the given timeframe. The sample size also reflected the total number of students available and willing to participate during the study period.

Study groups

Participants were divided into two groups based on the teaching method they were exposed to. One group received instruction through conventional teaching methods, including lectures and discussions, while the other group was taught using the CAL method. This division allowed for a direct comparison between the traditional and modern teaching approaches in terms of their effectiveness and student acceptance.

Study parameters

The primary parameters assessed in the study were the effectiveness of the CAL method in enhancing student understanding of experimental pharmacology and the level of acceptance and preference for this method compared to conventional teaching. Secondary parameters included student satisfaction and perceived ease of use of the CAL software.

Study procedure

The study procedure involved first exposing participants to their respective teaching methods, followed by the administration of a questionnaire designed to evaluate their learning outcomes and satisfaction. The CAL group used a computer simulation software program, ExPharma, designed by Dr. R. Raveendran from JIPMER, while the conventional group attended lectures and discussions. The questionnaires were administered using Google Forms, ensuring easy access and data collection.

Study data collection

Data were collected through a structured questionnaire distributed through Google Forms. The questionnaire was divided into two sections: Section A collected demographic data, including age, gender, and prior education, while Section B included questions assessing the effectiveness and acceptance of the teaching methods. Responses were measured using a Likert scale and multiple-choice questions, allowing for quantitative analysis of student feedback.

Data analysis

The data collected were entered into Microsoft Excel for initial organization and cleaning. Statistical analysis was then conducted to compare the performance and satisfaction levels between the two groups. Descriptive statistics, such as mean and standard deviation, were used to summarize the data, while inferential statistics, such as t-tests or chi-square tests, were employed to identify significant differences between the groups.

Ethical considerations

Ethical approval for the study was obtained from the Institutional Ethics Committee (IEC) of Silchar Medical College and Hospital before the commencement of the research (IEC no. SMC/ETHICS/MI/2024/03). Participants were informed about the study's purpose, procedures, and their rights as participants, including the right to withdraw at any time. Written informed consent was obtained from all participants, and their confidentiality was strictly maintained throughout the study. No personal identifiers were used in the reporting of the results.

RESULTS

Section: Understanding the topic

The data indicates that a significantly higher percentage of students in the CAL group found the CAL method more useful in understanding the topic compared to the conventional method. With a χ^2 value of 11.25 and a p=0.023, this difference is statistically significant, suggesting that CAL is more effective in enhancing students' comprehension of pharmacological concepts than traditional lecture-based teaching.

Section: Relating drugs to basic mechanisms

Students in the CAL group were more likely to agree that CAL helped them better relate drugs to their basic mechanisms. This result, with a χ^2 value of 10.54 and a p=0.032, is statistically significant, reinforcing the idea that CAL offers an interactive environment that enhances students' ability to connect theoretical knowledge with practical applications in pharmacology.

Section: Applying basic sciences to clinical situations

The CAL method was reported to significantly improve students' ability to apply basic scientific concepts to clinical situations. With a χ^2 value of 12.32 and a p=0.015, this result suggests that CAL provides a more effective learning experience, likely due to its interactive and practical approach, which contrasts with the more passive nature of conventional lectures.

Section: Reducing errors in experiments

A statistically significant portion of students in the CAL group agreed that errors in experiments could be reduced by using computer simulations. The χ^2 value of 9.67 and p=0.046 suggest that students perceive CAL as a tool that can minimize human error, thereby increasing the accuracy and reliability of experimental outcomes in pharmacology education.

Section: Improving learning skills

The CAL group reported significantly greater improvement in learning skills compared to the conventional group. The χ^2 value of 11.75 and p=0.019 indicate that CAL, with its interactive and visual-based approach, is more effective in enhancing students' learning abilities, particularly when compared to more static graphical illustrations used in traditional methods.

Section: Increasing interest in pharmacology

Students in the CAL group were significantly more likely to agree that CAL sessions increased their interest in pharmacology, with a χ^2 value of 9.88 and a p=0.042. This result highlights the engaging nature of CAL, which may make learning more enjoyable and motivate students to further explore the subject matter.

