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Effect of Simulation based teaching strategy in Engineering Physics course

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Abstract— **Computer-based simulations have gained significant popularity in science education, particularly in subjects like Physics that involve intricate and abstract concepts. Simulations offer learners the opportunity to engage with complex phenomena and manipulate them, making them particularly valuable in these contexts. In line with this notion, our study adopted a teaching strategy centered on simulations. This approach was implemented in two separate classes of first-year Bachelor of Technology (F. Y. B. Tech) students, specifically for the Engineering Physics course. In one of these classes, simulations were solely utilized without incorporating any formative assessment, while the other class was exposed to a strategy that combined simulations with formative assessment. Our observations revealed that solely using simulations during instruction did not contribute significantly to conceptual understanding. However, when simulations were integrated with formative assessment, a substantial improvement in understanding was noted. Through our data analysis, a noteworthy discrepancy in average scores between the two classes became apparent. Notably, the class that experienced the simulation-based formative assessment strategy demonstrated a higher average score of 63.85.**

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I. INTRODUCTION

Engineering Physics is one of the basic and common courses for almost all branches of engineering education. The majority of the engineering branches are based on concepts in physics, and therefore, understanding the major key concepts in physics is necessary in engineering education. However, many physics phenomena are abstract and, hence, understanding them becomes difficult for students. It is a great challenge for the learners to grasp these complex concepts and processes, e.g., the particle in box problem in quantum physics or the stimulated emission process in the production of LASER, etc.

It is required to have context-based approaches in science education for a more positive attitude of learners toward science and also a solid basis for scientific understanding of such complex topics (Bennet & Jennings 2011). Considering this, there is a need for teaching methods that will help learners gain conceptual understanding of abstract concepts such as difference between different types of damped oscillations, quantum mechanics theories such as wave particle duality, particle in infinite potential box problem, production of laser light etc. In these situations, interactive computer-based solutions could aid in promoting the acquisition of knowledge and understanding in a thorough manner. In this regard, computer-based simulations are becoming more popular not only as a means of learning for science courses like Physics, Chemistry, and Biology but also as an assessment tool to analyse students' learning (Quellmalz et al., 2008; Rutten, van Joolingen, & van der Veen, 2012). "Simulations are generally defined as imitations of the operation of a real-world process or system over time" (Banks, Carson, Nelson & Nicole, 2010). In an interactive simulation, one is allowed to change the parameters and see what effect it has on the result. "The fact that computer simulations represent a model of a system (natural or artificial) or a process with all its determining parameters enables the learner to safely experiment and simulate in an artificial learning environment" (Jong & van Joolingen, 1998). "Useful conclusions about the design and use of simulations for physics teaching can be understood from the cognitive load theory (CLT). According to cognitive load theory, the human working memory has a relatively small capacity, i.e., it can hold approximately small chunks of knowledge (5-7) at the same time" (De Jong 2010). For effective teaching, it is necessary to reduce cognitive overload. There are three types of cognitive load: intrinsic, extraneous, and germane. The intrinsic load is related to the difficulty of subject matter (Cooper 1998; Sweller and Chandler 1994); it is also related to the prior knowledge of the learners. The intrinsic load cannot be changed by instructional treatments. On the other hand, extraneous cognitive processes that do not aid in the

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development of the target knowledge lead to extraneous load. Lastly, cognitive processes that actively contribute to knowledge production are what lead to germane load (De Jong 2010). All these loads are additive and one must manage them in such a way that cognitive load will be reduced, extraneous load must be adjusted, and germane load must be promoted (Paas et al. 2003).

In the process of teaching and learning, the germane load will be increased by learning with simulations that will explore the cause and effect of scientific phenomena. Computer simulations provide chances for active learning, contextualized training, and the use of visualizations to make complex topics easier to understand, and as per CLT theory, it will also help to avoid the cognitive overload on the learners.

This paper describes the comparison of simulation-based formative assessment on the learning of the F. Y. B. Tech students in the Engineering Physics course. We investigated the effects of the methods on the academic performance and conceptual understanding of abstract concepts from the Physics syllabus. While using this simulation-based methodology, we kept in mind not to overcome the cognitive load as per the CLT theory.

II. RESEARCH METHDOLOGY

For the present study, we have used easily available online simulations from different platforms. We used the simulations for topics like oscillations, quantum physics, LASER and fibre optics from the Engineering Physics Course. Table I gives the information about how the activity is mapped with the curriculum. As stated earlier, we have tried to evaluate the effects of simulations on students' learning. We tried to balance the intrinsic, extraneous, and germane loads by providing prior knowledge before the simulation, keeping the activity shorter, and avoiding simulations with complex interfaces.

