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Gender Differences in Performance and Motivation: Comparing Virtual and Hands-On Lab Techniques

Perbedaan Gender dalam Performa dan Motivasi: Perbandingan Teknik Laboratorium Virtual dan Langsung

Aisha Bagiwa Lawal
Department of Science Education, Ahmadu Bello University, Zaria, Nigeria
email: aishabagiwalawal@gmail.com

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ABSTRACT

This research explored gender differences in performance and motivation by comparing virtual and hands-on laboratory techniques among N.C.E Biology students in Katsina State, Nigeria. The study focused on four objectives, one of which was to assess the differences in academic performance between male and female students using virtual laboratory techniques. It included four research questions and tested four null hypotheses. A one-shot case study design was employed, with both pretest and posttest assessments for two experimental groups. The study's population consisted of 357 students: 313 males and 114 females, from which 120 N.C.E III biology students were randomly selected and divided into two experimental groups. The instruments used are: Conservation Performance Test (CPT), Virtual Laboratory Motivation Questionnaire (VLMQ), and Hands-on Laboratory Motivation Questionnaire (HLMQ), with reliability coefficients of 0.80, 0.85, and 0.75, respectively. Data was collected and analyzed post-treatment, with research questions answered through means, standard deviations, mean ranks, and sums of ranks. The null hypotheses were tested using t-tests and Mann Whitney U-test statistics. According to the findings, there was no significant difference between the academic performance of male and female students exposed to virtual and hands-on laboratory methods; the mean difference for virtual and hands-on laboratories was 0.17 and 0.65 in favor of female students, respectively. Additionally, the levels of motivation for both types of laboratory techniques were comparable between male and female students. It was recommended that virtual and hands-on laboratory strategies be used to teach biology to both genders, as they boost performance and motivation.

Keywords: *gender, hands-on, motivation, performance, virtual.*

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INTRODUCTION

Science education has traditionally relied heavily on hands-on laboratory experiments, which give students actual experience and the chance to enhance their skills. In biology education as a branch of science education, laboratory experiments are essential for students to develop practical skills, observe phenomena, and understand complex biological processes. However, with the advent of virtual laboratory, students can now participate in computer-generated experiments that replicate actual settings.

> *"Through the use of a virtual laboratory, students can enhance their educational experience, conduct experiments as though they were in actual laboratories, and develop their proficiency with tools and materials, gather data, interact with the process of conducting an experiment (with an infinite supply of supplies), and write up the results. (Tatli and Ayas, 2013)"*

According to Lawal (2024), virtual laboratories in biology offer a complimentary approach, providing simulated experiments and interactive models that mimic real world conditions.

Despite the benefits of both virtual and hands-on laboratory strategies, there's a rising curiosity about how they affect students' performance especially with regards to gender disparities. Myers (2018) defined gender as "the qualities whether societal or biological that define males and females". Myers stated the gender schema theory "as the structured networks of knowledge about what it means to be male or female". Dawal (2021) opined that "The goal of examining gender disparities is to determine whether males and females have equal access to chances for the realization of their human rights, as well as the ability to contribute to and benefit from all areas of national development".

Research has shown that gender significantly impacts students' performance in Science, Technology, Engineering, and Mathematics (STEM) subjects. In response to this, much research has been carried out with mixed reports. For instance, Wong and Hanafi (2007) noted that "the prevailing view suggests boys, due to their natural affinity for technology, may excel in technology-enhanced learning environments, while girls may encounter obstacles that hinder their learning outcomes in such settings". Even so, Muoneme (2016) rejected it after discovering that "technology and computer use are gender friendly". Dawal (2021) discovered that "female students outperformed male students in biology, while males performed better in other STEM subjects". In the same vein, Maikano, Bichi, and Shaibu (2016) investigated gender differences in academic performance among senior secondary school students when teaching ecology through both indoor and outdoor instructional methods. The researchers found there was no disparity in the academic achievement of male and female students exposed to outdoor and indoor laboratory instructional strategies, suggesting that both approaches to teaching were gender friendly. All of these observations and studies by various scholars suggests that this area will benefit from further research.

