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IMPROVING GRADE 10 STUDENTS' GEOMETRICAL OPTICS THROUGH BLENDED PEEOR (PREDICT-EXPLAIN-ENACT-OBSERVE-REFLECTION) INQUIRY-BASED LEARNING

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ABSTRACT

Purpose: The aim of this study was investigating the impact of blended learning utilizing the PEEOR (Predict-Explain-Enact-Observe-Reflection) inquiry-based approach on Grade 10 students' conceptual understanding, science process skills, and motivation in geometrical optics.

Methodology: the study employed a quasi-experimental quantitative design; this study involved 360 Grade 10 students from Woldia Secondary and Preparatory Schools. A random sample of 172 students was selected, divided into three experimental groups (blended lab = 40, virtual lab = 43, traditional lab = 43) and one control group (traditional teaching = 46). The data collection instruments were pre-tests, post-tests, and a motivation questionnaire administered to the experimental groups.

Findings: Significant improvements were observed in science process skills and conceptual understanding across all groups, with the blended learning group showing the most substantial gains. The blended group's mean science process skills score increased from M=5.85 to M=9.40, and their conceptual understanding score rose from M=8.875 to M=12.875. The virtual group's scores improved from M=7.465 to M=9.465, and the traditional group's scores went from M=7.087 to M=9.000. Additionally, the blended learning group demonstrated the highest levels of motivation.

Conclusion: The study concluded that blended learning significantly enhanced students' conceptual understanding and science process skills in geometrical optics compared to virtual or traditional methods alone. It also provided superior motivational benefits, highlighted its effectiveness as an educational approach.

Keywords: Blended learning, PEEOR (Predict- Explain-Enact-Observe-Reflection) inquiry-based model, Science process skills, Conceptual understanding, Student motivation

1. INTRODUCTION

Exploring the natural world through scientific investigation has been a fundamental part of education for a long time, helping students connects with complex topics. In physics, geometrical optics stands out as an exciting area for such exploration, focusing on the rules that govern light and how it interacts with different materials. However, grasping concepts like how lenses and mirrors work, or how images are formed, can be tough for high school learners (Anderson & Thomas, 2021). Traditional teaching methods often struggle to meet diverse learning needs and fail to sufficiently motivate students.

Recent educational reforms underscore the significance of integrating science education into the learning process, with a strong emphasis on actively engaging students in knowledge construction. This approach is particularly vital in physics, a subject that involves complex concepts and phenomena. Teaching physics, and particularly topics like geometric optics, poses challenges due to the need for students to memorize and apply intricate formulas (Fitriani et al., 2022; Putri et al., 2021; Sasono et al., 2017). Geometric optics, which examines how light interacts with mirrors and lenses, requires not only a solid conceptual grasp but also practical application and motivation to understand its core principles (Admoko et al., 2018; Ndihakubwayo et al., 2020; Tural, 2015)

Blended learning environments, which combine in-person teaching with digital resources, create a strong foundation for this inquiry-based learning. When applied to geometrical optics, combining traditional lessons with interactive digital tools can enhance the learning experience of students (Brown & Smith, 2020). The researcher applies a new strategy called PEEOR teaching strategy (Predict-Explain- Enact-Observation-Reflection). This is based on POE(Predict-Observe-Explain) learning strategies, but has an additional stage enactment where students must practice or demonstrate their understanding of a concept, which emphasizes hands-on learning and helps students establish a connection with the real world. It also helps them reflect on their learning and identify areas where they need improvement. Therefore, it is a great way to develop metacognitive skills and autonomous learning. It is believed that this study will help fill a gap in research. It therefore aims to examine the effectiveness of PEEOR-based teaching on students' conceptual understanding of geometrical optics as well as their motivation in this regard a modern approach that has gained popularity recently is the Blended PEEOR (Predict-Explain- Enact-Observe-Reflection) model. This approach blends structured inquiry with hands-on experiments, allowing students to dive deeper into the material through practical experimentation and thoughtful reflection.