The research was conducted with two sets of first-year computer engineering (F. Y. B. Tech) students named as control and experimental group with group size of 69 each. Notably, both groups shared the same course faculty. To ensure a diverse representation, students in both the control and experimental groups were selected based on a combination of gender and academic performance. In the control group, the faculty utilized simulations without incorporating any formative assessment. In the experimental group, simulation- based formative assessment was introduced. Both groups were taught by the same faculty. Before the actual experiment, we assessed the scores of both classes on the topic one through a ten-mark multiple-choice question test. The questions were based on the learning outcomes such as illustrate the effect of damping on oscillatory motion, explain the role of external periodic force in forced oscillations, determine the relaxation time for a damped oscillatory motion, and explain the condition of resonance on forced oscillation and effect of damping on resonance condition. The analysis revealed that the control group achieved an average score of 7.12, whereas the experimental group attained an average score of 6.41. This shows there was a slight and insignificant difference in the initial performance of the two classes

In the control group, the faculty presented the simulation while the students observed it on a projection screen. On the other hand, in the experimental group, students watched the simulation on a screen and were given the opportunity to interact with it using a computer. The faculty delivered the same explanation of the concept and simulation for both groups. However, the experimental group had the advantage of directly engaging with the simulation and revisiting it as needed. In contrast, the control group mainly observed while the faculty controlled the simulation and gathered relevant data. The faculty led similar discussions about the topic and its outcomes in both groups. Moving to the assessment phase, only the experimental group received a set of questions that they could solve by utilizing the simulation. The experimental group had more autonomy in exploring the simulation, verifying the accuracy of their answers, and could pause and resume the simulation at their discretion. They could explore all aspects of the simulation and were required to submit answers to the faculty based on their observations and findings.

TABLE I
Details of particular content from the Engineering physics course for which the activity is implemented with corresponding learning outcomes

Unit	**Concept**	**Learning outcome**
Oscillations	Effect of damping on oscillatory motion Comparison between oscillations in overdamped, critically damped and underdamped conditions.	To compare behavior of oscillatory motion under different damping conditions
Quantum Physics	Particle in 1D infinite potential box problem, energy quantization, wave function and probability distribution function	Calculate and interpret the energy and probability distribution function for the particle in the 1D infinite potential well
LASER	Basic interactions: Stimulated absorption, Spontaneous emission, stimulated emission, population inversion, Laser system	Explain the basic interactions like stimulated absorption, spontaneous emission, and stimulated emission using energy level diagram.
Fiber optics	Principle of total internal reflection	Determine the conditions to achieve the phenomena of total internal reflection

The first simulation is based on the topic oscillations. It focuses on categorizing damped motion into three types: underdamped, overdamped, and critically damped oscillations. This simulation enables learners to visually comprehend the impact of damping on oscillatory behavior. They have the ability to adjust damping coefficients and examine their influence on the oscillations. Fig. 1 shows the snapshot of this simulation.

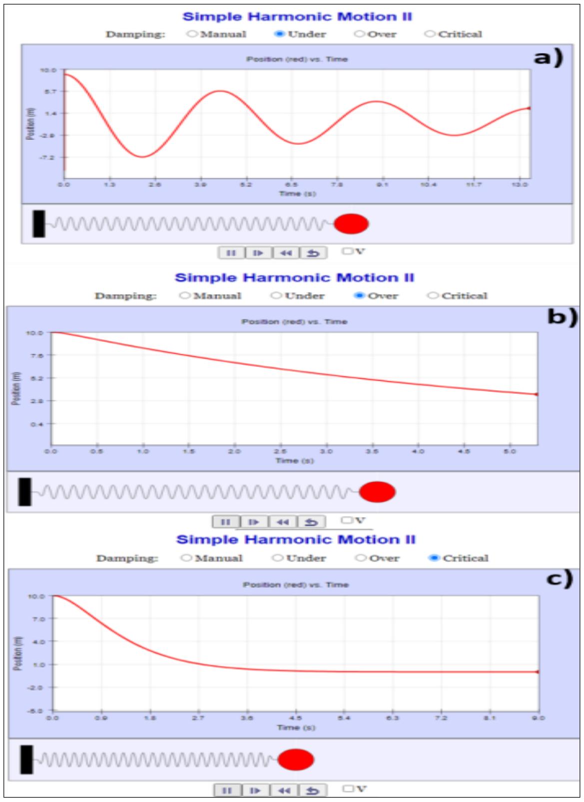

Fig. 1. Snapshot of simulation for comparison for damped oscillations a) Underdamped, b) Overdamped, and c) Critically damped (Source:https://www.compadre.org/osp/EJSS/4026/134.html)