Motivation in gender differences is another issue of concern in this study and had been the subject of educational research for several years. Meece *et al.* (2006) defined motivation as "the psychological driver that determines an individual's direction of effort and level of persistence when faced with obstacles". Singer, Hilton, and Schweingruber (2016), in the Americas laboratory report, suggests that "ordinary experiences can contribute to fostering student's interest in science and learning science. Evidence indicates that participating in laboratory experiences and other learning activities within integrated instructional units can boost student's interest in science and motivation to learn it".

Despite the rather limited amount of studies conducted into the gender differences in motivation of students towards laboratory approaches in biology, several studies have nevertheless been identified in science teaching generally. The research of Reese (2013) found out that "female students exhibit higher motivation to learn biology than males at both the beginning and end of semester, a trend that held true for both the entire Biology I course and the virtual laboratory group". A further investigation conducted by Cavallo, Potter, and Rozman (2010) found that "when the motivational goals and learning styles of male and female college science students were compared, male students achieved higher final grades compared to female students, a difference that was statistically significant". Both reports contrast with the findings of Radulovic, Zupanec, and Stojanovic (2022) discovered that "while male students scored higher than female students in terms of the perceived importance of physical science and self-efficacy, there were no significant gender differences in their motivation to pursue the subject". The study also found that "virtual experiments had a more positive impact on female students' motivation to learn physics compared to traditional, real-life experiments".

The issue of gender in academic performance and motivation is controversial and inconclusive, with males and females exhibiting different learning styles and preferences, despite the importance of laboratory experiments in biology teaching. Although virtual laboratories have opened up new learning opportunities, it is still unclear whether gender equity in biology is better supported by virtual or hands-on laboratories, which include restrictions that exacerbate the situation, such as restricted access, safety problems and ethical considerations. Thus, the objective of this research is to explore the best strategy for advancing gender parity and enhancing biology students' learning outcomes by examining gender variations in performance and motivation in both hands-on and virtual biology laboratories. Also, the researcher seeks to provide insight into how educators may enhance laboratory instruction to promote gender parity and increase student learning outcomes in biology by comparing the efficacy of virtual and hands-on laboratory techniques in biology education.

Review of Related Literature

Relevant literature has been reviewed and findings from the reviewed literature reveal various results on both virtual and outdoor laboratories effect on the performance and motivation in respect to gender disparities. Numerous studies conducted by various researchers have examined the impact of virtual laboratories on student achievement and motivation. For example, Gambari *et al.* (2017) investigated the effects of virtual laboratories on the achievement levels and gender differences of secondary school chemistry students in both individualized and collaborative learning environments in Minna, Nigeria. Their findings revealed that "students in the collaborative virtual laboratory setting outperformed those in the individualized setting". Additionally, a significant difference was observed in the chemistry achievement scores of male and female students in the individualized virtual laboratory setting.

Gunawan (2018) explored the influence of virtual laboratories and gender on senior high school students' creativity in physics. The study found that "virtual laboratories enhanced students' verbal, numerical, and figural creativity. While male and female students scored similarly in verbal creativity, female students outperformed their male counterparts in numerical and figural creativity".

Al-Hassan (2016) from the University of Khartoum, Sudan, examined the effect of virtual laboratories on academic achievement and learning motivation among Sudanese secondary school students. The findings indicated that "students appreciated the ease of manipulation and experimentation in virtual laboratories more than in traditional manual laboratories, which many chemistry educators consider an essential component of the laboratory experience".

Garver (2016) conducted research in Montana on the influence of outdoor learning environments on students' motivation, engagement, and cognition in science. His results demonstrated "a positive correlation between outdoor learning and increased student motivation, engagement, and achievement".

Reese (2013) studied the impact of face-to-face and virtual laboratories in an introductory biology course at the University of Florida, focusing on students' motivation to learn biology. The findings indicated that "the virtual laboratory environment did not have a significant effect on students' motivation compared to traditional laboratories".