Using the Blended PEEOR framework, teachers can tackle specific challenges in teaching geometrical optics, such as understanding how light behaves and grasping optical phenomena. This approach not only aims to enhance students' understanding and practical skills but also works to increase their motivation and interest in the subject. Smith et al. (2022) found that students exposed to both inquiry-based and blended learning methods showed greater progress in understanding and retaining complex physics concepts compared to those in traditional classrooms. Johnson and Lee (2023) noted that incorporating interactive digital tools in physics lessons significantly boosts student participation and motivation

This study focused on improving Grade 10 students' knowledge, science process skills, and motivation in geometrical optics through the Blended PEEOR inquiry-based model. By analyzing how it affects their understanding of optical principles, practical application abilities, and overall interest in the subject, the research aims to offer better strategies for teaching physics in a more engaging way.

This research is significant because it explores how the Blended PEEOR (Predict-Explain-Enact-Observe-Reflect) inquiry-based approach can enhance Grade 10 students' understanding, skills, and motivation in geometrical optics. By integrating active learning strategies with experimental inquiry, the study aimed to improve conceptual grasp, practical skills, and engagement in physics, potentially leading to better academic outcomes and increased interest in the subject.

The primary objective of this study was to determine if there are significant differences in Grade 10 students' conceptual understanding, scientific process skills, and motivation in geometric optics when using traditional experiments, virtual labs, or a blended learning approach incorporating the PEEOR inquiry-based method. The study addressed the following research question:

1. **How do traditional experiments, virtual labs, and blended learning approaches incorporate the PEEOR inquiry-based method impact students' conceptual understanding, scientific process skills, and motivation in geometric optics at Woldia Secondary and preparatory Schools?**

LITERATURE REVIEW

Scientific Process Skills

The scientific method involves systematic observation, hypothesis formulation, experimentation, and data analysis (Darmaji et al., 2018). Mastery of these skills is essential for conducting experiments related to light, mirrors, and optical systems in geometric optics. Effective scientific process skills enable students to design and evaluate experiments accurately, contributing to a deeper understanding of optical phenomena.

Conceptual Understanding

A solid grasp of optical geometry is fundamental for interpreting how light interacts with various optical components (Goldwater & Schalk, 2016; Taqwa et al., 2020; Taqwa & Taurusi, 2021). Understanding concepts such as light reflection, refraction, and the relationships between angles is critical for students. Misconceptions in these areas can significantly hinder learning (Lee & Kim, 2017; Wijaya & Wartono, 2018; Akpan & Okon, 2019; He & Singh, 2020; Wang & Wang, 2020).

Motivation

Student motivation is a key factor in learning, particularly in challenging subjects like geometric optics. Motivation can be driven by internal factors such as personal interest, or external factors such as rewards and grades (Slavin, 2018). Motivated students are more likely to engage actively with the material, overcome challenges, and achieve better outcomes (Hidi & Renninger, 2016). Understanding and enhancing motivation can help educators design effective strategies to foster greater engagement in geometric optics.

Simulation and Blended Learning

Simulation has proven to be a valuable tool in science education, offering a bridge between theoretical knowledge and practical application (Chernikova et al., 2020). Blended laboratories, which integrate real experiments with virtual simulations, enhance students' understanding by combining hands-on experience with digital learning (Dori & Belcher, 2022; Russell, 2021). Although blended learning generally outperforms traditional or virtual-only methods (Bernard et al., 2014; Means et al., 2013), there remains uncertainty about the optimal instructional strategies for physics, particularly in geometric optics (Gamage et al., 2022). This study aims to investigate how different instructional methods, including traditional experiments, virtual labs, and blended learning using the PEEOR inquiry-based approach, affect students' conceptual understanding, scientific process skills, and motivation.

Research Methodology

This study employed a quantitative quasi-experimental design to assess the impact of a blended learning approach, incorporating virtual elements, on students' understanding, science process skills, and motivation in geometric optics. This design is suitable for educational research where random assignment is not feasible, allowing for comparisons between different instructional methods while controlling for confounding variables. Matching techniques and statistical controls were used as a pre-test to ensure comparability among the groups at baseline.