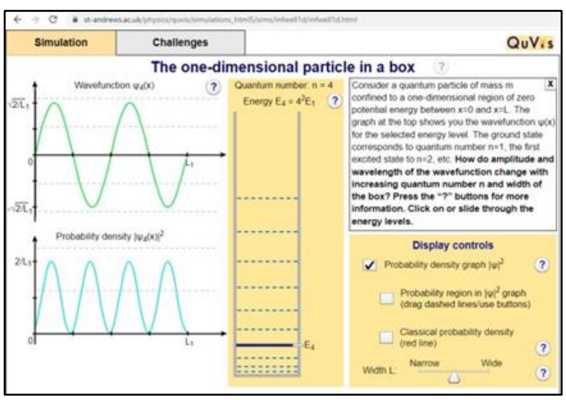

Fig. 2. Snapshot of simulation for parcel in 1D infinite potential box problem (Source: https://www.st-ndrews.ac.uk/physics/quvis/simulations_html5/sims/infwell1d/infwell1d.html)

The next simulation addresses the particle in a 1D infinite potential box problem from the topic quantum physics, a concept within Quantum Physics that is entirely novel for learners. Although they can solve the problem using equations in class, comprehending the energy variations in distinct quantum states, the particle's associated wave function, and the distribution of probabilities poses a challenge. This simulation serves to elucidate these terms with clarity. A visual representation of this simulation is depicted in Figure 2. Moving on, the next simulation centers around the topic of LASER. This specific simulation proves highly valuable in grasping the processes of absorption and emission involved in light generation. It guides students in understanding the significance of phenomena like pumping, metastable states, and population inversion in facilitating laser action. Moreover, students gain insights into the precise conditions conducive to the production of laser light. A snapshot of this simulation is presented in Figure 3.

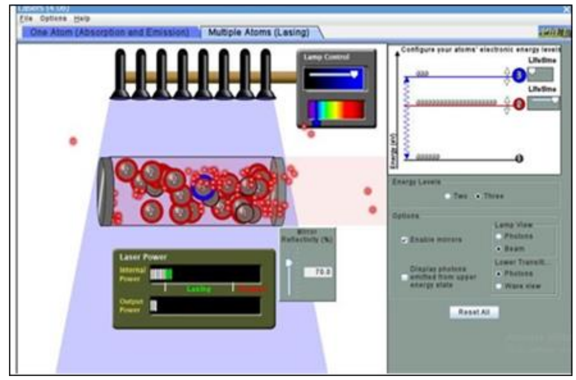

Fig. 3. Snapshot of simulation for LASER (Source: https://phet.colorado.edu/)

Concluding the series, the last simulation revolves around the principle of total internal reflection (TIR). This principle holds importance in launching light within optical fibers. Through this simulation, students engage with diverse medium conditions through which light rays pass. They also learn the prerequisites for the occurrence of the TIR phenomenon. A snapshot of this simulation is presented in Figure 4.

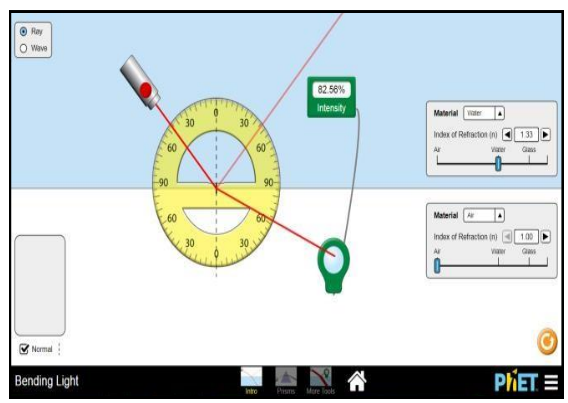

Fig. 4 Snapshot of simulation for Total internal reflection (Source: https://phet.colorado.edu/)

A sample questions asked for formative assessment of topic LASER is given below;

1. When atoms are transferred from lower energy state to higher energy state? What is requirement for that?
2. How the lifetime of excited state affecting number of atoms?
3. When the mirrors are not placed what kind of emission you are able to see?
4. When you change the reflectivity of the mirror from 0 to 90, is it affecting output?
5. Comment now based on this simulation what are the requirements for LASER production?