Finally, Elawadi and Tolba (2009) performed a comparative analysis of the educational objectives of three laboratory techniques: hands-on, simulated, and remote laboratories. Their research concluded that "hands-on laboratory proponents emphasized the importance of developing design skills, whereas remote laboratory supporters did not prioritize this objective in their evaluations".

The comparison of virtual and hands-on laboratory techniques is significant for understanding gender differences in learning because it will determine which approach produces better learning outcomes for male and female students. It is also important for addressing gender-based motivation differences because research shows that men and women have different ideas about what is important and motivating for a good education in school.

The reviewed studies across biology and other disciplines reveal that research on gender differences in academic achievement and motivation in virtual and hands-on laboratories is relatively new. Most existing research focuses on overall performance and motivation in these laboratory environments but pays little attention to gender-specific responses. Additionally, many studies are limited to STEM fields or specific disciplines. The current literature predominantly emphasizes academic performance while overlooking underlying cognitive and psychological factors. Therefore, this study seeks to address this gap by investigating gender differences in performance and motivation in virtual and hands-on laboratory techniques. By doing so, it aims to contribute to the development of a more inclusive and effective biology teaching environment.

Theoretical Framework

This study is guided by three key theories: Mayer's (2001) Cognitive Theory of Multimedia Learning, Bruner's (1960) Constructivist Theory, and Self-Determination Theory developed by Ryan and Deci (2000). Mayer's theory posits that "students learn more effectively when both words and images are used together rather than relying on words alone, enabling them to form connections between verbal and visual representations". The Cognitive Theory of Multimedia Learning aims to describe the cognitive processes that occur in learners' minds during meaningful learning through multimedia instruction. When considering the virtual laboratory strategy, Mayer's theory will be adopted because this learning theory places the learner as the sole constructor of knowledge and emphasizes the importance of the learners' inquiry process. Here, when learners are exposed to virtual learning both males and females will construct their own knowledge by selecting, organizing, and integrating relevant visual and verbal information thereby making it a long-term memory. This interactive nature helps in motivation, especially among students who find real world environments intimidating.

The second theory that guided this research is Bruner's constructivism model of teaching and learning which serves as the theoretical framework for hands-on laboratory strategy. Constructivism, according to Bruner, "is a learning theory suggesting that individuals develop new understanding through the interaction between their existing knowledge, beliefs, and new ideas or information they encounter, often shaped by prior experiences". Constructivists assert that "knowledge and meaning are constructed through the interplay of personal experiences and external concepts". When learners engage in hands-on activities, they acquire knowledge by interacting with specimens and equipment, fostering both practical and cognitive engagement. Bruner (1961) introduced the concept of discovery learning, emphasizing that "it begins when science teachers intentionally present a problem with inconsistencies in the provided information, encouraging students to explore and resolve these discrepancies through inquiry and critical thinking".

Applying Bruner's concepts to hands-on laboratory strategies involves engaging students in practical activities and presenting them with contradictions that create intellectual discomfort. This discomfort motivates learners to seek solutions by activating cognitive processes such as observing, hypothesizing, measuring, problem identification, data collection, classifying, and inferring. Practical activities are more emphasized at this stage of tertiary education because the learners are capable of experimenting and manipulating data with a guide to their understanding, achievement, and acquisition of desired skills. Conant (1951) proposed that "learning science involves a network of interconnected concepts and conceptual frameworks that emerge through experimentation and observation, serving as a foundation for further scientific inquiry". This theory implies that scientific knowledge is not fixed but evolves with new experiments and observations. Previous research highlights the motivational benefits of practical work in science education. Wellington (2005) emphasized its role in engaging students, while Abrahams (2009) found it more effective than writing tasks. Additionally, Toplis (2012) noted that "practical work enhances students' understanding of theoretical concepts".

