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Beyond the Confines of Achievement in Secondary School Biology: Higher-order thinking in Focus

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A B S T R A C T

Thinking at a rate higher than memorizing ideas or recalling verbatim what was learned in the previous lessons is a challenging task in teaching and learning biological concepts. Past studies have established many strategies to address this, but they are not directly linked to the ultimate solution to the problem. This study investigates the potency of problem-solving strategy to enhance student's ability in higher-order thinking tasks in biology. A total of 118 senior secondary two biology students in their intact group participated in the study. The study employed a quasi-experimental group design. Data on higher-order thinking tasks were collected using 20 multiple-choice items titled Achievement Test in Higher-order Thinking Tasks (ATHOTT). Mean and standard deviation depicted in bar charts provide answers to the three research questions, while analysis of covariance was employed to test the hypotheses. The results revealed that problem-solving strategy enhanced students' response to higher-order thinking tasks, male and female students did not differ in response to higher-order thinking tasks, and gender did not mediate with the problem-solving strategy to enhance students' response to higher-order thinking tasks in biology. Teachers are, therefore, implored to engage students in problem-solving activities.

1. Introduction

Nations of the world face various challenges and diverse problems, from social, political, economic, religious, health, food, and pollution to environmental degradation (Adeyemi, 2011). Providing solutions to the world's emerging problems needs individuals who can think critically. Higher-order thinking is a significant skill to proffer solutions to problems competently. This throws a

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challenge of breeding and developing students or individuals who are highly skillful in thinking and capable of proffering solutions to emerging world problems, especially in the 21st century. Adeyemi (2011) observed that higher-order or critical thinking uses logic and broad intellectual criteria – clarity, credibility, accuracy, precision, relevance, depth, breadth, fairness, and significance. Similarly, Foundation for critical thinking (2009) describes higher-order thinking as the intellectually disciplined process of actively and skilfully conceptualising, applying, analyzing, synthesizing and evaluating information gathered from observation, experience, reflection, recognising, or communication as a guide to belief and action. Instructions that enhance thinking skills have been found to promote intellectual growth and foster academic achievement gains (Djami & Kuswandono, 2020; Jamari et al.,2017).

Goethals (2013) describes higher-order thinking (HOT) as what results from problem-solving or analysis. For Kruger (2013), higher-order thinking (HOT) involves concept formation, critical thinking, creativity/brainstorming, problem-solving, mental representation, reasoning, and logical thinking. Centre for Development and Learning (CDL, 2013) describes higher-order thinking as including "Concept formation, concept connection, getting the picture, visualisation, problem-solving, questioning, idea generation, analytical (critical) thinking, practical thinking and creative thinking.". The ability of students to tackle questions or problems at a higher-order level of thinking resides in their level of attainment in higher-order thinking skills (Silitonga, Panjaitan & Supriyati, 2020). Therefore, classroom instruction in biology education should entrench teaching HOTs because acquiring adequate knowledge of biology can be applied to solve complex real-life problems, especially in health-related issues, environmental pollution, and food production.

Indeed, higher-order thinking occurs when the students analyse, synthesize/create and evaluate, or make a judgment. Students are involved in higher-order thinking when they visualize a given problem by separating relevant information from irrelevant information, seeking reasons and causes, and *justifying* solutions (Byrnes, 2001). Using higher-order thinking to process learning promotes retention and makes learning more evident than learning processed through lower-order thinking. It fosters more profound conceptual knowledge in students, resulting in the easy application of such knowledge to solve new problems.

The instructional model of Bloom categorizes thinking skills into knowledge, comprehension, application, analysis, synthesis, and evaluation. The thinking skills of analysis, synthesis, and evaluation are considered higher-order skills (Anderson & Krathwhol, 2001). Hence, higher-order thinking skills become the higher capabilities of the last three aspects of human thinking. This implies that students' abilities to handle higher thinking tasks rely heavily on their level of higher-order thinking skills (Silitonga, Panjaitan & Supriyati, 2020).

