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Blended learning and geometrical optics: Examining the interplay of conceptual understanding, motivation, and science process skills

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Abstract

This study to examine the Interplay of Conceptual Understanding, Motivation, and Science Process Skills in geometric optics. Utilizing a quasi-experimental design, 117 Grade 10 students from Woldia Preparatory and Secondary Schools were divided into four groups: one control group (traditional teaching method) and three experimental group (blended lab, virtual lab, and traditional lab). The research employed pre- and post-intervention exams to the relationship among the variable. Results indicated that weak and statistically insignificant correlations between conceptual understanding, science process skills, and motivation. Specifically, the Spearman's rho correlations showed minimal relationships among these variables. However, a logical regression revealed that while conceptual understanding did not significantly influence science process skills, motivation had a positive and statistically significant effect on these skills. This suggests that enhanced motivation is linked to improved science process skills, while conceptual understanding alone does not have a strong impact. The findings highlight the need for further research to explore these relationships in greater depth and to refine educational strategies for teaching geometric optics. Recommendations include a balanced instructional focus, contextualized learning, diverse instructional strategies, and continuous formative assessments to better address the needs of students and enhance their learning outcomes.

Keywords: Geometric optics, Blended learning, Science process skills, Student motivation

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1. INTRODUCTION

Geometric optics is a vital field of physics that explores how light travels and interacts with various objects. As educational technology advances, blended learning environments integrating traditional lab instruction with virtual components are becoming increasingly prevalent. In this context, it is essential for students not only to grasp conceptual systems but also to develop scientific process skills (SPS) and effectively engage with challenging topics like geometric optics (Ertmer & Ottenbreit-Leftwich, 2020; Krajcik et al., 2021).

A solid understanding of fundamental physics concepts, such as potential energy and wave behavior, is crucial for students to conduct meaningful experiments, analyze data, and apply scientific reasoning. Research by Leite et al. (2021) showed that students with a strong conceptual foundation in physics are better equipped to apply programming skills and conduct scientific investigations. Additionally, Miller et al. (2022) found that when students understand complex physics concepts, their motivation increases, resulting in greater confidence and a desire to learn more.

Active participation in science process skills such as experimentation, observation, and analysis strengthens and deepens conceptual understanding. Practical exercises and scientific investigations help bridge the gap between theory and real-world application, fostering a more robust grasp of fundamental physics principles (Szczepanowski et al., 2023). Moreover, timely feedback and reinforcement for their achievements can boost motivation among students who do extremely well in these skills (Zhao & Zhang, 2023).

Intellectual clarity requires significant motivation. Motivated students are more likely to invest the time and effort necessary to develop a solid understanding of physics. This strong motivation leads to deeper engagement with complex information, enhancing comprehension and retention (Pintrich & Schunk, 2023). Motivated students also tend to participate more actively in science projects, further developing their programming skills. Gikandi et al. (2023) found that these students often employ scientific methods that enhance their capabilities.

The PEEOR (Prediction, Explanation, Enactment, Observation, and Reflection) inquiry-based approach offers a structured yet flexible framework for blended learning environments. This model encourages students to test hypotheses, make predictions, defend their choices, evaluate findings, and critically reflect on their learning experiences. Amssalu et al. (2024) suggest that the PEEOR model can enhance the development of science process skills while improving motivation and conceptual understanding.

Despite these insights, significant gaps remain in the research on geometric optics education. Analyzing the interplay between key educational constructs such as conceptual understanding, science process skills, and student motivation is challenging due to the lack of clear definitions and practical applications for these terms. Furthermore, there is still limited knowledge regarding how blended learning frameworks influence these constructions, underscoring the need for further research.

Research Questions

1. What is the relationship between students' conceptual understanding of geometrical optics and their science process skills when using the PEEOR inquiry-based approach in a blended mode of physics experimentation?

2. In what ways do students' motivation levels affect their conceptual understanding and application of science process skills in the context of geometrical optics?