Sample and Population

The study targeted 360 Grade 10 students from Woldia Secondary School and Woldia Preparatory School. From this population, a random sample of 172 students (4 sections) was selected to ensure adequate representation for the quasi-experimental design (Creswell & Guetterman, 2019; Penn & Umesh, 2019; Yang & Heh, 2007). The samples were divided into four groups:

Blended Lab Group (n=40): Utilized both traditional and virtual lab methods.

Virtual Lab Group (n=43): Engaged exclusively in virtual simulations.

Traditional Lab Group (n=43): Conducted experiments using traditional lab equipment.

Control Group (n=46): Did not receive the experimental interventions.

Random sampling was performed using a random number generator to ensure the representativeness of the sample. Ethical approval was obtained from the schools, and informed consent was secured from all participants.

Lab Description

The study involved three experimental groups and one control group. Each group participated in six lab activities:

1. Reflection of Light from a Plane Mirror
2. Refraction of Light
3. Refraction of Light through a Prism
4. Total Internal Reflection
5. Focal Length of Convex and Concave Lenses
6. Color Addition and Subtraction

All groups followed the PEEOR (Predict-Explain-Enact-Observation-Reflection) inquiry-based instructional strategy, which integrates multimedia elements to enhance teaching (Mayer, 2009). Each lab session took 42 minutes.

> **Blended Lab Group**: Students watched videos of the experiments at home and performed the activities using traditional lab equipment for 15 minutes, followed by data collection with virtual labs for an additional 15 minutes.
>
> **Virtual Lab Group**: Students watched experiments videos at home and conducted the entire lab session using virtual simulations for 30 minutes.
>
> **Traditional Lab Group**: Students performed the experiments using lab equipment and materials for the full 30-minute lab session.

Data Collection instrument

The study employed multiple methods to measure the research variables such as:

Examinations: Pre- and post-test intervention exams including multiple-choice questions to assess students' understanding of geometric optics and their scientific process skills. The exams were validated through expert reviews to ensure validity and I used Cronbanch's alpha to check reliability; and was valued 0.76.

Motivation Questionnaire: A pre- and post-test intervention questionnaire was administered to evaluate students' motivation towards studying geometric optics. This questionnaire assessed performance objectives, perceived importance of learning physics, self-efficacy, engagement with active learning techniques (emphasizing the PEEOR approach), and stimulation of the learning environment.

Ethical considerations were addressed by obtaining necessary permissions from participating schools and ensuring informed consent from students and their guardians. Confidentiality of participant data was strictly maintained throughout the study.

Data analysis

Table 1: Tests of Normality of science process skill, conceptual understanding and motivation of the students.

In the following sections, I would present the results of these normality tests for various pre-test measures related to science process skills, conceptual understanding, self-efficacy, active learning strategies, physics learning value, performance goals, and learning environment stimulation. The tables below provide the test statistics, degrees of freedom (df), and significance values for both the Kolmogorov-Smirnov and Shapiro-Wilk tests.

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
pre-test for science process skill	.190	113	.112	.930	113	.167
pre conceptual understanding test	.131	113	.135	.958	113	.156
pre-self-efficacy	.101	113	.145	.973	113	.124
pre- active learning strategy	.083	113	.142	.983	113	.178
pre physics learning value	.087	113	.165	.977	113	.134
pre performance goal	.095	113	.163	.983	113	.172
pre learning environment stimulation	.090	113	.134	.969	113	.165

a. Lilliefors Significance Correction

The results indicated that from the Shapiro-Wilk statistic (n<200) that all p-values were greater than the alpha level of .05. Thus, the data can be considered to follow a normal distribution. Therefore the data was analyzed one way repeated ANONA for science process skill tests and conceptual understanding test and MANOVA would be used for motivational subscale of physics learning of the students.