Fig. 5 shows the proof of the formative assessment i.e., sample responses by the students for questions asked during the activity.

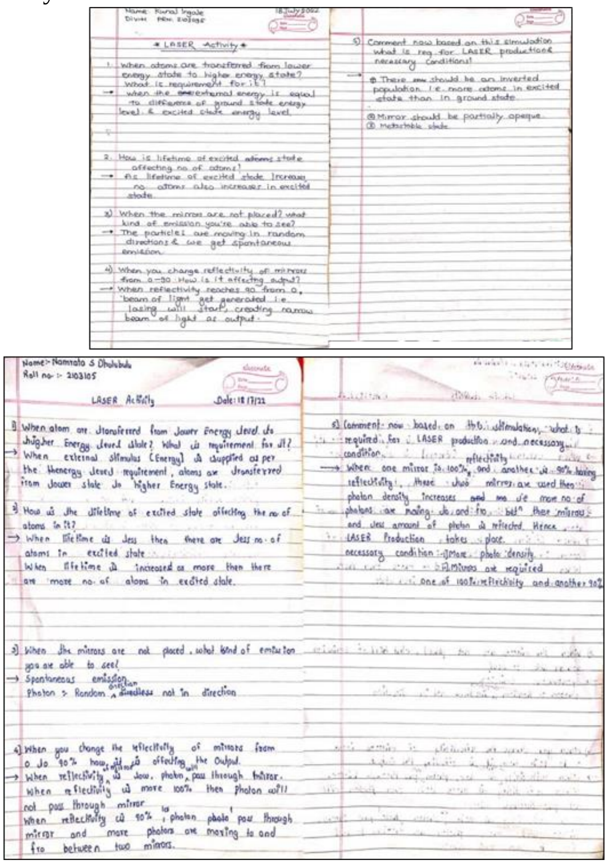

Fig. 5: Snapshot of responses by students for formative assessment of LASER simulation

After every simulation activity, we conducted a similar formative assessment based on the content for the experimental group.

Even though the activity is good for students' learning, there were some problems we had to deal with. For example, it was difficult to find a simulation that fit the curriculum because we, the faculty, are not skilled in creating our own. As a result, we had to rely on the internet for available simulations, which meant that the activity could only cover a limited amount of the curriculum. Sustaining students' high levels of interest is another difficulty. To address this, we chose simulations that are simple enough for students to operate, while more sophisticated ones may prove to be too much for them. Due to time constraints, the activity was carefully designed before it was implemented, and students are encouraged to complete some readings before class.

III. RESULT AND DISCUSSION

Hypothesis

Use of simulations based formative assessment can be a powerful strategy for enhancing the teaching of Physics, aiding in the comprehension of complex abstract ideas that involves comparing the underdamped, critically damped and overdamped motion. Energy, wavefunction and probability associated with particle trapped in 1 dimensional infinite potential well, the basic interactions involved in the laser production such as absorption and emission, the importance of metastable state and role of optical resonator cavity, the exact conditions required for total internal reflections and why it is required in optical fibers etc. Integrating simulation-based teaching methods allows students to grasp challenging theoretical concepts in Physics that might otherwise be difficult to visualize. This, in turn, has the potential to enhance students' academic performance by helping them better understand these concepts, leading to improved results in the examination.

The proposed hypothesis is not new and previously used in other pedagogical studies involved with simulation-based teaching. We were interested to check the validity of this hypothesis on our students as majority of our students are from rural background and also, they are first year students. Many times, we observed that first year student’s response to activity-based teaching becomes crucial as they are not much familiar with this type of teaching methodology in their earlier studies. So, for us it has been challenging task actually to make the students comfortable and participate in the activity.

Variables:

Independent variable: Use of simulation based formative assessment as an active learning strategy

Dependent variables: Performance of students in written exam.

Null hypothesis (H0): There is no significant difference between the performance of F.Y. B. Tech students using simulation based formative assessment

Alternative hypothesis (Ha): The implementation of simulation based formative assessment as an active learning strategy significantly improves the learning of the abstract concepts in Physics and examination performance of F.Y. B. Tech students.

Written Examination

The written examination is a conducted for 1 hour based on content taught using simulation for 25 marks.