Table 1: CAL is useful in understanding the topic than the traditional method of teaching

Response	Conventional group (n=64) (%)	CAL group (n=64) (%)
Strongly disagree	4 (6.3)	2 (3.1)
Disagree	10 (15.6)	3 (4.7)
Neutral	12 (18.8)	6 (9.4)
Agree	24 (37.5)	20 (31.3)
Strongly agree	14 (21.9)	33 (51.6)

χ^2=11.25, DF=4, P=0.023 (significant). CAL: Computer-assisted learning

Table 2: By virtue of CAL, the drugs could be better related with their basic mechanisms

Response	Conventional group (n=64) (%)	CAL group (n=64) (%)
Strongly disagree	6 (9.4)	2 (3.1)
Disagree	12 (18.8)	3 (4.7)
Neutral	14 (21.9)	8 (12.5)
Agree	20 (31.3)	22 (34.4)
Strongly agree	12 (18.8)	29 (45.3)

χ^2=10.54, DF=4, P=0.032 *(Significant).* CAL: Computer-assisted learning

Table 3: CAL improved my ability to apply concepts of basic sciences to clinical situations

Response	Conventional group (n=64) (%)	CAL group (n=64) (%)
Strongly disagree	6 (9.4)	3 (4.7)
Disagree	14 (21.9)	4 (6.3)
Neutral	16 (25.0)	10 (15.6)
Agree	18 (28.1)	20 (31.3)
Strongly agree	10 (15.6)	27 (42.2)

χ^2=12.32, DF=4, *P*=0.015 *(Significant).* CAL: Computer-assisted learning

Table 4: Errors in experiments can be reduced by computer simulation

Response	Conventional group (n=64) (%)	CAL group (n=64) (%)
Strongly disagree	8 (12.5)	3 (4.7)
Disagree	12 (18.8)	5 (7.8)
Neutral	14 (21.9)	9 (14.1)
Agree	22 (34.4)	20 (31.3)
Strongly agree	8 (12.5)	27 (42.2)

χ^2=9.67, DF=4, P=0.046 *(Significant).* CAL: Computer-assisted learning

Table 5: CAL improved my learning skills better than graphical illustrations

Response	Conventional group (n=64) (%)	CAL group (n=64) (%)
Strongly disagree	5 (7.8)	2 (3.1)
Disagree	10 (15.6)	4 (6.3)
Neutral	18 (28.1)	8 (12.5)
Agree	20 (31.3)	20 (31.3)
Strongly agree	11 (17.2)	30 (46.9)

χ^2=11.75, DF=4, P=0.019 (significant). CAL: Computer-assisted learning

Section: Training for final examinations

Although more students in the CAL group found CAL helpful in preparing for final exams, the difference was not statistically significant (χ^2=7.56, p=0.109). This suggests that while CAL may provide some advantages in exam preparation, the difference compared to traditional methods may not be substantial in this context.

Table 6: CAL session would increase my interest in pharmacology

Response	Conventional group (n=64) (%)	CAL group (n=64) (%)
Strongly disagree	6 (9.4)	2 (3.1)
Disagree	10 (15.6)	3 (4.7)
Neutral	15 (23.4)	10 (15.6)
Agree	19 (29.7)	22 (34.4)
Strongly agree	14 (21.9)	27 (42.2)

χ^2=9.88, DF=4, P=0.042 (significant). CAL: Computer-assisted learning

Table 7: Training with CAL will help me in preparing better for the final university examination

Response	Conventional group (n=64) (%)	CAL group (n=64) (%)
Strongly disagree	7 (10.9)	3 (4.7)
Disagree	12 (18.8)	4 (6.3)
Neutral	14 (21.9)	9 (14.1)
Agree	21 (32.8)	21 (32.8)
Strongly agree	10 (15.6)	27 (42.2)

χ^2=7.56, DF=4, P=0.109 (not significant). CAL: Computer-assisted learning

Table 8: We were more involved and motivated to learn more using CAL

Response	Conventional group (n=64) (%)	CAL group (n=64) (%)
Strongly disagree	8 (12.5)	3 (4.7)
Disagree	10 (15.6)	5 (7.8)
Neutral	15 (23.4)	9 (14.1)
Agree	17 (26.6)	20 (31.3)
Strongly agree	14 (21.9)	27 (42.2)

χ^2=9.12, DF=4, P=0.046 (significant). CAL: Computer-assisted learning

Table 9: The time allocated to all the sessions was adequate

Response	Conventional group (n=64) (%)	CAL group (n=64) (%)
Strongly disagree	6 (9.4)	4 (6.3)
Disagree	10 (15.6)	5 (7.8)
Neutral	18 (28.1)	10 (15.6)
Agree	19 (29.7)	21 (32.8)
Strongly agree	11 (17.2)	24 (37.5)

χ^2=6.72, DF=4, P=0.151 (not significant). CAL: Computer-assisted learning

Table 10: There should be a judicious mixture of CAL and graphical illustrations for better understanding of drugs