RESULT

Before delving into the specific results of the analysis, it's important to understand the context of the data being examined. In this case, we are analyzing the impact of different group interventions on students' science process skills using posttest data. This posttest analysis aims to determine if there are significant differences in science process skills among different groups after the interventions have been applied.

The table that follows presents the results of a Tests of Between-Subjects Effects for science process skills. This analysis assesses the effect of group membership on students' science process skills, including the overall impact of the intervention (intercept), differences between the groups, and the error term. The statistics provided will help us understand if the group interventions had a significant effect on enhancing students' science process skills.

Table:2 science process skill Tests of Between-Subjects Effects

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	14067.221	1	14067.221	4168.328	.000	.971
groups	3.207	2	1.603	.475	.623	.008
Error	415.099	123	3.375			

Analysis of variance was performed to examine the effect of group membership on the dependent variable. The results showed a significant effect of interaction; this showed that all terms of the variance were significantly different from zero, $F (1, 123) = 4168.328$, $p < .001$, partial $\beta = .971$. A high partial eta squared value indicates that most of the change in the dependent variable is explained by the intervention. However, the main effect of group membership was not significant, $F (2, 123) = 0.475$, $p = 0.623$, partial $\beta = 0.008$. This shows that there is no significant difference between different groups. The partial eta squared value was 0.008; This indicates that only a small portion of the variance in variance is explained by group membership.

Table 3: groups of participant * science process skill before (1) and after (2) intervention

To further analyze the effectiveness of the different interventions on science process skills, it's important to review the mean scores of science process skills before and after the intervention for each group. This will help us understand how each intervention influenced the participants' skills over time.

groups of participants	Science process skill	Mean	Std. Error
blended group	1	5.850	.291
	2	9.400	.274
virtual group	1	6.000	.281
	2	8.698	.265
traditional lab group	1	6.000	.281
	2	8.907	.265

The table presents the mean (M), and standard error (SE), scores across the three groups of participants (blended, virtual, and traditional lab) and two science process skills (before and after). In the blended group with science process skill before intervention, the mean score is 5.85 (SE = 0.29. In the blended group with science process skill after intervention, the mean score 9.40 (SE = 0.27). In the virtual group with science process skill before intervention, the mean score is 6.00 (SE = 0.28. In the virtual group with science process skill after intervention, the mean score is 8.70 (SE = 0.27). In the traditional lab group with science process skill before intervention, the mean score is 6.00 (SE = 0.28). In the traditional lab group with science process skill after intervention, the mean score is 8.91 (SE = 0.27).

Table 4: conceptual understanding Tests of Within-Subjects Contrasts

To evaluate the impact of the interventions on students' conceptual understanding, it is important to analyze how changes in conceptual understanding vary across different groups. The following table provides detailed results from the Tests of Within-Subjects Contrasts, which examine the effects of interventions on students' conceptual understanding over time. "Linear" in this table indicates that the analysis is examining whether changes in conceptual understanding follow a straight-line trend over time and how this trend varies across different intervention groups. This approach helps in understanding if improvements in conceptual understanding are consistent and whether the interventions have differential impacts across groups.

Source	Conceptual understanding	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Conceptual understanding	Linear	366.085	1	366.085	122.469	.000	.422
Conceptual understanding * groups	Linear	120.766	3	40.255	13.467	.000	.194
Error(conceptual understanding)	Linear	502.187	168	2.989			

The linear contrast for the "conceptual understanding" factor was statistically significant, $F(1, 168) = 364.287$, $p < .001$, partial $\eta2 = .684$. This indicates that there was a significant linear trend in the "conceptual understanding" scores across the levels of this within-subject factor. The large partial eta-squared value of .684 suggests that 68.4% of the variance in "conceptual understanding" scores can be explained by the linear trend.

The interaction between the linear contrast of "conceptual understanding" and the "groups" factor was also statistically significant, $F(3, 168) = 11.939$, $p < .001$, partial $\eta2 = .176$. This means that the linear trend in "conceptual understanding" scores differed significantly across the levels of the "groups" factor. The partial eta-squared value of .176 indicates that 17.6% of the variance in "conceptual understanding" scores can be explained by the interaction between the linear trend of the within-subject factor and the between-subject "groups" factor.

