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From Simulation to Solution: Examining Algodoo-Enhanced Collaborative Learning for Developing Physics Education Students' Problem-Solving and Divergent Thinking Skills in South-Western, Nigeria

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Abstract

The teaching and learning of physics in Nigerian schools still relies heavily on conventional laboratory practices where students observe handbook demonstrations, follow prescribed procedures and arrive at predetermined answers. While the Traditional Demonstration-Cookbook Laboratory Method has served its purpose over the years, its continued effectiveness regarding how students are being prepared for future physics learning environment raises concern. This concern becomes more worrisome with the growing move towards computer-based and technology-supported assessment in Nigeria. Against this background, this study examined the use of Algodoo-enhanced collaborative learning as an alternative approach for developing physics education students' problem-solving and divergent thinking skills in South-western, Nigeria. Algodoo provides a virtual environment where learners construct, manipulate and test physics models, observe the consequences of changing variables and can discuss possible solutions with their peers. It adopted a quasi-experimental approach involving 67 physics education students across universities in South-western, Nigeria. Data were collected using Classroom Observation Protocol for Undergraduate Students and Physics Divergent Thinking Instrument and analysed using descriptive statistics, ANCOVA and MANCOVA. The study was guided by the view that technology should not merely replace physical laboratory equipment but provide learners with opportunities to think, try out ideas, make mistakes, revise their approaches and learn from one another. Findings revealed that the group exposed to Algodoo-enhanced collaborative learning demonstrated significantly higher problem-solving and divergent thinking skills in physics compared to their counterpart in the control group ($p < 0.05$). Interaction effect of digital literacy was observed. The study concluded that Algodoo-enhanced learning improved the SDG skills of quality education. These findings therefore have implications for strengthening physics teacher preparation towards a more flexible combination of physical and virtual laboratory experiences in Nigerian education.

Background to the Study

Science education requires more than the memorization of laws, definitions, and mathematical procedures. For learning of physics to be effective, learners should be able to interpret illustrations, identify variables that are relevant, connect theoretical principles with observable events, generate possible explanations, and evaluate different solutions. These necessities make problem-solving and divergent thinking important outcomes of physics teacher education. Physics problem-solving requires understanding a situation, identifying appropriate principles, developing procedures, and evaluating the results obtained (Diani, Aanggoro & Suryani, 2023). Divergent thinking in physics, on the other hand, is the ability to generate multiple ideas or approaches to a problem and is commonly expressed through flexibility, fluency, originality, and elaboration (Hidayati, Supriyati, & Buti, 2021). A physics learner who possesses both capacities will no doubts be better prepared to confront unfamiliar problems and design impactful scholarly experiences for future learners of physics as a teacher.

Despite these requirements, Omosule, et. al., (2026) submitted that physics learning in Nigeria is often experienced as a process of making learners reproduce worked examples, apply familiar procedures, and conscripting them to arrive at predetermined answers. They noted further that Traditional Demonstration-Cookbook Laboratory Method (TD-CLM), although useful for demonstrating procedures and reinforcing established principles, may offer limited opportunities for neophytes to manipulate representations, investigate "what-if" situations, explore alternative explanations, or defend competing solutions. This concern is particularly important in teacher education because prospective teachers are often seen as reproducing the instructional approaches with which they themselves were trained, even when such approaches may not adequately prepare them for contemporary classroom realities. The challenge becomes more worrisome when access to physical laboratories are marred with inadequate facilities, equipment breakdown, equipment-students' ratio, institutional closures, and other constraints.

Empirical evidence from Babajide, Omosule and Akinlo (2025) revealed that collaborative and learner-centred approaches to science education can improve academic achievement, reduce anxiety, and create opportunities for students to negotiate, explain and refine scientific ideas within supportive learning environments. Developing these capacities is therefore important in physics teacher education, where students are expected not only to understand scientific principles but also to apply them flexibly in solving problems. In the same vein, Awodun, (2024) opined that practical physics in many higher-education contexts remains largely dominated by traditional demonstration-cookbook laboratory instructions. The report noted that such practices, no doubts, limit opportunities for students to visualise abstract phenomena, test alternative explanations, communicate ideas, and construct solutions collaboratively. This does not suggest that the conventional physical laboratory has lost its relevance. Rather, it means that its limitations can be complemented by learning environments that allow students to discover phenomena beyond what is immediately possible with available laboratory facilities.