The third theory, Self-Determination Theory developed by Ryan and Deci (2000), is a theory of motivation that aims to explain individuals' goal-directed behavior. The theory proposes three universal innate psychological needs: (1) Competence—defined by a perceived self-belief in one's ability to perform well in an activity; (2) Autonomy or freedom of choice—perceived autonomy is high when students feel they are engaging in project-based learning or field trip because they choose to do so, not because they feel pressured; and (3) Psychological relatedness—defined by a sense of shared experience and meaningful relationships. Therefore, NCE Biology students are motivated by activities which allow them to form and enjoy good relationships. Thus, students feel motivated by activities such as virtual learning or hands-on when the facilitator allows them to satisfy these three needs because these activities are enjoyable and driven by intrinsic motivation.

In this study, Bruner's learning model, Mayer's Cognitive Theory of Multimedia Learning, and Self-Determination Theory of motivation were applied to both outdoor and hands-on laboratory strategies. Considering gender differences in motivation and performance, these theories will guide the design of virtual and hands-on laboratories to promote equitable educational outcomes for all students.

Objectives

The research aims to accomplish the following:

- Investigate the differences in academic performance between male and female students exposed to the virtual laboratory technique.
- Investigate the differences in academic performance between male and female students exposed to the hands-on laboratory technique.
- Explore the variation in motivation levels between male and female students exposed to the virtual laboratory technique.
- Explore the variation in motivation levels between male and female students exposed to the hands-on laboratory technique.

Research Questions

The study aimed to address the following research questions:

- What is the difference in academic performance between male and female students exposed to the virtual laboratory technique?
- What is the difference in academic performance between male and female students exposed to the hands-on laboratory technique?
- What are the differences in motivation levels between male and female students exposed to the virtual laboratory technique?
- What are the differences in motivation levels between male and female students exposed to the hands-on laboratory technique?

Null Hypotheses

These are the null hypotheses developed for testing at $P \leq 0.05$ confidence levels based on the specified research questions:

H_{01}: There is no significant difference between the academic performance of males and females exposed to virtual laboratory technique.

H_{02}: There is no significant difference between the academic performance of males and females exposed to hands-on laboratory technique.

H_{03}: There is no significant difference in the motivation levels between males and females exposed to virtual laboratory technique.

H_{04}: There is no significant difference in the motivation levels between males and females exposed to hands-on laboratory technique.

METHODOLOGY

In this study, a one-shot case design was employed, involving pretests and posttests for both experimental groups. Initially, both groups I and II took a pretest (O1). Group I was taught conservation concepts using virtual labs, while Group II used hands-on labs. The conservation of natural resources is a vital topic in the Ecological Adaptation curriculum for Senior Secondary II (SSII) students, but it often receives inadequate attention, leading to poor performance in national exams like WAEC and NECO. Effectively teaching this concept to NCE (Nigeria Certificate in Education) students, who will become future teachers, could significantly enhance examination outcomes. Additionally, this topic can be taught using both virtual and outdoor laboratory methods. Following the treatment, posttests (O2) were administered. The study population included all NCE III biology students from two colleges of education in Katsina State, totaling 357 students (313 males and 114 females). The final year was chosen because BIO 321 (Applied Biology), which covers the conservation of natural resources, is a compulsory course that had already been taught. A sample of 120 students was chosen by simple random sampling using a balloting approach. Each group had 60 students, of which 39 and 21 were male and female for the virtual lab, and 42 and 18 were female and male for the hands-on lab, with an average age of 22. Each group consisted of 60 students, consistent with Kerlinger (1973) and the Central Limit Theorem, which recommends a minimum sample size of 30 for studies of this kind (Tuckman, 1975). Three research instruments were employed in the study:

- Conservation Performance Test (CPT) – This tool consisted of two sections. Section A gathered participants' biodata, while Section B comprised 40 multiple-choice questions, each with four options (A–D). Students were required to choose the correct answer for each item. The questions were designed to evaluate students' knowledge and skills related to biological conservation concepts.
- Virtual Laboratory Motivation Questionnaire (VLMQ) – This instrument also contained two sections. Section A collected personal information, and Section B included 30 items assessing students' motivation toward learning conservation concepts of biology in a virtual laboratory environment. A four-point Likert scale was used to record responses.
- Hands-On Laboratory Motivation Questionnaire (HLMQ) – Similarly structured in two sections, Section A gathered personal details, while Section B featured 30 items measuring students' motivation toward conservation concepts of biology in hands-on laboratory settings. Responses were measured using a four-point Likert scale.