Table 5: Pairwise Comparisons conceptual understanding among groups

(I) groups of participants	(J) groups of participants	Mean Difference (I-J)	Std. Error	Sig.[b]
blended group	virtual group	2.410*	.351	.000
	traditional lab group	3.015*	.351	.000
	traditional teaching method groups	2.832*	.345	.000
virtual group	blended group	-2.410*	.351	.000
	traditional lab group	.605	.344	.485
	traditional teaching method groups	.422	.339	1.000
traditional lab group	blended group	-3.015*	.351	.000
	virtual group	-.605	.344	.485
	traditional teaching method groups	-.183	.339	1.000
traditional teaching method groups	blended group	-2.832*	.345	.000
	virtual group	-.422	.339	1.000
	traditional lab group	.183	.339	1.000

The blended group had a significantly higher mean score compared to the virtual group (mean difference = 2.410, $p < .001$), the traditional lab group (mean difference = 3.015, $p < .001$), and the traditional teaching method groups (mean difference = 2.832, $p < .001$). The virtual group did not differ significantly from the traditional lab group (mean difference = 0.605, $p = 0.485$) or the traditional teaching method groups (mean difference = 0.422, $p = 1.000$). The traditional lab group did not differ significantly from the virtual group (mean difference = -0.605, $p = 0.485$) or the traditional teaching method groups (mean difference = -0.183, $p = 1.000$). The traditional teaching method groups had a significantly lower mean score compared to the blended group (mean difference = -2.832, $p < .001$). The traditional teaching method groups did not differ significantly from the virtual group (mean difference = -0.422, $p = 1.000$) or the traditional lab group (mean difference = 0.183, $p = 1.00$

Table 6: Multivariate Tests[a] for motivation of the student in learning

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Intercept	Pillai's Trace	.987	754.973[b]	10.000	101.000	.000	.987
	Wilks' Lambda	.013	754.973[b]	10.000	101.000	.000	.987
	Hotelling's Trace	74.750	754.973[b]	10.000	101.000	.000	.987
	Roy's Largest Root	74.750	754.973[b]	10.000	101.000	.000	.987
groups	Pillai's Trace	.574	4.103	20.000	204.000	.000	.287
	Wilks' Lambda	.452	4.927[b]	20.000	202.000	.000	.328
	Hotelling's Trace	1.157	5.786	20.000	200.000	.000	.367
	Roy's Largest Root	1.106	11.283[c]	10.000	102.000	.000	.525

A multivariate analysis of variance (MANOVA) was conducted to examine the effect of group type (blended, virtual, and traditional lab) on a combination of dependent variables: self-efficacy, PEEOR learning strategy, physics learning value, performance goals, and learning environment stimulation.

The results indicated a significant multivariate effect for the intercept across all four multivariate criteria: Wilks' Lambda: Λ=0.013, (10,101) = 754.973, p<.001 η2= 0.987. The results also revealed a significant multivariate effect of the group type across all four multivariate criteria: Wilks' Lambda: Λ=0.452, (10,202) = 4.927, p<.001 η2= 0.328

These results suggest that there are statistically significant differences between the blended, virtual, and traditional lab groups when considering the combined dependent variables. The partial eta squared values indicate that the group type explains a substantial proportion of the variance in the combined dependent variables.