Although virtual simulation cannot completely replace the value of hands-on practical, it provides a useful complementary environment for making abstract and difficult physics situations more visible and manipulable. This is predominantly relevant because education, knowledge acquisition, evaluation, and practical work are progressively becoming influenced by digital technologies. The issue in physics teaching is therefore no longer about whether learners should continue to perform practical activities in the traditional laboratory, but whether these ones are being nurtured or equipped to investigate and solve problems relating to physics within increasingly digital learning and assessment environments. The need for this form of preparation is fast becoming more irresistible by the day, following the change in direction of educational assessment in Nigeria.

The West African Examinations Council (WAEC), for instance has announced plans towards computer-based assessment, including the eventual adoption of virtual practical examinations (WAEC, 2025). This advancement has significant consequences for physics educators across the country because, if learners are expected to demonstrate practical competence through digital environments, then their preparation will no longer be limited to manipulating physical apparatus and following prescribed laboratory procedures alone. They would have required to interact with digital representations of physical phenomena, control variables, manipulate quantities, test predictions, interpret outcomes, and make decisions based on digitally driven evidence. For prospective physics teachers, this means that teacher education programmes need to expose them to forms of practical engagement that are consistent with the changing nature of science teaching and assessment. Virtual practical experiences, when appropriately designed and effectively implemented, can therefore serve as a bridge between conventional laboratory experiences and the emerging digital demands of physics instruction.

Digital simulation remains a complementary means of addressing some of the limitations associated with purely verbal, symbolic, or demonstration-based instruction. Gokhan and Orhan, (2023) submitted that it allows learners to visualise motion, direction of forces, interactions, and changes in system variables while repeatedly testing predictions and examining the consequences of their decisions. Evidence from computer-assisted instruction has similarly reported positive effects on students' physics achievement and interest, while emphasising the importance of teacher preparedness, infrastructure, and institutional support (El Kharki et al., 2021). These findings support the educational value of simulation, but they do not suggest that technology alone produces deeper reasoning. A simulation may become nothing more than another method of displaying information if learners merely watch what happens without predicting, questioning, manipulating, making inference, explaining, and evaluating the results. Its educational value therefore depends largely on how it is integrated into purposeful tasks, interaction, feedback, and reflection.

Among available simulation tools, Euler and Gregorcic, (2019) submitted that Algodoo is particularly relevant because it is not restricted to the passive observation of pre-programmed demonstrations. They noted further that within the Algodoo environment, learners can construct scenes, introduce objects and forces, modify physical parameters, and observe the

consequences of their manipulations and decisions. The platform provides opportunities for learners to move beyond confirming practical manual answers to exploring how changes to a system result in different outcomes. This makes Algodoo suitable for inquiry-oriented activities and tasks in which learners may arrive at more than one valid representation, explanation, or solution. Research on Algodoo has described it as a relatively less-constrained digital learning environment in which students can engage in self-directed activity, while teachers can observe their actions and provide appropriate guidance (Aufa & Patricia, 2025).

The potential of Algodoo becomes even more meaningful when it is combined with collaborative learning. Physics problems are not always solved through individual effort; learners often benefit from explaining their reasoning to others, questioning assumptions, comparing approaches, and jointly deciding which solution is most reasonable (Omosule et al., 2026). To buttress this, Gokhan and Orhan, (2023) noted that in collaborative inquiry involving Algodoo, students have been reported to use speech, gestures, and visual elements displayed on the screen to communicate complex ideas that may initially be difficult to express verbally. Such interaction is important in physics education because learners frequently need to coordinate equations, diagrams, motion, measurements, and verbal explanations in making sense of a phenomenon. When students work together within a simulation environment, the technology provides a common space around which their ideas can be tested and discussed, while the collaborative process provides opportunities for those ideas to be questioned, modified, and refined. It is against this background that this study examines Algodoo-enhanced collaborative learning as a strategy for developing physics education students' problem-solving and divergent thinking skills in South-western Nigeria. The study is based on the position that simulation technology should not be treated as a replacement for the physical laboratory or as an end in itself. Rather, its value lies in what learners are enabled to do with it. When a virtual environment is combined with carefully structured collaborative tasks, students can be given opportunities to predict, manipulate, investigate, discuss, generate alternative solutions, and reflect on the outcomes of their decisions. Such experiences may end up providing a useful pathway for developing the flexible thinking and problem-solving capacities required of contemporary physics learners and future physics teachers, irrespective of their digital literacy levels (high or low).