All three instruments; the CPT, VLMQ, and HLMQ were adapted from Abubakar (2017), and Wada (2016), respectively. The instruments were validated by Ph.D.-qualified experts and senior academics from the Department of Science Education at Ahmadu Bello University, Zaria. A pilot test demonstrated reliability coefficients of $r = 0.80$ for BCPT, $r = 0.85$ for VLMQ, and $r = 0.75$ for HLMQ, confirming their suitability for the study. All 120 distributed questionnaires were completed and analyzed. Subsequent to the treatment, data were analyzed: Research Questions 1 and 2 were addressed using means and standard deviations to determine the mean differences, while Research Questions 3 and 4 were analyzed using mean ranks and sum of ranks to assess gender-based motivation levels. Null Hypotheses 1 and 2 were tested with independent t-tests to evaluate gender differences in performance, whereas Null Hypotheses 3 and 4 were examined using the Mann–Whitney U test to compare gender differences in motivation levels. All hypotheses were tested at a 0.05 level of significance.

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RESULTS AND DISCUSSION

Research Question 1

Table I: *Summary of Mean Difference between the Academic Performance of Males and Females Exposed to Virtual Laboratory Technique*

Gender	N	Mean	SD	Mean diff.
Male	39	25.19	3.47	0.17
Female	21	25.02	3.85	

According to Table I, the mean performance scores of male and female students who used the virtual laboratory technique were 25.19 and 25.02, respectively, with standard deviations of 3.47 and 3.85 for the respective genders. This means that there was a mean difference of 0.17 in favor of the female students. This implies that when using the virtual laboratory approach, male and female students do not perform significantly differently from one another.

Research Question 2

Table II: *Summary of Mean Difference between Academic Performance of Males and Females Exposed to Hands-on Laboratory Technique*

Gender	N	Mean	STD	Mean diff.
Male	41	22.88	3.42	0.65
Female	19	23.53	3.10	

Table 2 indicates that the mean performance scores are 22.88 for male students and 23.53 for female students, while having the standard deviation of 3.42 and 3.10 for males and females respectively, resulting in a mean difference of 0.65 in favor of female students. This implies that both males and females performed equally well when exposed to hands-on laboratory techniques.

Research Question 3

Table 3: *Mean Rank Differences in Motivation Levels between Male and Female Students Exposed to the Virtual Laboratory Technique*

Variable	N	Mean Rank	Sum of Rank
Male	39	28.87	1125.93
Female	21	33.52	703.92

Table 3 shows that the mean ranks for motivation are 28.87 for male students and 33.52 for female students, with sum of rank scores of 1125.93 and 703.92, respectively. This implies that when utilizing the virtual laboratory procedures, male and female students are similarly motivated.

Research Question 4

Table 4: *Mean Rank between the Levels of Motivation of Males and Females Exposed to Hands-on Laboratory*

Variable	N	Mean Rank	Sum of Ranks
Male	41	32.02	1312.82
Female	19	27.21	516.99

Table 4 indicates that the mean ranks for motivation are 32.02 for male students and 27.21 for female students, with total rank scores of 1312.82 and 516.99, respectively. This implies that when participating in the hands-on laboratory method, male and female students show comparable levels of motivation.

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Hypothesis One

Table 5: *Summary of T-Test Analysis between the Academic Performance of Males and Females Exposed to Virtual Laboratory Technique*

Variable	N	Mean	STD	Mean diff.	DF	t comp.	p	Remark
Male	39	25.19	3.47					
				0.17	58	0.17	0.86	Not sig.
Female	21	25.02	3.86					

Not significant at P > 0.05 level

According to the dependent t-test results above, the academic performance of male and female biology students using the virtual laboratory technique is not significantly different. An estimated p-value of 0.86, over the significance level of 0.05, and a computed t-value of 0.17, less than the t-critical value of 1.96 at degrees of freedom (df) 58, support this result. As such, the null hypothesis which states that there isn't a significant difference in academic achievement between males and females who use the virtual laboratory technique is hereby not rejected.