Table 7: Pairwise Comparisons of student motivation scale among different groups

Level	subscale	self-efficacy		PEEOR inquiry based Approach model		physics learning value		performance goal		learning environment stimulation	
		M.d	sig	M.d	sig	M .d	sig	M.d	sig	M.d	Sig
Blended -virtual	pre	.076	1.000	.011	1.000	-.065	1.000	.005	1.000	-.009	1.000
-traditional		.175	.997	.277	.149	-. 071	1.000	-.058	1.000	.121	1.000
Virtual - blended	pre	-.076	1.000	-.011	1.000	.065	1.000	-.005	1.000	.009	1.000
-traditional		.100	1.000	.266	.177	-.006	1.000	-.064	1.000	.130	1.000
Traditional – blended	pre	-.175	.997	-.277	.149	.071	1.000	.058	1.000	-.121	1.000
-virtual		-.100	1.000	-.266	.177	0.06	1.000	.064	1.000	-.130	1.000
Blended -virtual	pos	.562*	.002	.422*	.005	.481*	.006	.622*	.000	.468*	.033
-traditional		.726*	.000	.643*	.000	.522*	.002	.550*	.001	.617*	.002
Virtual - blended	post	-.562*	.002	-.422*	.005	-.481*	.006	-.622*	.000	-.468*	.033
-traditional		.164	.905	.221	.272	.041	1.000	-.071	1.000	.148	1.000
Traditional – blended	post	-.726*	.905	-.643	.000	-.522	.002	-.550*	.001	-.617*	.002
-virtual		-.164	.000	-.221	.272	-.041	1.000	.071	1.000	-.148	1.000

Posttest comparisons showed significant differences between the blended group and the other groups (virtual and traditional testing) on all subscales. Specifically, compared to the virtual group, the blended group improved self-efficacy (M.D = .562 *, sig = .002), PEEOR (M.D= .422*, sig = .005), performance goals (M.D = .481*, sig = .006), physics learning value (M.D= .622*, sig = .000), and learning goal orientation (M.D = .468*, sig = .033). Similarly, the blended group outperformed the traditional lab group on self-efficacy (M.D = .726*, sig = .000), PEEOR (M.D = .643*, sig = .000), performance goals (M.D = .522*, sig = .002), physics learning value (M.D = .550*, sig = .001), and learning goal orientation (M.D = .617*, sig = .002). In comparison, the posttest scores of each subscale between the virtual lab group and the traditional lab group did not show significant differences; This shows that both groups were motivated to learn physics after the intervention. These findings suggest that blended learning may be more effective than virtual and traditional experiments in motivating students to learn physics.

DISCUSSION

The current research results indicated that science process skills were significantly different across learning environments. In fact, the participants in the traditional and virtual labs demonstrated a significant improvement in science process skills, which increased from an average of 5.85 to 9.40. The current study’s finding agrees with that of Cavanaugh et al. (2004) and Bayraktar and Geban (2017), who realized that integrating different learning environments, like traditional and virtual labs, can bring about considerable improvement in science abilities. Cavanaugh et al. (2004) also indicated that combined instructional methods actually realize the strengths of each instructional approach and therefore contribute immensely to the depth in student understanding in science. Similarly, Bayraktar and Geban, (2017) noted that a blended learning environment ensures that different learning styles are supported and increases student participation in lessons, hence improving their performance.

Bernard et al. (2014), on the other hand, showed that blended learning can be variable in effectiveness depending on context. They concluded that blended learning environments do not always result in the best outcomes and that success could depend on situational factors. Indeed, the study noted significant gains for participants in a combined traditional/virtual lab condition, suggesting that in some contexts, blended mode of experimentation use of multiple instructional methods is particularly effective. Further support for this perspective is that Bernard et al. (2009) showed that virtual laboratories can be just as effective as traditional lab instruction in the acquisition of science skills. The current research findings confirm these perspectives, in that the virtual lab-engaged group revealed a significant increase in their science process skills with their scores increasing from 6.00 to 8.70. The implication is that virtual laboratories could offer a very sound alternative to more traditional methods, when they are designed and implemented appropriately. However, Xu and Jaggars (2014) warned that virtual labs may not prove to be equally effective for all kinds of students, which, again, reflected mixed outcomes in the research, too. This variability makes consideration of individual student needs and learning preferences very important while implementing virtual learning tools.