Detail and comprehensive knowledge of biology is sin -qua non for students to study biology-related fields (medical sciences, biotechnology, food science technology) to earn a higher education. Despite the role biology plays as a prerequisite for producing a high and skillful workforce for the 21st-century workforce, especially in health and food production, attainment in higher-order thinking questions at the national examination is low and persistently undesirable at the preceding level of tertiary education (Onuwegbeda, 2022).

The poor attainment of students in biology is unconnected with concepts students find challenging to learn and comprehend meaningfully due to the teachers' didactic and inappropriate instruction methods. Among the concepts students find challenging are genetics, respiration, photosynthesis, nervous system, endocrine system, variation, and evolution (Chief Examiners' Report, 2020; Okebukola, 2020). The report further reveals that students performed poorly in questions requiring higher-order thinking skills – protein synthesis in cells and genetics questions that demand/require deep thinking and reflective thinking (WAEC, Chief examiner reports, 2018, 2019 & 2020). The need to reverse the downward trends in students' attainment of concepts they find difficult to learn in biology makes teaching higher-order thinking skills with the problem-solving strategy imperative for this study.

In problem-solving strategy, students are privileged to ask questions of their own and take control of their activities by thinking of other possible ways to arrive at solutions to problems. They interact with the setting to define the problem, and they search for their solutions. These students are preparing for a time in life when they will face situations that must be structured as problems to be solved, and they are learning how to cope when solutions are elusive (Kani & Shahrill, 2015).

According to Dostal (2015), the thinking of an individual to solve a problem commences with the ability of the individual to be aware of the problematic situation. For an individual to solve a problem, they must be aware of the problem, able to decern the difficulty, and identify the obstacle to remove. Awareness of problems can be affected by inappropriate verbal utterances that should induce the situation or lack of knowledge. Individual needs to perceive the problem to develop the willingness to deal with the problem. Willingness to solve the problem requires initial information to negotiate ways of overcoming the obstacle or challenges. The willingness to proffer solutions rests on motivational and emotional constructs of interests, self-confidence, and the conception of own abilities (Dostal, 2015).

Salam (2022) discovers that problem-solving helps students better understand the nature and purpose of learning activities. That is, it helps students to understand how new knowledge is attained in an experimental situation. The problem-solving strategy begins by focusing students' attention on what they know before the inquiry. Students then generate research questions, design and conduct experiments, and interpret the data. Through interpretation, they arrive at new knowledge that must be integrated with their prior knowledge. Salam (2022) adds that problem-solving involves presenting learners with written-out problems in which the learner has to interpret the problem, devise a method to solve it, follow a procedural pattern to achieve the result, and analyze the result to see if it is an acceptable solution to the problem. This suggests that biology instruction should offer the learners opportunities that would enable them to relate favorably to difficult concepts and provide them with analytical, synthetical, and evaluative skills needed to solve their problems. In problem-solving, the teacher guides students to acquire and develop new levels of inquiry skills. Literature shows that the analysis used by experienced problem solvers, such as a verbal description or a picture, serves as a decision guide for planning and evaluating the solution (Djami & Kuswandno, 2020). This step is said to take extra time to complete but facilitates the efficient completion of further solution steps. Usually, the experienced problem solver can complete the problem in less time than the inexperienced solver.

Problem solvers have been examined by comparing and contrasting the problem-solving abilities of inexperienced and experienced problem solvers. The findings of Dostal (2015) revealed that the principal difference between the two was how they perceived, organized, and used their knowledge about solving a problem. According to such reports, experienced problem solvers rapidly redescribe the problem and often use qualitative arguments to plan solutions before elaborating on them in greater mathematical detail. In contrast, inexperienced problem solvers rush into the solution by stringing together miscellaneous mathematical equations and quickly encounter difficulties. Inexperienced problem solvers do not necessarily have this knowledge structure, as their understanding consists of random facts and equations with little conceptual meaning.

Previous studies attest to the potency of problem-solving strategy in bringing about meaningful learning of science (Jamari, Mohamed, Abdullahi, Zaid & Aris, 2017; Adeyemi, 211) in physics (Silitonga, Panjaitan&Supriyat, 2020; Djami & Kuswandno, 2020) in English (Zaharin, Sharif & Mariappan,2018; Afolabi & Akinbobola, 2009; Ali et al., 2010) in biology (Udeani & Adeyemo, 2011; Serin, 2011; Nfon, 2013). For instance, the study conducted by (Silitonga, Panjaitan & Supriya, 2020) shows that problem-solving promoted physics students' higher attainment in higher-order thinking skills and effectively enhanced students' higher-order thinking in physics.