Algodoo's open-ended environment creates a plausible bridge between simulation and divergent thinking. Through the tool, learners may represent a physical situation in different ways, generate multiple hypotheses, and explore alternative designs. While broader integrated STEM research has reported its positive effects on problem-solving, scientific creativity, and critical-thinking dispositions (Hwang, 2020), yet the existing literature nonetheless reveals a gap. Much of the available research examines achievement, conceptual understanding, interest, or general creativity rather than the combined development of physics problem solving and divergent thinking. In addition, evidence specifically involving physics education students in Lagos State is limited. Though many Nigerian studies demonstrate the promise of computer-assisted instruction and collaborative laboratory pedagogy, they do not sufficiently explain how an open-ended simulation functions when embedded in structured peer collaboration. The present study addresses this gap by

examining whether Algodoo-enhanced collaborative learning can improve both the quality of students' physics solutions and their capacity to generate varied, original, and elaborated approaches to physics problems.

Statement of the Problem

With WAEC's planned transition to virtual practical examinations by 2030, the continued reliance on traditional practical approaches raises serious concerns about students' readiness for a digitally driven physics assessment. Physics education students need strong problem-solving, divergent thinking, and digital skills to prepare future learners for this emerging reality. If teachers themselves are deficient in these competencies, what should we expect from the students they teach? This creates an urgent need to explore simulation-supported approaches such as Algodoo-enhanced collaborative learning.

Purpose of the Study

This study examined the influence of Algodoo-enhanced collaborative learning on physics education students' problem-solving and divergent thinking skills in South-western Nigeria, with particular attention to whether students' level of digital literacy moderates the effect of the instructional strategy on these skills.

Research Questions

i. What is the difference in the mean problem-solving skill scores of physics education students exposed to Algodoo-enhanced collaborative learning and those exposed to the Traditional Demonstration-Cookbook Laboratory Method (TD-CLM)?
ii. What is the difference in the mean divergent thinking skill scores of physics education students exposed to Algodoo-enhanced collaborative learning and those exposed to the Traditional Demonstration-Cookbook Laboratory Method (TD-CLM)?
iii. What are the mean problem-solving and divergent thinking skill scores of physics education students exposed to Algodoo-enhanced collaborative learning and TD-CLM across low and high levels of digital literacy?

Research Hypotheses

i. There is no significant main difference in the mean problem-solving skill scores of physics education students exposed to Algodoo-enhanced collaborative learning and those exposed to the Traditional Demonstration-Cookbook Laboratory Method (TD-CLM).
ii. There is no significant main difference in the mean divergent thinking skill scores of physics education students exposed to Algodoo-enhanced collaborative learning and those exposed to the Traditional Demonstration-Cookbook Laboratory Method (TD-CLM).
iii. There is no significant influence of digital literacy level and instructional strategy on physics education students' problem-solving and divergent thinking skills.

Methodology

The study adopted a quasi-experimental, pretest-posttest, non-equivalent control group design. With a population of 80 (200 level) university physics education students in South-western Nigeria, a sample size of 67 participants was randomly assigned into experimental and control group, using Taro Yamane's (1967) sample size formula. Two universities, having 33 participants were randomly assigned to the Algodoo-enhanced collaborative learning group, and 34 participants in two other universities were assigned for the Traditional Demonstration-Cookbook Laboratory Method (TD-CLM) group. Students in the experimental group engaged in collaborative practical activities using Algodoo, while those in the control group received instruction through the conventional laboratory approach. Data were collected through validated instruments for measuring physics problem-solving and divergent thinking skills, as well as a Digital Literacy Assessment Instrument used in classifying participants into low and high digital literacy levels. Answers were provided to research questions raised using descriptive statistics, while ANCOVA and MANCOVA were used to test the hypotheses at the 0.05 level of significance.