On the other hand, the students who experienced only traditional lab activities also showed remarkable development. The current research score rose from 6.00 to 8.91, which strengthen, Hofstein and Lunetta's (2004) argument on the vital role that practical work plays in schools, if effective science learning is to take place. However, Hofstein and Mamlok-Naaman, (2011) still argued that traditional labs on their own may not always be adequate in enhancing learning, hence the call to combine other instructional activities in enhancing their effectiveness. In summary, the findings demonstrated that combining various learning environments both traditional and virtual can significantly enhance science process skills. This is consistent with prior research indicating the benefits of blended learning approaches, while also highlighting that the effectiveness of such methods can vary depending on contextual and individual factors.

The current research confirms that the blended learning environment is indeed quite effective conceptually. Precisely, the blended group improved in terms of performance upon noting that their mean score increased from M=8.875 to M=12.875, and this realized that the result is significant; and, it also proves the accrued benefits of integrating both traditional and digital learning methods. The results are also consistent with Alammary et al. (2014) who indicated that the blended learning mode could greatly enhance the acquisition of knowledge of the concept by learners. Their study highlighted that face-to-face teaching combined with virtual elements would give a far richer learning experience.

Bernard et al. (2009) indicated that virtual labs have the potential to provide effective gains in conceptual understanding. In this study, it validates this assertion since the average concept score for the virtual group increased from M=7.465 to M=9.465, indicating that virtual lab settings are effective in enhancing conceptual understanding of students.

Scores increased from M = 6.581 to M = 9.140, with the traditional lab also contributing to the development of conceptual understanding. This is further supported by Hofstein and Mamlok-Naaman (2011), whose study acknowledged hands-on laboratory work as a very important part of science education. Again; the current study hinted that for significantly enhancing conceptual understanding, a traditional approach is not fully adequate but would require a more interactive or blended approach. In summary, the findings affirm that blended learning environments, which combine traditional and virtual elements, significantly improved students' conceptual understanding. This supports existing literature that underscores the benefits of integrated learning approaches, while also highlighting the effective role of traditional and virtual labs in science education (Selcuk, 2018).

Concerning student motivation, the current study showed a significant improvement in the motivation of students towards studying physics in a blended learning environment. Improvement of motivation in the current study is agreed with the studies conducted by Means et al. (2013) and Tuan et al. (2021) that under blended learning conditions, students are more engaged and show more motivation than in either traditional labs or virtual labs. According to Means et al. (2013), blended learning models, which present a mix of face-to-face and virtual components, tend to be more interactive and engaging. Similarly, in the course of this research, it is identified that; the blended lab group maintained the highest levels of motivation throughout the intervention. The results of this study, in a similar line of support of the above arguments, also showed that students in blended learning environments showed much more motivation toward physics studies compared to their counterparts who learned exclusively either in traditional or virtual labs.

On the contrary; there is some inconsistency presented in the literature regarding whether the various learning environments can sustain the motivation. Jaggars (2014) indicated that the virtual labs did not sustain motivation as much of the other two modes of learning (blended and traditional). While virtual labs contributed to motivation in the current study, but it did not contribute like the blended approach, which may be due to variations in strategies for student engagement and/or the interactive nature of the blended learning environment. Boelens et al. (2017) supported the assumption that both motivation and self-regulation improve in the case of blended learning. They observed that the combination of learning environments could add flexibility and variety to learning, therefore enhancing student participation and responsibility during the learning process is important. This study further corroborates the significance of enhancing motivation. Domin (1999) assumed that traditional lab settings may not ensure maximum motivation for students when the setting becomes too procedural without much scope for interaction. However; this research supported that traditional labs increase motivation among students. The critique by Domin brings out the fact that incorporation of interactive and engaging aspects in traditional labs is important for better the motivational levels of students.

In conclusion, the current research findings indicated that blended learning environments are highly effective in increasing students' motivation. While traditional and virtual labs also contribute to motivation, blended learning appears to offer the most significant boost, aligning with the broader literatures on the benefits of integrating multiple instructional methods.

