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HOW MODERN TEACHING TECHNOLOGIES INFLUENCE STUDENT ENGAGEMENT AND PERFORMANCE IN STEM SUBJECTS

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ABSTRACT

In this paper, we present an analysis of the relevance of traditional teaching methods for the exact sciences in the context of rapid technological advancement in education. The study offers a comparative evaluation of three instructional categories used in higher education: traditional theoretical instruction (classical lectures), conventional laboratory experiments (with standard assembly), and virtual simulators for physical phenomena. The research is based on quantitative data from 300 students, who completed a structured questionnaire using an eight-item Likert scale. The instrument measured perceptions regarding clarity of presentation, interest, learning motivation, independent exploration, concept retention, understanding of inter-concept relationships, and the practical applicability of the knowledge acquired. Statistical analysis reveals significant differences among the evaluated methods. Interactive and experimental approaches, particularly simulations, were perceived as more effective than traditional lectures in promoting deep conceptual understanding, critical thinking, and learner autonomy. Strong correlations indicate that such methods stimulate motivation and active cognitive involvement. Nevertheless, the relevance of traditional methods—lectures and classic hands-on activities—in structuring fundamental concepts remains evident. Therefore, a hybrid approach is recommended, one that leverages the complementarities of traditional methods and modern technologies, while maintaining a balance between direct, concrete experience and the flexibility offered by digital tools.

Keywords: STEM; teaching methods; simulation; experimentation; data analysis;

INTRODUCTION

In the context of the advent of new teaching technologies, the question arises: ‘Do classical didactic technologies for teaching the exact sciences still have a place in university education?’



In this paper, we aim to explore the relevance and complementarity of traditional teaching methods concerning emerging technologies, highlighting their advantages, challenges, and strategies for integration. We maintain that classical didactic tools—such as lectures, traditional experimental methods, and the use of textbooks—continue to play an important role in teaching the exact sciences. These approaches have been honed over time and have proven effective in facilitating the understanding of fundamental concepts.

Lectures delivered by experienced teachers continue to be a cornerstone of university education. They enable the structured and coherent presentation of material, aid comprehension of complex ideas through detailed explanations and real-world examples, and provide opportunities for immediate, direct interaction between students and faculty to clarify misconceptions.

Textbooks and printed resources offer a solid knowledge base and remain invaluable reference tools. They support systematic treatment of topics and are especially useful for review and reinforcement of learning. Moreover, engaging with textbooks fosters independent study skills and critical analysis.

Online platforms can augment traditional lectures by providing supplementary materials and interactive exercises. Such platforms allow students to revisit course content, access additional resources, and engage in discussion forums, thereby extending learning beyond the classroom walls.

Traditional hands-on experimental methods have long demonstrated their importance in practical science education. By working with real equipment under controlled conditions, students cultivate essential laboratory skills. The direct contact with materials and phenomena is difficult to replicate fully through virtual means. Taking all that into consideration, virtual simulations can serve as valuable preparatory tools for in-person labs, offering students a preliminary grasp of procedures before they enter the physical laboratory. Simulations are also well suited to illustrating phenomena that are impractical or unsafe to reproduce in a real-world setting. Integrating new technologies into university education presents both challenges and opportunities for creating a more efficient, adaptable learning environment.

Traditional experimental methods have again proven their value for practical training in the exact sciences. They provide irreplaceable hands-on experience and skill development, which virtual simulations alone cannot entirely substitute.

Modern technologies can personalize the learning process by providing adaptive feedback and support, while augmented and virtual reality applications can create immersive learning experiences that make understanding abstract concepts easier. These technologies can be integrated in a complementary fashion to create a hybrid learning environment that maximizes the benefits of both approaches.

1. LITERATURE REVIEW

Over the years, physics educators have sought the most effective pedagogical methods for teaching this discipline. Several studies have compared traditional instructional techniques with experimental approaches in physics education.

Wilcox and Lewandowski's (Wilcox și Lewandowski, 2016) paper, "Impact of Instructional Approach on Students' Epistemologies about Experimental Physics," analyzes students' responses to the E-CLASS questionnaire (Colorado Learning Attitudes about Science Survey for Experimental Physics) applied in university experimental physics labs. The authors conclude that incorporating application-oriented hands-on activities into physics laboratories helps students develop expert-like conceptions of experimentation, compared to labs in which activities are highly standardized and predetermined.