2. METHOD AND MATERIALS

This study examines the effects of a blended learning approach that includes virtual elements on student’s comprehension, science process skills and motivation in geometrical optics using a quantitative approach and a quasi-experimental design. Because random assignment of participants to groups may not be possible in educational research the quasi-experimental design is chosen. This design makes it possible to compare various teaching strategies while utilizing statistical controls and matching techniques to account for any confounding variables.

Sample and Population

A total of 360 grade 10 students from Woldia Preparatory School and Woldia Secondary School comprised the study population. 117 students (48%) of the total were chosen at random from this group. According to Creswell and Guettermans (2019) recommendations and in line with earlier studies (Penn & Umesh 2019 Yang & Heh 2007) this sample was judged sufficient for the quasi-experimental design. The sample was split into four groups: one comparison group (n=46) and three treatment groups (blended lab group n=40 virtual lab group n=43 traditional lab group n= 43). To guarantee representativeness and reduce selection bias random sampling was carried out using a random number generator. Getting permission from the schools and getting informed consent from each participant's protector were ethical requirements.

Instruments and Data Collection

To comprehensively measure the research variables the following methods and instruments were utilized:

- Pre- and Post-Intervention Tests: To evaluate students' conceptual understanding of geometrical optics, we employed a test consisting of 20 multiple-choice questions focused on key concepts, alongside 15 multiple-choice questions assessing their science process skills. The validity and reliability of the tests were established through pilot testing, incorporating feedback from subject matter experts. The validation process included analysis of test reliability statistics and expert evaluations. The reliability coefficients of conceptual understanding test and science process skill test are 0.84 and 0.78 respectively.
- Motivation Questionnaire: The treatment groups completed a 23-item questionnaire before and after the intervention to assess their motivation to learn about geometrical optics. This questionnaire evaluated several factors, including performance objectives, perceived value of learning physics, self-efficacy, active learning strategies particularly focusing on the PEEOR approach and stimulation from the learning environment. The questionnaire was developed using established scales, and its validity and reliability were confirmed through pilot testing. The reliability coefficient of motivation questionnaire is .79.

Ethical Considerations

Getting written consent from the participating schools and guaranteeing informed consent from the students and their guardians were ethical considerations. Participants received guarantees about the privacy of their answers and the freedom to leave the study at any moment without incurring any fees. To safeguard the privacy of the participants all data was anonymized.

Data analysis

The results of the normality tests conducted on the scores for science process skills, conceptual understanding, and motivation. These tests are essential for determining whether the data follows a normal distribution, which is a key assumption for many statistical analyses.

Table 1:

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
science process skill score	.157	113	.000	.921	113	.000
conceptual understanding score	.251	113	.000	.762	113	.000
motivation score	.111	113	.002	.953	113	.001

a. Lilliefors Significance Correction

From the above table normality based on the result of the Shapiro-Wilk statistic (n<200) which showed that all p-values were less than .05 alpha level. As a result, it is not possible to say that the data is distributed normally. Therefore, to analyze the data regarding the relationship between conceptual understanding science process skills and student motivation toward geometrical optics spearman's correlation and a kernel regression were used.

3. RESULTS

The table presents the results of Spearman's rank correlation coefficients among three variables: science process skill score, conceptual understanding score, and motivation score. Spearman's correlation is a non-parametric measure that assesses the strength and direction of the association between two ranked variables.

Table 2

Correlation among conceptual understanding science process skill, and motivation of the student.

			science process skill score	conceptual understanding score	motivation score
Spearman's rho	science process skill score	Correlation Coefficient	1.000	-.118	.137
		Sig. (2-tailed)	.	.189	.147
	conceptual understanding score	Correlation Coefficient		1.000	.077
		Sig. (2-tailed)		.	.416
	motivation score	Correlation Coefficient			1.000
		Sig. (2-tailed)			.

From the above table the results of the analysis were as follows:

Conceptual Understanding and Science Process Skills Scores: There was very little negative correlation (ρ = -0. 118) between the scores for conceptual understanding and science process skills. At p = 0. 189 this correlation was not statistically significant. This finding implies that there isn't a significant correlation between student's conceptual grasp of geometrical optics and their proficiency with science process skills within this sample.