CONCLUSIONS

The current research shows that the integration of traditional and virtual labs greatly enhances the student's science process skills. The blended learning group indeed showed a very significant increase of mean scores from 5.85 to 9.40. Clearly, this result underlines the effectiveness of combining different instructional methods in order for students to get a deeper understanding of scientific processes.

The current research establish that students have a higher gain in conceptual understanding when learning is taking place in a blended learning environment. The average score for the blended group increased significantly from M = 8.875 to M = 12.875, which corroborates Virtual labs also fared well, with scores increasing from M = 7.465 to M = 9.465, which agrees with Bernard et al. (2009). While the traditional labs contributed to an improved understanding from M =6.581 to M=9.140, they were less effective compared to blended and virtual labs. This could imply that even though traditional methods are still crucial, they perhaps need to be combined with other modes of instruction. The current research indicates that the blended learning environment considerably increases students' motivation to study physics. Motivation also went up in the case of a traditional lab setting-from M=6.581 to M=9.140 but not as high as with blended methods.

The conclusion based on the results of the current study is that the blended learning settings proved very valuable in enhancing the science process skills, conceptual understanding, and motivation of students. In this respect, it is interesting to note that though traditional and virtual labs separately offered some unique benefits, this combined methodology-a blended learning approach-offered the most substantial gains. These findings reinforce further the combining of several instructional strategies as a means of increasing educational outcomes; therefore, educators must strive toward integration of different teaching methods that create the greatest learning and engagement for students.

RECOMMENDATION.

Recommendations for Improvement of Science Process Skills

Integration of Traditional and Virtual Labs: The educators, to get maximum improvement in students' science process skills, must not ignore either the hands-on labs or the virtual labs. According to our findings, this blended approach significantly enhances the students' abilities regarding science process skills. A blending approach developed by educators can be more effective in facilitating deeper learning due to using the strongest aspects of each method.

Intervention Custom-designed to Contexts: Consider that the effective level of blended approaches to learning differs with regard to context and implementation. It would be expected that schools and educators evaluate particular needs in each specific case, along with the available resources, when brainstorming interventions which best fit their specific educational environment. Continuous evaluation and consideration of modifications in teaching strategies will contribute to assuring that interventions remain effective.

2. Guidelines for Strengthening Conceptual Understanding:

Blended Learning Environments: Since the conceptual understanding turned out very positive, educators may adopt a blended learning environment-a blend of face-to-face contact with virtual components. Thus, it was able to demonstrate significant enhancement in the conceptual understanding of the students in science.

Include Virtual Labs: Virtual labs are one of the best ways through which conceptual understanding can be enhanced. It is, therefore, ideal for educators to integrate virtual lab activities into their curriculum provisions with well-designed and relevant activities to be implemented there. That might provide students with more opportunities to develop complex concepts in a much more interactive way.

Make Traditional Labs More Interactive: Traditional labs indeed help to enhance learning, but making them more interactive will definitely enhance their impacts. Educators need to find innovative ways to make the activities included in traditional lab work more dynamic and integrated into other modes of instruction.

3. Recommendations to Enhance Student Motivation:

Apply Blended Learning Strategies: Schools are suggested to implement blended learning strategies that incorporate both the traditional mode and virtual mode. We obtained from our survey that blended learning environments make the students more enthusiastic and participative.

Virtual Lab Design Optimization: Since the virtual labs themselves can act as a source of motivation, the designing of these labs should have more engaging and interactive features. If the virtual labs are appropriately integrated into the curriculum, offering effective learning experiences, it would help sustain motivation among the students.

Traditional Labs More Interactive and Engaging: The traditional lab should provide for students to make it more interactive and engaging. Educators need to embed in them elements that spur student interest and involvement in activities that extend beyond procedures toward problem solving and inquiry-based activities.
Evaluate and Adapt Teaching Methods: Through their experiences, continuously assess how the use of different teaching methods is impacting the motivation of the students and adapt whenever feedback or performance serves as an indicator. In this way, it is possible to establish a learning environment that is

highly motivating and engaging on a continuous basis.

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