In "Secondary Analysis of Teaching Methods in Introductory Physics: A 50 k Student Study" (Von Korff *et al.*, 2016), the authors examine Force Concept Inventory (FCI) and Force and Motion Conceptual Evaluation (FMCE) data from approximately 50,000 students in introductory physics courses. Their findings indicate that interactive learning techniques are significantly more effective than traditional lectures in promoting conceptual learning gains.

In (Smith și Holmes, 2017) the authors compare three common approaches in university physics instruction that all follow the predict–observe–explain pattern but yield different educational outcomes. They discuss possible mechanisms—prediction, cognitive load, and student engagement—that explain measurable



differences in learning gains, and they recommend that laboratory courses be redesigned to emphasize genuine experimentation and reflection rather than mere verification.

A comparative analysis of these three studies converges on the need for a pedagogical approach that activates students' cognitive engagement and leverages the complementarities between traditional and innovative methods. First, interactive-engagement methods—including activities that require students to predict, observe, and explain—generate significantly higher learning gains than traditional lectures, regardless of class size, institution type, or students' initial preparation (as evidenced by FCI and FMCE results). Second, comparing classical experiments, traditional demonstrations, and modern, technique-enhanced demonstrations shows that effective laboratory work must allow students to formulate their own hypotheses, manage their informational load, and actively integrate new knowledge; absent these elements, classical labs do not deepen conceptual understanding. Third, curricular reforms (e.g., ISLE, Modeling Instruction, Studio Physics, SCALE-UP) have a dual impact: they enhance students' understanding of the experimental process and their epistemological attitudes, and they contribute to narrowing the gender gap by providing proportionally greater benefits to female students.

2. RESEARCH METHODOLOGY

Using a quantitative research approach, we set out to analyse the impact of different learning methods on university students, including classical experimentation, simulation of physical phenomena, and traditional demonstrations.

2.1. Data and Sample

Data from 300 participants were analyzed, with the research instrument consisting of the questionnaire whose structure is presented in Table 1.

Table 1. Questionnaire Structure

Question	Statement	Traditional Theoretical Instruction	Classical Assembly Labs	Simulation of Physical Phenomena
Q1	The taught material was easy to understand			
Q2	It captured my attention and interest			
Q3	It helped me understand physical phenomena			
Q4	It motivated me to learn more			
Q5	It encouraged me to ask questions and explore			
Q6	I retained the taught concepts better			
Q7	I understood the relationships between concepts better			
Q8	I feel that I could apply the knowledge in real life			

Each statement was rated on a 1–5 Likert scale as follows:

1 – Strongly disagree; 2 – Somewhat disagree; 3 – Neutral; 4 – Somewhat agree; 5 – Strongly agree.

2.2. Data Analysis and Results

The first step in analyzing the data collected from respondents was to assess the internal consistency of the items (Q1–Q8). To this end, a reliability analysis was performed (Table 2), yielding Cronbach's alpha values above 0.90 for all three instructional methods (A, B, and C), which indicates strong internal consistency.



Table 2. Scale Reliability Statistics

Method	Scale Reliability Statistics (Cronbach's α)
A	0,931
B	0,910
C	0,905

For each of the three instructional approaches examined (A – Theoretical Instruction, B – Classic Assembly Labs, C – Simulation of Physical Phenomena), over 40 % of respondents awarded scores of 4 (Agree) or 5 (Strongly Agree).

In Figure 1, the response frequencies for each individual questionnaire item under Method A are plotted. Similarly, for Method B (Classic Assembly Labs), Figure 2 displays the frequency of responses for each questionnaire item. Figure 3 also contains the students’ rates for all eight items for the theoretical-instruction condition.