Motivation and Science Process Skills: There was a slight positive correlation (ρ = 0. 137) between the scores for science process skills and motivation. The correlation (p = 0. 147) was not statistically significant. Higher science process skills may be linked to higher motivation as indicated by a slight positive trend, but this relationship is not statistically significant in this context.

Conceptual Understanding and Motivation: A slight positive association was shown by the correlation between conceptual understanding and motivation scores (ρ = 0. 077) although this was not statistically significant (p = 0. 416). This suggests that there is little correlation between student's motivation to learn geometrical optics and their comprehension of the subject.

Omnibus Test[a]

Likelihood Ratio Chi-Square	df	Sig.
4.824	2	.090

Dependent Variable: science process skill score

Model: (Intercept), conceptual understanding score, motivation score

- Compares the fitted model against the intercept-only model.

A chi-square test of independence was conducted to examine the association between the learning groups (blended, virtual, traditional) and learning outcomes. The results showed a non-significant association, χ^2 (2, N = 172) = 4.824, p = 0.090. This suggests that there is insufficient evidence to conclude that learning outcomes differed significantly across the three learning groups.

Parameter	B	df	sig	Exp(B)
Intercept	1.94	144.095	1	0.000
Conceptual understanding Score	-0.013	1.296	1	0.255
Motivation score	0.078	3.943	1	0.047
Scale	0.029			

A logistic regression analysis was conducted to examine the relationship between conceptual understanding score, motivation score, and the outcome variable of science process skill

- **Intercept:** The intercept term, B = 1.94, was statistically significant ($p < .001$), indicating a baseline level of the outcome variable when all predictors are zero.

- **Conceptual Understanding Score:** The coefficient for conceptual understanding score, B = -0.013, was not statistically significant (p = .255). This suggests that conceptual understanding score was not significantly associated with the outcome variable in this model.
- **Motivation Score:** The coefficient for motivation score, B = 0.078, was statistically significant (p = .047). This indicates that higher motivation scores were significantly associated with science process skills.
- **Exp(B)**: The exponentiated coefficients (Exp(B)) represent the odds ratios. For example, for motivation score, Exp(B) = 0.078, indicating that for a one-unit increase in motivation score, the odds of science process skills increase by a factor of 0.078.

4. DISCUSSION

Science Process Skills and Conceptual Understanding

The current study found a weak correlation (ρ = -0.118) between these two variables, which was not statistically significant (p = 0.189). This suggests that strong conceptual understanding does not consistently translate into improved science process skills, highlighting the challenges of applying theoretical knowledge in practical contexts. Supporting this perspective, Bretz and Towns (2020) also found that while a solid grasp of conceptual knowledge is essential for applying scientific principles, the link between conceptual understanding and science process skills is often weak. Their findings indicate that simply enhancing conceptual knowledge does not guarantee significant improvements in practical science skills.

In contrast, Smith and Wiser (2021) noted that although empirical data typically show a weak correlation often influenced by factors such as prior knowledge and instructional quality a positive relationship is still generally anticipated. This expectation aligns with the current study's findings, reinforcing the notion that context and instructional approaches play crucial roles. On a more optimistic note, Chen and Wei (2022) reported a moderate to strong positive correlation between conceptual understanding and science process skills. Their findings suggest that a deeper grasp of concepts can enhance the application of scientific processes, supporting the idea that fostering conceptual understanding may positively impact practical skills.

Moreover, Duncan and Rogat (2021) emphasized that instructional strategies designed to develop both conceptual understanding and process skills simultaneously can yield significant positive correlations, thereby enhancing students' scientific abilities. This suggests that targeted instructional approaches may effectively bridge the gap between conceptual knowledge and practical application.

Science Process Skills and Motivation

The current study reveals a small positive correlation between motivation and science process skills (ρ = 0.137), which was not statistically significant (p = 0.147). This suggests that motivation alone may not reliably predict the development of science process skills. Supporting this view, Zimmerman and Schunk (2022) found that while motivation can enhance science process skills, the correlation is not always strong. Their research emphasizes the complexity of this relationship, highlighting how motivational factors interact with other educational elements, which can sometimes obscure direct connections. They advocate for a more holistic approach that considers multiple educational factors, cautioning against relying solely on motivational strategies to improve science process skills. Similarly, Bian, Leslie, and Cimpian (2021) examined the interplay between motivation and science process skills, noting that individual differences and the learning environment often moderate this relationship. While their results indicated a positive correlation, it was not consistently strong or significant, echoing the findings in the current study.