A study conducted by Udeani & Adeyemo (2011) to determine the relationship between teachers' problem-solving abilities, students' learning styles, and students' achievement discovered a significant positive relationship between biology teachers' problem-solving skills and students' achievement in Biology and that teachers' problem-solving ability was practical on students' achievement in biology. At the same time, Afolabi and Akinbobola's (2009) study on constructivist problem-based learning techniques and achievement of Physics students with low ability levels in Nigeria showed that using problem-based learning techniques improved the performance of low ability levels in Physics. Similarly, in a study to foster higher-order thinking and problem-solving through media, (Jamari, Mohamed, Abdulah, Zaid & Aris, 2017) established that problem-solving can realign and monitor the review thought process, enhance the quality of learning and promote higher-order thinking skills in students.

Reports of international studies acceding to the efficacy of problem-solving strategy in meaningful learning have been documented. Ali, Hukamdad, Akhter & khan (2010) conducted a study to determine the potency of using the problem-solving method in teaching Mathematics on the achievement of students in Pakistan. The result of the study revealed that the use of problem-solving strategies enhanced students' achievement in Mathematics. Serin (2011) found in a survey to measure the academic achievement level of 52 participants exposed to computer-based instruction through problem-solving techniques performed significantly better than the participants in the control group. The finding revealed a statistically significant increase in achievement and problem-solving skills of the experimental group students than those in the control group.

A similar trend was found in a study by Husamah, Fatmawati & Setyawan (2018). Using OIDDE (Orientation, Identify, Discussion, Decision, and Engage) learning model to foster students' higher-order thinking skills by assessing three aspects of thinking skills- self-regulated, critical, and creative thinking. The results revealed that the model (OIDDE) improved students' self-regulated, critical, and creative thinking. Despite the growth in the literature on the effect problem- solving strategy on students' achievement in biology, studies relative to higher-order thinking ability of students remain relatively sparse. This scarcity precludes secondary school teachers from employing strategies that enhance higher-order thinking ability in students. Therefore, this study focuses on the potency of problem-solving strategy on students' higher-order thinking ability in genetics.

Gender has been identified as one of the factors interacting with achievement. Studies on gender deference and achievement show different results. For instance, Jegede & Olu-Ajayi (2017), in their study to determine the effects of mentoring and gender on the achievement of low-performing students, discovered that female students outshine their male counterparts. Similarly, Isaak, Kleinert, and Wilder (2022) showed a significant effect of gender on students' use of learning strategies (rehearsal, organisation, effort, and time management) in biology. Conversely, other studies found no significant difference between male and female achievement when taught with innovative, hands-on, and student-centered teaching methods (Danmole & Lameed, 2014; Ekineh & Adolphus, 2019; Mashebe & Zulu, 2022; Adam, Lameed & Benjamin, 2022). This may suggest that the efficacy of the use of appropriate instructional strategies might have helped to bridge the gender gap.

In addition, classroom instruction-related factors, sociocultural practices, poverty, perception of the value of education, and assessment procedures are identified to engender differences in performance between males and females in school science subjects (Uwadiae, 2006). He stressed further that sex-biased phrases in questions could affect candidates' performance by sex. It was, however, revealed that the study on gender bias and differential achievement in Science, Technology, and Mathematics at the SSCE showed that at least 93.3% of the items in selected Science, Technology, and Mathematics (SSCE) objective test papers were gender biased (WAEC, 1999).

However, Ekineh and Adolphus (2019) stress adopting instructional processes incorporating teaching strategies that encourage females to participate fully in science education and advocate a constructivist learning model. It is always common knowledge that males are not intellectually superior to females. Therefore, the under-achievement of females relative to males in science subjects is not due to any exceptional mental ability on the part of the males. UNICEF (2020) links females' under-representation and under-achievement in science and technology disciplines to interrelated socio-cultural and interacting school factors. These act singly and jointly to depress female interest, enrolment participation, and achievement in science subjects at various levels of the education system in Nigeria.