	Q1a	Q2a	Q3a	Q4a	Q5a	Q6a	Q7a	Q8a
1	4	25	9	32	38	29	30	42
2	44	48	40	61	42	34	48	36
3	78	80	100	83	72	71	63	84
4	111	69	78	69	82	100	84	78
5	63	78	73	55	66	66	75	60

Figure 1. Distribution of Scores for Case A

	Q1b	Q2b	Q3b	Q4b	Q5b	Q6b	Q7b	Q8b
1	3	0	2	34	31	3	6	12
2	11	26	26	36	41	39	27	24
3	64	61	68	70	56	75	75	72
4	120	90	102	81	70	108	105	102
5	102	123	102	79	102	75	87	90

Figure 2. Distribution of Scores for Case B

	Q1c	Q2c	Q3c	Q4c	Q5c	Q6c	Q7c	Q8c
1	0	2	0	12	17	0	3	9
2	12	10	6	29	18	18	15	12
3	21	30	42	69	55	36	45	63
4	93	51	99	73	80	104	78	72
5	174	207	153	117	130	142	159	144

Figure 3. Distribution of Scores for Case C

We observed that the frequency of “Agree” (4) and “Strongly Agree” (5) responses is greater than the frequency of the rest of the answers (Figure 4).

“Agree” and “Strongly Agree” ratings	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
MethodA	58%	49%	50%	41%	49%	55%	53%	46%
MethodB	74%	71%	68%	53%	57%	61%	64%	64%
MethodC	89%	86%	84%	63%	70%	82%	79%	72%

Figure 4. The cumulative proportion of “Agree” and “Strongly Agree” ratings



For example, considering Method B (Classic Assembly Labs), the cumulative proportion of “Agree” and “Strongly Agree” ratings exceeds 50 % for every one of the eight questions under the classic-lab condition, indicating strong overall student endorsement of this hands-on approach (Figure 5).

In the case of Method C, for all items (Q1–Q8), the combined proportion of “Agree” (4) and “Strongly Agree” (5) responses exceeds 60 % (Figure 5).

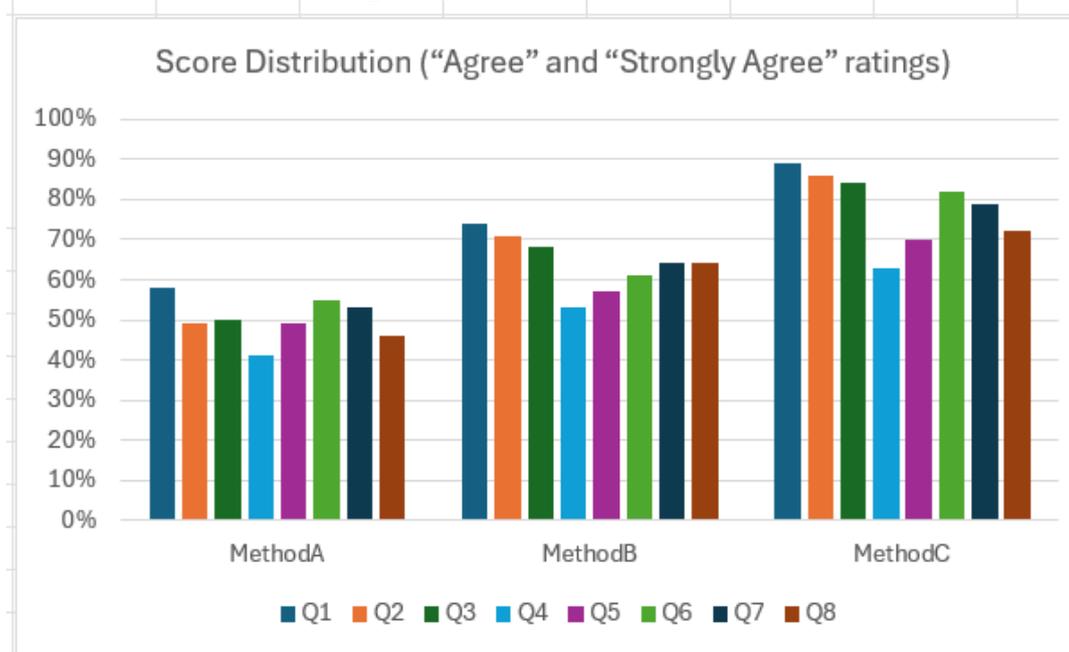


Figure 5. Distribution of Scores (“Agree” (4) and “Strongly Agree” (5) responses) – MethodA, MethodB, MethodC

In the source file, the following variables were considered: respondent, Q1a–Q8a (which store the responses to the eight questions for case A – Theoretical Instruction), Q1b–Q8b (which store the responses to the eight questions for case B – Classic Assembly Labs), and Q1c–Q8c (which store the responses to the eight questions for case C – Simulation of Physical Phenomena). Three additional variables—ScoreMeanA, ScoreMeanB, and ScoreMeanC—were introduced to represent the mean scores across items 1–8 for cases A, B, and C, respectively.