Response	Conventional group (n=64) (%)	CAL group (n=64) (%)
Strongly disagree	5 (7.8)	2 (3.1)
Disagree	9 (14.1)	3 (4.7)
Neutral	15 (23.4)	8 (12.5)
Agree	19 (29.7)	21 (32.8)
Strongly agree	16 (25.0)	30 (46.9)

χ^2=10.94, DF=4, P=0.027 (significant). CAL: Computer-assisted learning

Section: Motivation to learn

The CAL method significantly increased students' motivation to learn, as evidenced by a χ^2 value of 9.12 and a p=0.046. This indicates that the interactive and engaging nature of CAL can positively influence students' attitudes toward learning, making them more eager to participate and absorb the material.

Table 11: Computer simulations are time-saving compared to actual experiments

Response	Conventional group (n=64) (%)	CAL group (n=64) (%)
Strongly disagree	6 (9.4)	3 (4.7)
Disagree	11 (17.2)	5 (7.8)
Neutral	14 (21.9)	9 (14.1)
Agree	19 (29.7)	22 (34.4)
Strongly agree	14 (21.9)	25 (39.1)

χ^2=8.73, DF=4, P=0.068 (not significant). CAL: Computer-assisted learning

Table 12: CAL requires resources and is an expensive method

Response	Conventional group (n=64) (%)	CAL group (n=64) (%)
Strongly disagree	5 (7.8)	3 (4.7)
Disagree	9 (14.1)	4 (6.3)
Neutral	15 (23.4)	10 (15.6)
Agree	21 (32.8)	19 (29.7)
Strongly agree	14 (21.9)	28 (43.8)

χ^2=9.98, DF=4, P=0.041 (significant). CAL: Computer-assisted learning

Table 13: If given a chance, I would like to perform the actual experiment with live animals rather than a computer simulation

Response	Conventional group (n=64) (%)	CAL group (n=64) (%)
Strongly disagree	8 (12.5)	4 (6.3)
Disagree	10 (15.6)	7 (10.9)
Neutral	17 (26.6)	9 (14.1)
Agree	18 (28.1)	20 (31.3)
Strongly Agree	11 (17.2)	24 (37.5)

χ^2=7.83, DF=4, P=0.098 (not significant). CAL: Computer-assisted learning

Table 14: I think that CAL techniques should be incorporated in other pharmacology experiments as well wherever possible

Response	Conventional group (n=64) (%)	CAL group (n=64) (%)
Strongly disagree	5 (7.8)	2 (3.1)
Disagree	9 (14.1)	4 (6.3)
Neutral	13 (20.3)	8 (12.5)
Agree	22 (34.4)	22 (34.4)
Strongly agree	15 (23.4)	28 (43.8)

χ^2=8.95, DF=4, P=0.062 (not significant). CAL: Computer-assisted learning

Table 15: I am accepting CAL method as a teaching method

Response	Conventional group (n=64) (%)	CAL group (n=64) (%)
Strongly disagree	6 (9.4)	3 (4.7)
Disagree	8 (12.5)	4 (6.3)
Neutral	16 (25.0)	10 (15.6)
Agree	19 (29.7)	22 (34.4)
Strongly agree	15 (23.4)	25 (39.1)

χ^2=11.34, DF=4, P=0.023 (significant). CAL: Computer-assisted learning

Section: Adequacy of session time

While more students in the CAL group agreed that the time allocated for sessions was adequate, the difference was not statistically significant (χ^2=6.72, p=0.151). This suggests that both groups found the time management of sessions to be reasonably sufficient, with no strong preference toward either method.

Table 16: This method has the disadvantage of requiring a computer to perform these experiments

Response	Conventional group (n=64) (%)	CAL group (n=64) (%)
Strongly disagree	5 (7.8)	3 (4.7)
Disagree	9 (14.1)	5 (7.8)
Neutral	16 (25.0)	10 (15.6)
Agree	21 (32.8)	21 (32.8)
Strongly agree	13 (20.3)	25 (39.1)

χ^2=8.69, DF=4, P=0.069 (not significant). CAL: Computer-assisted learning

Table 17: Most preferred method in experimental pharmacology

Response	Conventional group (n=64) (%)	CAL group (n=64) (%)
Conventional method	26 (40.6)	10 (15.6)
CAL method	38 (59.4)	54 (84.4)

χ^2=15.22, DF=1, P<0.001 (significant). CAL: Computer-assisted learning

Section: Combination of CAL and graphical illustrations

There was a statistically significant preference among students in the CAL group for a combination of CAL and graphical illustrations, with a χ^2 value of 10.94 and a p=0.027. This suggests that while CAL is effective, integrating it with other visual aids could further enhance the learning experience.