Despite the growth in the literature on the potency of problem-solving strategy on students' achievement in biology, studies relative to the higher-order thinking ability of students remains relatively sparse. This scarcity precludes secondary school teachers from employing strategies that enhance higher-order thinking ability in students. Hence, this study aimed to determine whether students exposed to problem-solving strategy can tackle higher-order thinking tasks in secondary school biology and, therefore, investigate the interactive effect of gender efficacy of problem-solving to promote higher-order thinking skills in biology students. The study seeks to achieve the following objectives. To determine

1. the effect of problem-solving strategy on the higher-order thinking ability of students in genetics
2. the impact of gender on the achievement of students taught using a problem-solving strategy

the interaction effect of gender and treatment on students' response to higher-order thinking tasks in genetics

2. Methodology

The research design employed in this study was quasi-experimental (pre-test, post-test non-equivalent group design). This is due to the inability of the researchers to randomly assign participants to the experimental and control group at the time of data collection. Achievement test in higher-order thinking tasks (ATHOTS) constitutes the instrument used for data collection. The ATHOTS comprises questions on levels of analysis, synthesis, and evaluation. The test items were selected from past questions of the West African Examination Council to ensure alignment with the level of students involved in the study. A test must be at the comprehension level and beyond (Ausubel, Novak, and Hanesian 1978). To this end, the initial 53 items drawn for the test were submitted to a validation panel of five seasoned biology teachers and experts in test construction. Their judgments concerning the spread of the items over the content areas of interest and the cognitive level measured were used to select the 35 items for the test. The instrument was valid and reliable because the questions were extracted from the WAEC standard questions. Every correct option to tackle higher-order thinking tasks in biology attracted one mark to measure students' ability to tackle problems in genetics at higher-order thinking levels.

Treatment Procedure

This began with administering a pre-test to the participants and introducing topics with simplified questions. Problems were posed for participants to brainstorm, after which solutions to the problems were provided with the full attention and involvement of the students in the problem-solving group. While solutions were provided, students were asked about their idea and contribution to the topics under consideration. After taking the students through three minimum worked examples, participants were given exercises on related problems to proffer answers or work in the class. At the end of each contact period, students were saddled with a take-home assignment(problem) for practice. In the next contact period, students' homework was checked, and the corrections made were effected. This was followed by posing new problems on other topics for interaction and discussion in the next class or contact. Treatment lasted for four weeks, followed by the administration of a post-test. Figures 1,2,3,4 shows samples of problems researchers engaged with the students.