To identify which statistical analyses could be applied to the collected data, the normality assumption of the total score distributions for each instructional method was first examined. Using the Shapiro–Wilk test (González-Estrada, Villaseñor și Acosta-Pech, 2022), p-values were found to be less than 0.05 for the Shapiro–Wilk statistics, despite those statistics exceeding 0.80. Under these conditions, the data do not conform to normal distribution.

2.3. Case Study 1

Formulation of Hypotheses:

H₀: There are no significant differences among the mean scores assigned to instructional methods A, B, and C.

H₁: There are significant differences among the mean scores assigned to the three methods.

To determine whether the scores obtained for the three teaching methods differ significantly, the Friedman test (*Friedman Test Tutorial: Analyzing Repeated Measures Data*, fără dată) was conducted using the Jamovi application (<https://www.jamovi.org/>). The Friedman test is a nonparametric statistical method used to compare more than two related groups (Sheldon, Fillyaw and Thompson, 1996) (Liu and Xu, 2022) (or repeated measures). It serves as a nonparametric alternative to repeated-measures ANOVA when the



assumptions of normality or variance homogeneity required by ANOVA are not met, and it is useful for identifying significant differences among groups.

The Friedman test was applied to compare participants' mean scores across the three experimental conditions (A, B, and C). The result indicates a statistically significant difference among the three methods, $\chi^2(2) = 219, p < .001$ (Figure 6).

Students' perceptions of the effectiveness of different instructional methods (theoretical – A, classic experimental – B, simulation-assisted experimental – C) differ significantly.

Post-hoc Durbin–Conover tests revealed that all method pairs differ significantly ($p < .001$), with the largest difference observed between the theoretical method (A) and the simulation-assisted method (C). In other words, the results indicate that Method C is perceived as significantly more effective than the other two.

Repeated Measures ANOVA (Non-parametric)

Friedman				
	χ^2	df	p	
	219	2	< .001	

Pairwise Comparisons (Durbin-Conover)				
			Statistic	p
ScoreMeanA	-	ScoreMeanB	10.04	< .001
ScoreMeanA	-	ScoreMeanC	18.53	< .001
ScoreMeanB	-	ScoreMeanC	8.49	< .001

[3]

Descriptives		
	Mean	Median
ScoreMeanA	3.40	3.50
ScoreMeanB	3.79	4.00
ScoreMeanC	4.21	4.38

Figure 6. Repeated Measures ANOVA (Non-parametric) Test Results

2.4. Case Study 2

Formulation of Hypotheses:

H₀: There is no correlation among the scores assigned to items Q2a, Q6a, and Q7a.

H₁: There is a positive correlation among the scores assigned to these three items.

An analysis was conducted on the data from the theoretical-instruction condition (A) to determine whether correlations exist among Q2a (“It captured my attention and interest”), Q6a (“I retained the taught concepts better”), and Q7a (“I understood the relationships between concepts better”). Accordingly, Spearman’s rank-order correlation was applied, yielding the results shown in Figure 7.



Correlation Matrix

		Q2a	Q6a	Q7a
Q2a	Spearman's rho	—		
	df	—		
	p-value	—		
Q6a	Spearman's rho	0.628 ***	—	
	df	298	—	
	p-value	< .001	—	
Q7a	Spearman's rho	0.635 ***	0.784 ***	—
	df	298	298	—
	p-value	< .001	< .001	—

Note. * $p < .05$, ** $p < .01$, *** $p < .001$

Figure 7. Correlation Matrix

Between Q2a and Q6a there is a strong positive correlation ($\rho = 0.628$, $p < 0.001$), indicating that students who awarded high scores on Q2a also tended to give high scores on Q6a. In other words, those who were engaged by the theoretical presentation retained the material more effectively, as one would expect. Likewise, as shown in Figure 8, Q2a and Q7a also exhibit a strong positive correlation ($\rho = 0.635$, $p < 0.001$). We can conclude that students who were drawn in by the lecture understood the new concepts more deeply.