Hypothesis Two

Table 6: *Summary of T-Test Analysis between the Academic Performance of Males and Females Exposed to Hands-on Laboratory Technique*

Variable	N	Mean	STD	Mean diff	DF	t-computed	P	Remark
Male	41	22.88	3.42					
				0.65	58	0.70	0.49	Not Sig.
Female	19	23.53	3.10					

Not significant at P > 0.05 level

Table 6 data shows that the observed t-value is 0.70 and the p-value is 0.49, with 58 degrees of freedom. Because the calculated t-value of 0.70 is below the t-critical value of 1.96 and the p-value of 0.49 is greater than the critical p-value of 0.05, the hypothesis asserting that there is no significant difference in the academic performance of male and female students exposed to the hands-on laboratory technique is retained.

Hypothesis Three

Table 7: *Summary of Mann-Whitney U Tests Difference between the Levels of Motivation of Males and Females in Virtual Laboratory*

Variable	N	Mean Rank	Sum of Ranks	Mann Whitney	DF	Z	P-value	Remark
Male	39	28.87	1125.93					
				473.00	58	0.99	0.33	Not Sig
Female	21	33.52	703.92					

Table 7 presents the results, which show that the computed p-value of 0.33 is more than the significance level of 0.05. Moreover, the calculated Z score of 0.99 is less than the 473.00 Mann-Whitney score. Male and female students who used the virtual laboratory technique had mean rank motivation levels of 28.87 and 33.52, respectively, indicating that both sexes had similar motivation levels. As a result, the null hypothesis which states that there is no significant difference in the motivation levels between males and females exposed to virtual laboratory technique is upheld.

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Hypothesis Four

Table 8: *Summary of Mann-Whitney U Tests Difference between the Levels of Motivation of Males and Females Exposed to Hands-on Laboratory Strategy*

Variables	N	Mean Rank	Sum of Ranks	Mann U Whitney	DF	Z	P-Val	Remark
Male	41	32.02	1312.82					
				327.000	58	0.99	0.32	Not Sig.
Female	19	27.21	516.99					

Not significant at P > 0.05 level

Table 8 presents the estimated p-value, which is greater than the significance level of 0.05, and the computed Z-score, which is less than the Mann-Whitney score of 327.000. For students exposed to the hands-on laboratory strategy, the mean rank for motivation levels is 32.02 for male students and 27.21 for female students, suggesting that both groups have similar levels of motivation. Since there is no significant difference in the motivation levels of male and female students exposed to the hands-on laboratory technique, the null hypothesis is upheld.

Discussion

What is the difference in academic performance between male and female students exposed to the virtual laboratory technique? This research question is addressed through the analysis shown in Tables I and V, which reveal that, although female students had slightly higher mean scores compared to male students, the difference was not statistically significant, leading to the retention of the null hypothesis. This finding aligns with Gambari *et al.* (2017), who found that "gender did not influence academic performance in Chemistry, Physics, or Biology". It also supports Usman Usman, Alabi, Falode & Muhammad (2019), who reported "no significant gender differences when teaching geography using virtual laboratories". However, this contrasts with Oser (2013), which suggested that "virtual laboratories were more beneficial for males compared to females in terms of material environment, while traditional instruction was equally effective for both genders". Similarly, Ezenwosu and Nworgu (2013) found that "male students slightly outperformed female students when biology was taught through peer tutoring". The current study's results may be attributed to the perception that biological sciences do not have a significant gender gap, allowing both male and female students to engage equally in the virtual laboratory setting. The finding, grounded in the study's theoretical framework, supports Mayer's Theory of Multimedia Learning, which emphasizes that learning occurs through the integration of words and visuals rather than being influenced by demographic variables such as gender. The absence of a significant performance gap between male and female students indicates that the multimedia design of the virtual laboratory effectively supported learning for both groups, demonstrating that well-designed multimedia resources can foster equal learning outcomes irrespective of gender.