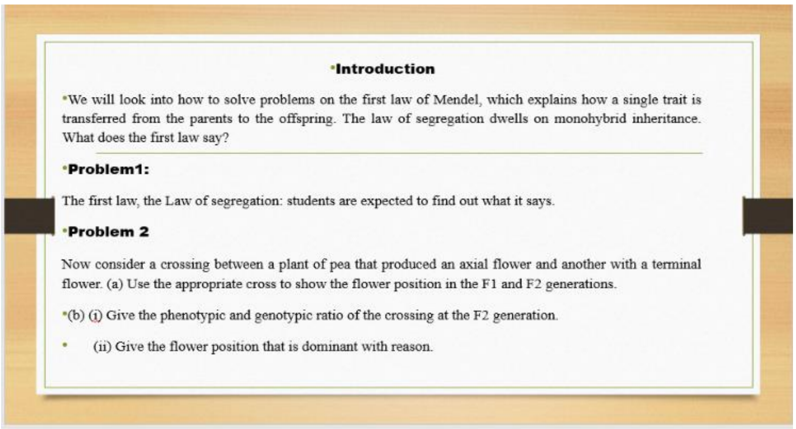

Figure 1. Sample of Problems Given to Students in the Class

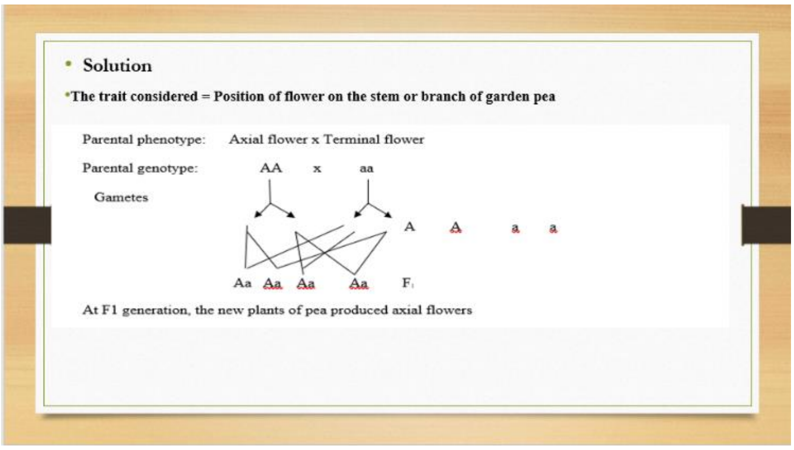

Figure 2. Solution of Sample Problems Given to Students in the Class

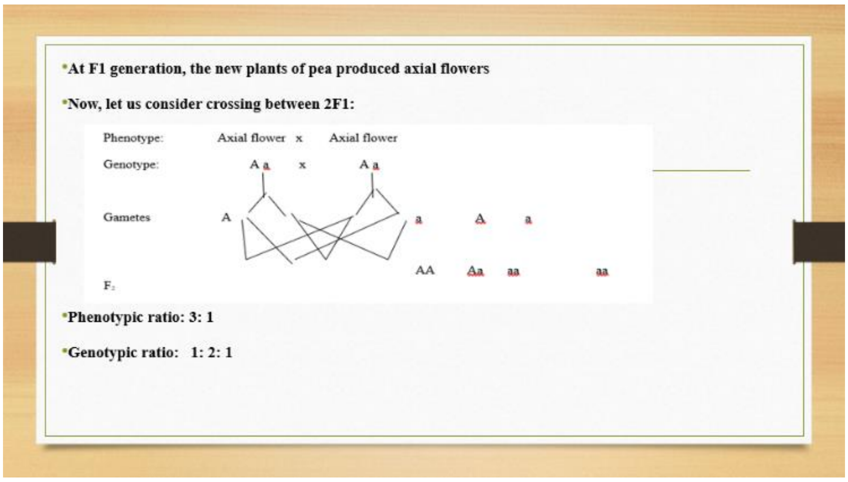

Figure 3. Solution of Sample Problems Given to Students in the Class

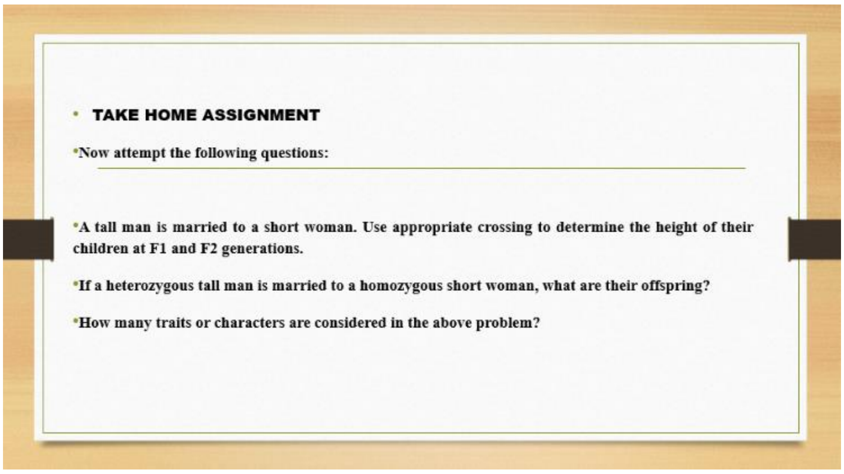

Figure 4. Sample Problems Given to Students as a Take-Home Assignment

3. Results and Discussion

The analysis followed a step-by-step procedure, with the test f the parametric assumptions before we applied the ANCOVA statistics to the data. The Shapiro-Wilk's normality test showed that the study participants were not significantly different from a normal population: [(N=118=.66; p> .05]. The Levene's test (test of homogeneity) also confirmed that the two groups were not significantly different from one another (F= .112; P >.05). Having met these assumptions, we applied the one-way ANCOVA statistics on the achievement test scores of the students in the two groups, using the scores generated from the post-test as the dependent variable, teaching methods as the fixed factors and the pre-test as the covariate.