TABLE II
PERFORMANCE OF CONTROL AND EXPERIMENTAL GROUP IN WRITTEN EXAMINATION

	No. of Students	
Marks	**Control**	**Experimental**
25	0	2
24-20	15	32
19-15	16	14
14-10	16	14
Less than 10	22	7

The Table II, illustrates the recorded marks attained by both control and experimental group in the written test. Notably, the findings reveal a considerable disparity in performance between the two groups. The experimental group exhibits enhanced academic performance in comparison to the control group. Particularly noteworthy is the observation that a significant proportion of students (approximately 49%) in the experimental group have achieved scores exceeding 20 marks. It is worth noting that in the experimental group, only 7 students achieved scores below 10 marks, whereas the control group had a higher count of 22 students in this lower score range, The graphical representation of this result is shown in Fig. 6.

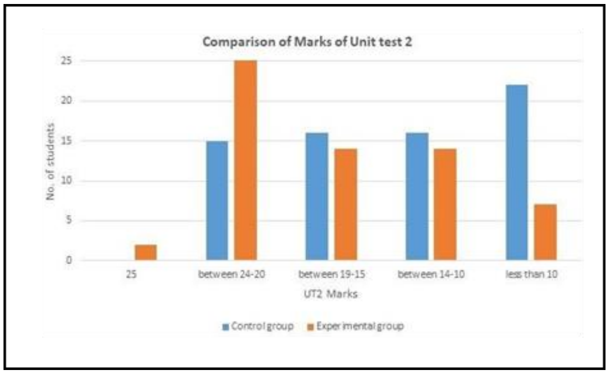

Fig. 6 Graph showing comparison of marks received by the control and experimental group after written test

TABLE III
SUMMARY OF SCORE IN WRITTEN TEST OF CONTROL AND EXPERIMENTAL GROUP

Groups	N	Mean	Std.	t	df	Sig. (2 tailed)
Control	69	13.5	6.41	4.02	133	9.66E-05
Experimental	69	17.6	5.54			

Independent samples t-test as seen in Table III, revealed that there was a significant difference between performance of control and experimental group. The mean value indicated that participants from experimental group showed more achievement in written test with mean score of 17.6 while control group students scored 13.5. The significant value for the test is less than 0.05 so rejecting the null hypothesis and accepting the alternative hypothesis that there is a significant difference between achievements of students in experimental group due to simulation based formative assessment.

TABLE IV
SUMMARY OF SCORE IN FINAL END SEMESTER EXAM OF CONTROL AND EXPERIMENTAL GROUP

Grade	Control	Experiment
Number of Samples	69	69
Highest Score	94	95
Lowest Score	5	26
Average	56.57	63.853

Moreover, in order to assess the enduring impact of the proposed approach, we also analyzed students' scores in the end semester examination and is shown in table IV. The end semester examination is a written examination of 100 marks with a 3-hour duration. The table shows the highest, lowest, and average scores for the control and experimental groups, respectively. From it, we again observed a good average score for the experimental group, which is 63.85 compared to 56.57 for the control group. The improved performance can be attributed to better understanding of abstract concepts through simulation based formative assessment. Finally, we collected online feedback about this teaching technique from the experimental group. The responses of it in the form of pie chart is shown in Fig. 7 and 8.

Fig. 7. Feedback of the students about the simulation-based teaching strategy

Fig. 8. Feedback of the students about the simulation-based teaching strategy

The majority of students (66%) considered this activity simple and enjoyable. They also agreed that this method aids in improving conceptual grasp of the content.

IV. CONCLUSIONS

In essence, the study's results highlight the impact of simulation-based formative assessment on students' learning within an engineering physics course. The findings indicate that the integration of simulation-based strategies with formative assessment contributes to students achieving both a strong conceptual understanding and favorable grades. This confirms the validity of hypothesis that simulation based formative assessment has significant effect on the performance of the students instead of just showing the simulations in the class as confirmed by t test and performance of students in written examinations. Notably, 66% of students expressed satisfaction with this approach, finding it straightforward, enjoyable, and beneficial for grasping concepts. The application of this teaching method may encourage physics instructors to expand their pedagogical approaches by incorporating formative assessment techniques alongside simulations. The study's findings clarify how, in our particular educational setting, the use of simulation-based learning offers insightful information about student involvement and comprehension. Building on these findings, future work will concentrate on improving and expanding the range of simulation-based activities in the curriculum. We intend to gather feedback from educators and students in order to maximize the effectiveness of simulations and better serve the unique requirements of our student body, especially those from rural backgrounds and first-year students. Furthermore, we want to investigate the long-term effects of simulation-based learning on students' knowledge retention.

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