2.5. Case Study 3

Formulation of Hypotheses:

H₀: There is no correlation among the scores assigned to items Q2b, Q4b, and Q8b.

H₁: There is a positive correlation among the scores assigned to these three items.

For Method B (Classic Assembly Labs), a strong positive correlation was found between Q2b (“It captured my attention and interest”) and Q4b (“It motivated me to learn more”) ($\rho = 0.654$, $p < 0.001$). This indicates that students who were engaged by the hands-on lab activities also reported being motivated to learn more.

Furthermore, the analysis reveals a statistically significant, strong positive correlation between Q2b (“It captured my attention and interest”) and Q8b (“I feel that I could apply the knowledge in real life”) ($\rho = 0.634$, $p < 0.001$). In other words, students who found the classic-lab exercises engaged also believe that they can apply what they learned in real-world contexts (Figure 8).



Correlation Matrix		Q2b	Q4b	Q8b
Q2b	Spearman's rho	—		
	df	—		
	p-value	—		
Q4b	Spearman's rho	0.654 ***	—	
	df	298	—	
	p-value	< .001	—	
Q8b	Spearman's rho	0.634 ***	0.536 ***	—
	df	298	298	—
	p-value	< .001	< .001	—

Note. * $p < .05$, ** $p < .01$, *** $p < .001$

Figure 8. Correlation Matrix among Items Q2b, Q4b, and Q8b

2.6. Case Study 4

Formulation of Hypotheses:

H₀: There is no correlation among the scores assigned to items Q7c, Q4c, and Q5c.

H₁: There is a positive correlation among the scores assigned to these three items.

In the case of Method C – Simulation of Physical Phenomena, the statistical analysis indicates high Spearman correlation coefficients between Q7c (“I understood the relationships between concepts better”) and both Q4c (“It motivated me to learn more”) and Q5c (“It encouraged me to ask questions and explore”) (Figure 9). Students who gave high scores to Q7c also gave high scores to Q4c and Q5c. In other words, with Method C students not only developed a deeper understanding of the concepts and their interrelationships, but were also directly motivated to learn more, to pose questions to the instructor, and to engage in independent exploration.

Correlation Matrix		Q7c	Q4c	Q5c
Q7c	Spearman's rho	—		
	df	—		
	p-value	—		
Q4c	Spearman's rho	0.612 ***	—	
	df	298	—	
	p-value	< .001	—	
Q5c	Spearman's rho	0.573 ***	0.470 ***	—
	df	298	298	—
	p-value	< .001	< .001	—

Note. * $p < .05$, ** $p < .01$, *** $p < .001$

Figure 9. Correlation Matrix among Items Q7c, Q4c, and Q5c



2.7. Case Study 5

Formulation of Hypotheses:

H₀: There is no correlation among the scores assigned to instructional methods A, B, and C.

H₁: There is a positive correlation among the scores assigned to the instructional methods under consideration.

Because the data violate the normality assumption and are ordinal in nature (Likert scale), Spearman’s rank-order correlation coefficient (ρ) was applied to evaluate the association among the mean scores for the three teaching methods (Ali Abd AlHameed, 2022) (Figure 10).

Correlation Matrix		ScoreMeanA	ScoreMeanB	ScoreMeanC
ScoreMeanA	Spearman's rho	—		
	df	—		
	p-value	—		
ScoreMeanB	Spearman's rho	0.673 ***	—	
	df	298	—	
	p-value	< .001	—	
ScoreMeanC	Spearman's rho	0.460 ***	0.621 ***	—
	df	298	298	—
	p-value	< .001	< .001	—

Note. * $p < .05$, ** $p < .01$, *** $p < .001$

Figure 10. Correlation Matrix for mean scores of the three teaching methods

The results indicate statistically significant positive associations between all pairs of methods ($\rho = 0.673$ between A and B, $\rho = 0.621$ between B and C, $\rho = 0.460$ between A and C; all $p < 0.001$), suggesting a moderate consistency in participants’ preferences. At the same time, the weaker correlation between the theoretical lecture method and the simulation-based method points to a possible difference in how these approaches are perceived.