Results

Research Question One: What is the difference in the mean problem-solving skill scores of physics education students exposed to Algodoo-enhanced collaborative learning (Alg+CL) and those exposed to the Traditional Demonstration-Cookbook Laboratory Method (TD-CLM)?

Table 1: Mean and Standard Deviation of Physics Education Students' Problem-Solving Skill Scores by Instructional Strategy (Algodoo-Enhanced Collaborative Learning, Alg+CL Versus Traditional Demonstration-Cookbook Laboratory Method, TD-CLM)

Strategy	N	Pre-Test Mean	Pre-Test SD	Post-Test Mean	Post-Test SD	Mean Diff.
Alg+CL	33	15.61	1.71	32.24	3.31	16.63
TD-CLM	34	15.62	1.67	22.68	2.21	7.06
Total	67	15.61	1.68	27.39	5.58	11.78

Table 1 shows that the Alg+CL group had a pre-test mean score of 15.61 (SD = 1.71), which increased to 32.24 (SD = 3.31) at post-test, giving a mean difference of 16.63. The TD-CLM group, on the other hand, increased from a pre-test mean of 15.62 (SD = 1.67) to a post-test mean of 22.68 (SD = 2.21), with a mean difference of 7.06. Thus, students exposed to Alg+CL recorded a noticeably higher improvement in problem-solving skill than those taught using TD-CLM. This suggests that the Alg+CL strategy provided a more supportive learning experience for developing students' problem-solving skills.

Research Hypothesis One: There is no significant main difference in the mean problem-solving skill scores of physics education students exposed to Algodoo-enhanced collaborative learning and those exposed to the Traditional Demonstration-Cookbook Laboratory Method (TD-CLM).

Table 2: ANCOVA, Estimated Marginal Means and Pairwise Comparison of Physics Education Students' Problem-Solving Skill by Instructional Strategy

Strategy	Adj. Mean	Std. Error	Type III SS	df	Mean Diff.	F	Sig.	Partial η^2
Alg+CL	32.24	0.50	1532.69	1	1532.69	187.09	< 0.001	0.75
TD-CLM	22.68	0.49						

Table 2 shows that instructional strategy had a significant influence on students' problem-solving skill, $F(1, 64) = 187.09$, $p < 0.001$, partial $\eta^2 = 0.75$. Further probe showed that students exposed to Alg+CL recorded a higher adjusted mean score ($M = 32.24$, $SE = 0.50$) than those exposed to TD-CLM ($M = 22.68$, $SE = 0.49$). The mean difference of 9.57 points were significant, 95% CI [8.17, 10.96], $p < 0.001$. Hence, the null hypothesis was rejected, indicating that Alg+CL produced significantly higher problem-solving scores than TD-CLM.

Research Question Two: What is the difference in the mean divergent thinking skill scores of physics education students exposed to Algodoo-enhanced collaborative learning and those exposed to the Traditional Demonstration-Cookbook Laboratory Method (TD-CLM)?

Table 3: Mean and Standard Deviation of Physics Education Students' Divergent Thinking Skill Scores by Instructional Strategy (Algodoo-Enhanced Collaborative Learning, Alg+CL Versus Traditional Demonstration-Cookbook Laboratory Method, TD-CLM)

Strategy	N	Pre-Test Mean	Pre-Test SD	Post-Test Mean	Post-Test SD	Mean Diff.
Alg+CL	33	15.61	1.66	24.18	5.15	8.57
TD-CLM	34	15.74	1.76	18.91	1.33	3.17
Total	67	15.67	1.70	21.51	4.56	5.84

Table 3 shows that the Alg+CL group improved from a pre-test mean of 15.61 (SD = 1.66) to a post-test mean of 24.18 (SD = 5.15), giving a mean difference of 8.57. In comparison, the TD-CLM group increased from 15.74 (SD = 1.76) to 18.91 (SD = 1.33), with a mean difference of 3.17. Thus, students exposed to Alg+CL recorded a considerably greater improvement in divergent thinking than those exposed to TD-CLM. The observed difference suggests that Alg+CL may be more effective in promoting students' divergent thinking skills. The statistical significance of this difference is, however, determined by the corresponding hypothesis test.

Research Hypothesis Two: There is no significant main difference in the mean divergent thinking skill scores of physics education students exposed to Algodoo-enhanced collaborative learning and those exposed to the Traditional Demonstration-Cookbook Laboratory Method (TD-CLM).