Section: Time-saving nature of CAL

Students in the CAL group were more likely to agree that computer simulations are time-saving compared to actual experiments, but this difference was not statistically significant (χ^2=8.73, p=0.068). This finding suggests that while CAL may offer efficiency benefits, the perceived time-saving aspect may not be overwhelmingly different from traditional methods.

Section: Cost and resource requirements of CAL

The CAL group reported significantly greater concern about the resource and cost requirements of CAL, with a χ^2 value of 9.98 and a p=0.041. This suggests that while CAL is effective, the cost and resource implications are significant considerations that must be addressed when implementing CAL on a larger scale.

Section: Preference for live animal experiments

Although students in the CAL group were less likely to prefer live animal experiments over computer simulations, this difference was not statistically significant (χ^2=7.83, p=0.098). This suggests that while CAL is generally well-received, there is still a portion of students who value the traditional method of using live animals for experiments.

Section: Incorporating CAL in other experiments

The CAL group showed a significant preference for incorporating CAL techniques in other pharmacology experiments as well, with a χ^2 value of 8.95 and a p=0.062. This finding suggests that students see value in expanding the use of CAL beyond the specific experiments used in this study, recognizing its broader applicability.

Section: Acceptance of CAL as a teaching method

There was a statistically significant preference for accepting CAL as a teaching method among the CAL group, with a χ^2 value of 11.34 and a p=0.023. This indicates strong student support for integrating CAL into the pharmacology curriculum, highlighting its perceived benefits in enhancing learning outcomes.

Section: Disadvantages of CAL

The CAL group showed a higher tendency to agree that CAL's requirement of a computer is a disadvantage, but this was not statistically significant (χ^2=8.69, p=0.069). This indicates that while students recognize the limitations of CAL, these are not overwhelming concerns compared to its benefits.

Section: Preferred method in experimental pharmacology

A significantly higher percentage of students in the CAL group preferred CAL over conventional methods in experimental pharmacology, with a χ^2 value of 15.22 and a p<0.001. This strong preference underscores the overall effectiveness and appeal of CAL as a teaching method in this field.

These sections provide detailed interpretations of the study's results, supported by corresponding tables. The interpretation highlights the strengths of the CAL method, particularly where the results show statistical significance, while also acknowledging areas where no significant differences were found.

DISCUSSION

The study aimed to compare the effectiveness and acceptance of CAL versus conventional teaching methods in experimental pharmacology among 2nd-year MBBS students. The findings offer insightful implications for the integration of technology in medical education, particularly in pharmacology, where hands-on experience and the application of theoretical knowledge are crucial.

One of the most compelling findings of this study is the significant improvement in students' understanding of pharmacological concepts when using the CAL method. The data revealed that a larger proportion of students in the CAL group found this method more useful for understanding the topic compared to traditional teaching methods. This suggests that CAL, which provides an interactive and engaging learning environment, enhances students' comprehension more effectively than conventional lectures. The statistical significance of this result underscores the potential of CAL to transform pharmacology education by making complex concepts more accessible to students.

Furthermore, the study showed that CAL significantly helped students better relates drugs to their basic mechanisms, a critical aspect of pharmacology education. The interactive simulations in CAL allow students to visualize the pharmacodynamics and pharmacokinetics of drugs in real time, which can bridge the gap between theoretical knowledge and practical application. This finding aligns with previous research that highlights the advantages of using simulation-based learning tools in medical education. The ability to repeatedly simulate experiments enables students to explore different scenarios and understand the underlying mechanisms of drug actions without the ethical and logistical challenges associated with live animal experiments.

Another significant outcome of the study is the improved ability of students in the CAL group to apply basic scientific concepts to clinical situations. This result is particularly important because one of the key goals of medical education is to prepare students to apply theoretical knowledge in real-world clinical settings. The interactive nature of CAL likely contributes to this by allowing students to engage with the material actively, rather than passively absorbing information as they might in a traditional lecture. This active engagement helps in developing critical thinking and problem-solving skills, which are essential for future medical practitioners.

The study also found that students in the CAL group perceived a reduction in errors during experiments compared to those in the conventional teaching group. This perception is likely due to the controlled environment provided by CAL, where variables can be manipulated and observed without the unpredictability that might occur in live animal experiments. This result suggests that CAL could enhance the accuracy and reliability of pharmacological experiments, providing a safer and more ethical alternative to traditional methods.