As evidenced by these significant positive correlations among scores for the three instructional methods (theoretical lectures, classic assembly labs, and physical-phenomena simulations), students do not view the methods as mutually exclusive but rather as complementary. Moreover, application of the Friedman test revealed significant differences among the teaching methods, indicating variations in the level of preference or appreciation afforded to each. The statistically significant pairwise differences (A–C, A–B, and B–C) demonstrate that each method contributes uniquely to the learning process and is perceived by students as having distinct yet compatible pedagogical value. We can therefore conclude that the three methods are complementary and that their integration into a hybrid instructional design could effectively address the needs and preferences of students in technical education.

2.8. Case Study 6

Formulation of Hypotheses:

H₀: There is no correlation among the mean scores assigned to the method A/method B/method C and the students’ Grades.

H₁: There is a positive correlation among the mean scores assigned to the method A/method B/method C and the students’ Grades.

A variable Grades represents the category of students’ grades as is presented in the Table 3.



Table 3. Students' Grades distribution

Grades	Students' Grade	Total students
1	<5	32
2	5-6	94
3	7-8	108
4	9-10	66

Spearman's correlations were conducted to examine the relationships between students' perceptions of teaching methods (A, B, C) and their exam performance (Grades). Strong positive correlations were found among the perception scores of the different methods (ρ is between 0.46 and 0.67, $p < .001$), indicating that students evaluated the methods consistently. However, no significant correlations were found between perception scores and Grades (the value ρ is between -0.08 and 0.05, $p > .05$), suggesting that students' subjective evaluations of the teaching methods were not associated with their exam performance. Students have a general view about the quality of teaching, and their grades can be influenced by other factors: learning style, exam difficulty, individual motivation, learning skills, time management etc. From pedagogical point of view, we can say that declared satisfaction does not guarantee measured performance. We formulate the next question: Students' perceptions significantly differ between groups ("good students" vs. "bad students")? Three new variables were added (StudentsPerceptionA, StudentsPerceptionB, StudentsPerceptionC) for each method, taking value 1 - if the mean score is greater than 4, and 0 in the rest of cases. A Kruskal-Wallis H test was conducted to examine whether students who rated teaching method A/method B/method C as very good (StudentsPerceptionA = 1/ StudentsPerceptionB = 1/ StudentsPerceptionC = 1) differed in exam performance (Grades) from those who did not (StudentsPerceptionA = 0/ StudentsPerceptionB=0/ StudentsPerceptionC = 0). The results indicated no significant difference, $H_{MethodA}(1) = 0.349, p = 0.555$; $H_{MethodB}(1) = 0.105, p = 0.746$; $H_{MethodC}(1) = 0.0826, p = 0.774$ suggesting that a very positive perception of method A or method B or method C was not associated with higher exam grades (Tabel 4).

Table 4. Kruskal-Wallis H test results

Method	χ^2	df	p
A	0.349	1	0.555
B	0.105	1	0.746
C	0.0826	1	0.774

We conclude that the method may be appreciated, but it does not cover the skills assessed on the exam. If the method provides an enjoyable experience but does not clarify the concepts, students' performance does not increase. Even if the method is perceived as "very good", students' lack of practice can limit learning.

CONCLUSION

The results suggest that experimental and interactive methods can enhance students' understanding of concepts in the exact sciences and foster critical thinking skills and learner autonomy. At the same time, classical didactic technologies—developed and refined over time, such as lectures and traditional hands-on experimentation—continue to play a vital role in teaching and understanding the exact sciences.

Integrating new technologies into university education presents both challenges and opportunities to create a more efficient and adaptable learning environment. It is essential to maintain a balance between traditional methods and emerging technologies because each approach has its own strengths and limitations, and their complementary integration can maximize the overall effectiveness of the learning process. Our research indicates that while students may rate certain teaching methods as highly effective, these ratings do not translate into higher exam grades. When we interpret positive students' feedback as indicative of learning effectiveness, we should consider additional factors that contribute to their performance, such as individual effort, study strategies, and course assessment alignment.



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