Table 4: ANCOVA, Estimated Marginal Means and Pairwise Comparison of Physics Education Students' Divergent Thinking Skill by Instructional Strategy

Strategy	Adj. Mean	Std. Error	Type III SS	df	Mean Diff.	F	Sig.	Partial η^2
Alg+CL	24.20	0.65	469.52	1	5.30	33.46	< 0.001	0.34
TD-CLM	18.90	0.64						

Table 4 shows that instructional strategy had a significant influence on students' divergent thinking skill, $F(1, 64) = 33.46$, $p < .001$, partial $\eta^2 = 0.34$. Further investigation revealed that students exposed to Alg+CL had a higher adjusted mean score ($M = 24.20$, $SE = 0.65$) than those exposed to TD-CLM ($M = 18.90$, $SE = 0.64$). The mean difference of 5.30 was statistically significant, 95% CI [3.47, 7.13], $p < 0.001$. Therefore, the null hypothesis two was rejected. The partial η^2 of 0.34 indicates a substantial influence of instructional strategy on students' divergent thinking skill.

Research Question Three: What are the mean problem-solving and divergent thinking skill scores of physics education students exposed to Algodoo-enhanced collaborative learning and TD-CLM across low and high levels of digital literacy?

Table 5: Mean and Standard Deviation of Students' Problem-Solving and Divergent Thinking Skills by Instructional Strategy and Digital Literacy Level

Strategy	Digital Literacy Level	N	Probl_Solv.	SD	Div. Think.	SD
Alg+CL	Low	24	30.33	0.92	21.21	1.41
	High	9	37.33	1.12	32.11	1.76
TD_CLM	Low	28	22.68	2.39	18.86	1.15
	High	6	22.67	2.07	19.17	2.14

Table 5 shows that within the Alg+CL group, students with high digital literacy recorded higher mean scores in both problem-solving ($M = 37.33$, $SD = 1.12$) and divergent thinking ($M = 32.11$, $SD = 1.76$) than those with low digital literacy ($M = 30.33$, $SD = 0.92$; $M = 21.21$, $SD = 1.41$), respectively. However, the pattern was different for the TD-CLM group, where low- and high-digital-literacy students recorded almost similar problem-solving means ($M = 22.68$ and 22.67), while the high-literacy group had only a slightly higher divergent-thinking mean ($M = 19.17$) than the low-literacy group ($M = 18.86$). Overall, the descriptive results suggest that digital literacy may be particularly beneficial when students are exposed to Alg+CL. The statistical significance of this pattern is determined by the interaction test in the corresponding hypothesis.

Research Hypothesis Three: There is no significant influence of digital literacy level and instructional strategy on physics education students' problem-solving and divergent thinking skills (PSS and DT).

Table 6: Multivariate Test of the Interaction Influence of Instructional Strategy and Digital Literacy Level on Students' Problem-Solving and Divergent Thinking Skills

Effect	Pillai's V	F	Hyp df	Error df	Sig	Partial η^2
Strategy*Digital Literacy levels	0.77	100.53	2	60	<0.001	0.77

Table 6 shows the multivariate test of the interaction influence of instructional strategy and digital literacy level on students' problem-solving and divergent thinking skills. The result indicates a statistically significant interaction influence, Pillai's Trace = 0.77, $F(2, 60) = 100.53$, $p < 0.001$, partial $\eta^2 = 0.77$. This means that the influence of instructional strategy on the combined measures of problem-solving and divergent thinking skills differed according to students' level of digital literacy. The partial eta squared value of 0.77 also indicates a very large interaction influence. Therefore, the null hypothesis, which states that there is no significant interaction influence of instructional strategy and digital literacy level on students' problem-solving and divergent thinking skills, was rejected.