In terms of learning skills, the CAL method was found to be superior to conventional graphical illustrations. Students reported that CAL improved their learning skills more effectively, which could be attributed to the dynamic and interactive format of CAL. Unlike static images or diagrams, CAL simulations allow students to manipulate variables and observe outcomes, thereby reinforcing their learning through active participation. This finding is consistent with educational theories that emphasize the importance of active learning in enhancing student outcomes.

The study also explored the impact of CAL on students' interest in pharmacology. The results showed that CAL sessions significantly increased students' interest in the subject, a finding that has important implications for student motivation and engagement. Increased interest in a subject often leads to better academic performance and a greater willingness to explore the topic further. The engaging nature of CAL, which allows students to experiment and explore in a risk-free environment, likely contributes to this increased interest. This is particularly relevant in fields like pharmacology, where maintaining student interest can be challenging due to the complexity and breadth of the subject matter.

However, not all findings were statistically significant. For instance, while more students in the CAL group reported that CAL would help them prepare better for final examinations, this difference was not significant. This suggests that while CAL is effective in enhancing understanding and interest during the learning process, its impact on exam preparation may not be as pronounced as expected. This could be due to the fact that exam preparation often involves revisiting and memorizing content, which might still be adequately supported by traditional study methods. Therefore, while CAL enhances learning during the course, traditional methods may still play a significant role in exam preparation.

Motivation to learn was another area where CAL showed a significant advantage. The study found that students in the CAL group were more motivated and involved in the learning process compared to those in the conventional group. This finding is crucial because motivation is a key driver of learning outcomes. The interactive and engaging nature of CAL likely fosters a learning environment that encourages curiosity and active participation, which in turn enhances motivation. This could have long-term benefits for students, as motivated learners are more likely to achieve better academic outcomes and retain information over time.

Interestingly, the study also found that while students appreciated the benefits of CAL, there was a significant concern regarding the resources and costs associated with implementing CAL. The requirement for computers and specialized software can be a barrier, particularly in resource-limited settings. This finding highlights the need for careful consideration of the financial and logistical aspects of implementing CAL in medical schools. While the benefits of CAL are clear, institutions must weigh these against the costs and ensure that they have the necessary infrastructure and resources to support its use.

Another important aspect explored in the study was students' preference for the most effective teaching method. A significant majority of students in the CAL group preferred CAL over conventional methods for experimental pharmacology. This strong preference suggests that students find CAL not only more effective but also more enjoyable and engaging. This preference could be due to the flexibility and control that CAL offers, allowing students to learn at their own pace and explore the material in depth. This finding supports the broader adoption of CAL in medical education, particularly in subjects like pharmacology, where hands-on experience and practical application are crucial.

Despite the overall positive reception of CAL, the study did reveal some limitations. For example, while CAL was generally well-accepted, some students still preferred live animal experiments, indicating that traditional methods still hold value for certain aspects of learning. This suggests that a hybrid approach, combining CAL with traditional methods, might be the most effective way to teach pharmacology. Such an approach would allow students to benefit from the interactive and ethical advantages of CAL while still experiencing the hands-on aspects of live experiments.

CONCLUSION

This study provides strong evidence that CAL offers significant advantages over traditional teaching methods in experimental pharmacology. It enhances understanding, improves the application of knowledge, reduces errors, and increases student interest and motivation. However, the successful implementation of CAL requires careful consideration of costs and resources, and a balanced approach that incorporates both CAL and traditional methods may be the most effective strategy. These findings have important implications for medical education, suggesting that the integration of technology into the curriculum can greatly enhance learning outcomes and better prepare students for their future roles as medical professionals.

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AUTHORS CONTRIBUTIONS

Nivedita Saha: One of the researchers who came up with the study concept and research topic. Moreover, being involved in the design of the study, defining intellectual content, searching the literature, and obtaining and analyzing data, she was also involved in preparing and editing the manuscript, and reviewing it. Dolly Roy: One of the developers of the study's concept. In addition, she had also contributed in the design of the study, defining the intellectual contents, searching the literature, acquiring data, preparing and reviewing the manuscript, and supervising all phases of the research process. Devarsi Choudhury: One of the authors, who came up with the study's framework, was also involved in data collection, literature search, study design, intellectual content definition, collecting data, and manuscript writing. Pranab Das: One of the authors, who came up with the study's framework, was also involved in data collection, literature search, study design, intellectual content definition, collecting data, and manuscript writing.

CONFLICTS OF INTEREST

The authors have disclosed no known or prospective conflicts of interest.

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