In contrast, Liu and Hsieh (2023) identified a significant positive relationship, suggesting that motivated students are more likely to engage with and develop their science process skills. Their research indicates that motivation may have a more substantial impact than previously recognized, leading to significant improvements when motivation levels are high. Moreover, Zhang and Lee (2022) found a strong positive association between motivation and science process skills, particularly in inquiry-based and hands-on learning environments. Their findings underscore the importance of motivational strategies in these interactive contexts, suggesting that the setting can play a crucial role in enhancing the effects of motivation on science process skills.

Conceptual Understanding and Motivation

The current study reported a small positive correlation between conceptual understanding and motivation in science education ($\rho = 0.077$), which was not statistically significant ($p = 0.416$). This finding suggests that while a relationship exists, it may not be straightforward or strong, indicating that other factors might have a more profound influence on motivation. Supporting this perspective, Linnenbrink-Garcia and Pintrich (2022) explored the interaction between motivation and conceptual understanding. They noted that while deeper conceptual understanding can enhance motivation, the effect tends to be modest and contingent on teaching methods and individual student backgrounds. This aligns with the current findings, suggesting that the relationship between these variables is influenced by contextual factors.

In contrast, Graham and Harris (2023) argue that students' motivation increases when they can clearly see the real-world applications of their learning. However, they also acknowledge that this relationship is not always robust, further emphasizing the complexity of the interplay between motivation and conceptual understanding. On a more optimistic note, Wang and Zhang (2023) found a strong correlation between motivation and conceptual understanding, indicating that students with a solid grasp of concepts are more likely to engage deeply with the material and persist in their studies. This suggests that enhancing conceptual understanding can effectively boost students' motivation. Similarly, Johnson and Brown (2022) reported a somewhat positive relationship, highlighting a significant correlation between students' conceptual understanding of science and their enthusiasm to learn and participate actively in scientific endeavors. Together, these studies illustrate that while there is potential for a positive relationship between conceptual understanding and motivation, its strength and nature may vary depending on various contextual factors.

5. CONCLUSION

This study investigated the relationships between conceptual understanding, motivation, and science process skills in the context of geometrical optics learning across three different learning groups (blended, virtual, and traditional). No significant correlation was found between conceptual understanding and science process skills. Slight, but not significant, correlations were observed between:

Science process skills and motivation.

Conceptual understanding and motivation. Learning outcomes did not differ significantly across the three learning groups.

Motivation was found to be a significant predictor of science process skills, while conceptual understanding was not.

These findings suggest that while motivation plays a role in influencing science process skills, other factors not examined in this study may be more crucial in fostering conceptual understanding and its relationship with science process skills.

Recommendations

Based on the current research findings, the researcher would have the following recommendation

1. Further Investigation:

Conduct more in-depth research to explore the factors influencing the relationship between conceptual understanding and science process skills.

Investigate the potential impact of teaching methodologies, student characteristics (e.g., learning styles, prior knowledge), and the quality of instructional materials on these relationships.

2. Focus on Motivation:

Implement strategies to enhance student motivation in the learning process. This could include:

Creating engaging learning environments: Incorporating hands-on activities, real-world applications, and collaborative learning experiences.

Providing opportunities for student choice and autonomy: Allowing students to make decisions about their learning and pursue their own interests within the subject.

Offering personalized feedback and support: Providing regular feedback on student progress and offering individualized support to address specific learning needs.

3. Re-evaluate Learning Groups:

While no significant differences were found between learning groups in this study, further investigation may be warranted to explore the potential benefits of different learning modalities (e.g., blended, virtual, traditional) in specific contexts and for different student populations.

6. RECOMMENDATION

Recommendations/Future directions may stand alone or form a subsection of the discussion or results and discussion section. These include meaningful suggestions for further research and/or practical applications flowing from the study's conclusions.

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