Table 7: Tests of Between-Subjects Effects of the Interaction Influence of Instructional Strategy and Digital Literacy Level on Students' Problem-Solving and Divergent Thinking Skills

Variable	Source	Type II SS	Df	MS	F	Sig	Partial η^2
PSS	Strategy*Digital Literacy levels	129.56	1	129.56	157.14	<0.001	0.39
DT Skills	Strategy*Digital Literacy levels	310.84	1	310.84	39.56	<0.001	0.71

Table 7 provide further information on the interaction influence of instructional strategy and digital literacy level on each of the two dependent variables. For problem-solving skills, the interaction between instructional strategy and digital literacy level was statistically significant, $F(1, 61) = 157.14$, $p < 0.001$, partial $\eta^2 = 0.39$. This indicates that the influence of the instructional strategy on students' problem-solving skills varied significantly across the low and high digital literacy groups. The partial eta squared of 0.39 suggests a substantial interaction influence. Similarly, the interaction between instructional strategy and digital literacy level had a statistically significant influence on divergent thinking skills, $F(1, 61) = 39.56$, $p < 0.001$, partial $\eta^2 = 0.71$. This shows that the influence of the instructional strategy on divergent thinking skills was also dependent on students' level of digital literacy. The partial eta squared value of 0.71 indicates a very large interaction influence.

Taken together, the findings demonstrate that digital literacy significantly conditioned the influence of the instructional strategy on both problem-solving and divergent thinking skills. The significant multivariate interaction and the significant univariate interaction effects provide sufficient evidence to reject the third null hypothesis.

Discussion

Findings from this study provided empirical evidence on the contribution of Algodoo-enhanced collaborative learning to the development of physics education students' problem-solving and divergent thinking skills. For problem-solving skills, students exposed to Algodoo-enhanced collaborative learning recorded a higher post-test mean and a substantially greater mean gain than those taught using the Traditional Demonstration-Cookbook Laboratory Method (TD-CLM). The ANCOVA result further showed a significant influence of instructional strategy on problem-solving skills, with a large effect size. This finding supports that of Hwang, (2020) who submitted that allowing students to construct, manipulate and test physics situations virtually provided more opportunities to engage actively with problems rather than merely following prescribed procedures. The collaborative component strengthened these benefits, by allowing learners to explain their reasoning, compare approaches and correct one another during practical activities.

A similar pattern was observed for divergent thinking. Students in the Algodoo-enhanced collaborative learning group recorded a greater improvement than their counterparts in the TD-CLM group, and the ANCOVA revealed a significant influence with a substantial effect size. This is attributed to the open-ended nature of Algodoo, where students alter variables, try different arrangements and immediately observe the consequences of their decisions. Such freedom is less prominent in a demonstration-cookbook environment, where learners are often made to follow predetermined steps towards an expected answer. This finding is in line with that of Hidayati at al., (2021) who found that digital literacy aids students divergent thinking.

The study also established that digital literacy significantly interacted with instructional strategy in influencing both problem-solving and divergent thinking. The strong interaction effect shows that students' ability to use digital tools profoundly shaped the extent to which they benefited from the simulation-supported approach. This is in line with the finding of Akinoso (2026). Taken together, these findings suggested that Algodoo-enhanced collaborative learning is promising for physics teacher education, but its effectiveness is likely to be strongest when students possess adequate digital literacy and are properly guided in using the technology.

Recommendations

From the above findings arose the following recommendations:

i. Lecturers should redesign selected practical activities as open-ended simulation tasks rather than predetermined experiments. Students should be given problems for which they can construct different scenes, manipulate parameters and investigate more than one possible solution.
ii. Collaborative groups should be deliberately structured during Algodoo-based practical sessions. Each group may be assigned roles such as simulation designer, data recorder, checker and presenter so that participation will go beyond one technologically confident student doing the entire activity.

iii. Digital literacy should be assessed before students commence simulation-intensive practical work. Students with limited digital skills should be given preliminary hands-on orientation before being allowed to participate in collaborative Algodoo activities.
iv. Students with stronger digital literacy should be given more challenging simulation responsibilities rather than being merely used as technical assistants. They should be encouraged to explain their procedures to colleagues and contribute to the scientific reasoning behind the simulations.
v. Universities should consider establishing regular simulation-based practical sessions alongside physical laboratory work, rather than treating computer simulation as a replacement for the conventional laboratory. This would allow students to experience both actual apparatus and virtual manipulation.
vi. Universities preparing future physics teachers should include digital simulation competence in practical-methods courses. They should graduate with the ability to select appropriate simulation tools, design collaborative activities and guide secondary school students in using them for conceptual and problem-solving purposes.

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