What is the difference in academic performance between male and female students exposed to the hands-on laboratory technique? This research question is addressed through the analysis shown in Tables II and VI, which shows that male and female students exhibited comparable performance when using the hands-on laboratory technique. This finding aligns with Saudi dan Suleiman (2014), who reported "no significant difference in the academic performance of male and female students engaged in outdoor biology laboratory activities at the college level".also reported that "outdoor hands-on activities were effective for both genders and improved academic performance in N.C.E students". These results are supported by Sanusi (2019), Adanyi (2019), and Danjuma (2021), who found that "field trips and inquiry-based learning were equally effective in enhancing the academic performance of both male and female students compared to traditional

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lecture methods". Conversely, Alghamdi, Karpinski, Lepp, and Berkley (2020) found that "females showed stronger self-regulation in online contexts, while males had better technical skills and used a broader range of learning methods". The current study suggests that hands-on laboratory exercises are gender-neutral, benefiting all students equally at the college level. The finding aligns with Bruner's constructivist theory, which asserts that learning is influenced by active participation, scaffolding, and prior knowledge rather than by gender.

What are the differences in motivation levels between male and female students exposed to the virtual laboratory technique? This research question is addressed through the analysis shown in Tables III and VII, which reveals no significant difference in motivation levels between male and female students exposed to the virtual laboratory technique. This suggests that both genders exhibited comparable motivation levels while engaging with the virtual laboratory, although female students had a slight advantage. This finding is consistent with the research by Radulovic, Zupanec, and Stojanovic (2022), which reported "no significant gender differences in students' motivation to learn physics, although males rated the importance of physics and their self-efficacy higher than females". Their study also indicated that "virtual experiments were more motivating for female students compared to real experiments". Additionally, Obrentz (2012) found that "males had higher overall motivation to learn chemistry throughout the semester", while Sofiani, Fadhillah, and Sihite (2018) reported "a generally moderate positive attitude towards science among students, with no significant gender differences". The current study's findings may be explained by the perception that biological sciences are gender-neutral. The finding supports the Self-Determination Theory (SDT) of motivation, which asserts that motivation arises from meeting the fundamental psychological needs of autonomy, competence, and relatedness, rather than from inherent attributes like gender. The absence of a significant difference in motivation levels suggests that the virtual laboratory environment satisfied these needs equally for male and female students, leading to comparable motivation levels.

What are the differences in motivation levels between male and female students exposed to the hands-on laboratory technique? This research question is addressed through the analysis shown in Tables IV and VIII, which showed that both male and female students had equal motivation levels when using the hands-on laboratory technique. This finding aligns with the research by Egwu and Okigbo (2021), which revealed that "gender did not have a significant impact on secondary school students' achievement in ecology during field trips". Similarly, Adejoh *et al.* (2021) reported "no significant difference in achievement scores between male and female students taught ecology using field trips". Lawal (2017) also found "no significant performance difference between genders in experimental groups, suggesting that the laboratory strategy is gender-neutral". However, Brown and Brown (2019) found that "male students performed better and had higher levels of interest and motivation with field trip teaching methods compared to video technology methods". The current study's consistent results may be attributed to the hands-on teaching method, which fosters active learning, self-motivation, discovery learning, and experiential learning elements that engage and benefit both male and female students equally. The finding supports Self-Determination Theory (SDT), which emphasizes that motivation is driven by the fulfillment of autonomy, competence, and relatedness rather than by inherent characteristics like gender.

CONCLUSIONS

The study revealed that both the virtual laboratory and the hands-on laboratory strategies were equally effective for male and female students in terms of academic performance. It further showed that gender did not influence motivation levels, as male and female students exhibited comparable motivation when engaging with the virtual laboratory and demonstrated similar motivation when participating in the hands-on laboratory approach.

Recommendations

- Both male and female students should be taught concepts of biology with virtual and hands-on laboratory strategies as both enhance academic performance when used.
- Biology concepts should be taught to both male and female students using virtual and hands-on laboratory techniques, as both approaches boost student motivation.

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