Research question 1: What is the ability of the problem-solving strategy to enhance students' response to higher-order thinking tasks in genetics?

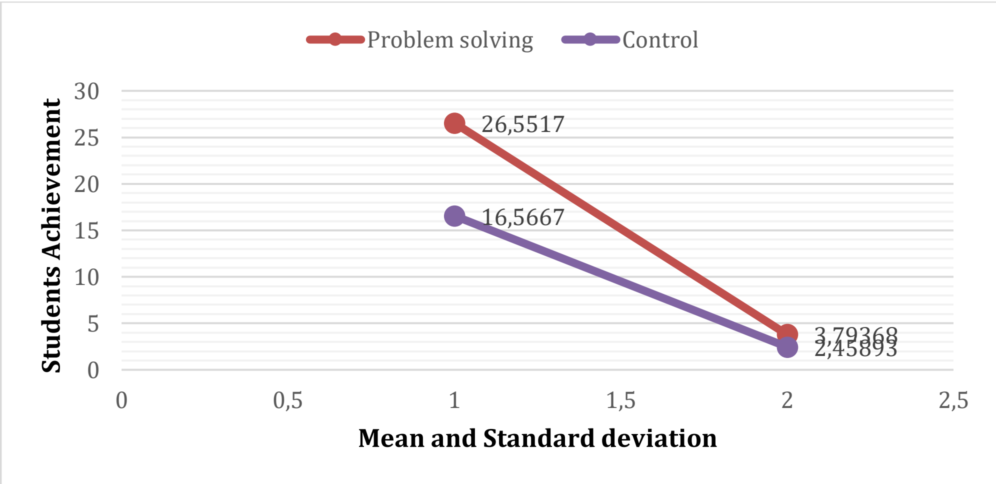

Figure 5. Mean and Standard Deviation of Students’ Ability to Tackle Genetics Problems at HOTS

As indicated in figure 5, the response means the score of students in higher-order thinking tasks in the problem-solving group (M = 26.55; S = 3.79) is higher than that of students in the conventional group (M = 16.57; S = 3.95).

Ho_1: There is no statistically significant effect of problem-solving strategy on students’ response to higher-order thinking tasks in genetics.

Table 1. ANCOVA- Students’ Post-Test Higher Order Thing Tasks in Problem-Solving Strategy and Control Groups

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	3207.186[a]	2	1603.593	202.599	.000	.779
Intercept	1424.057	1	1424.057	179.916	.000	.610
Pretest	266.840	1	266.840	33.713	.000	.227
Group	3186.968	1	3186.968	402.643	.000	.778
Error	910.238	115	7.915			
Total	58534.000	118				
Corrected Total	4117.424	117				

’9 (Adjusted R Squared = .775)

Results in table 1 show a statistically significant difference in the response of students to higher-order thinking tasks in the problem-solving and conventional method group F [(1,116) = 402; p <.05]. This indicates that exposure of students to problem-solving strategy has a significant effect on the ability of students to tackle higher-order thinking tasks in genetics; hence the null hypothesis of no significant effect of problem-solving strategy on students’ ability to respond to higher-order thinking tasks in genetics is rejected. The result of partial eta square (.778) indicates that problem-solving strategy contributed 77.8% high magnitude variance to students' ability to tackle higher-order thinking tasks in genetics. It was discovered that problem-solving strategy had a statistically significant effect on students' responses to higher-order thinking tasks in genetics (Table 2). The finding aligns with Adeyemi (2011), who found that students imbued with problem-solving ability would be able to solve personal, family, and societal problems. Students exposed to problem-solving strategy had the highest mean score response to higher-order thinking tasks in genetics than their counterparts in the conventional mode of instruction.

Similarly, the results revealed that students' exposure to problem-solving strategy contributed highly (77.5%) to the students' attainment in higher-order thinking tasks in genetics. This portends that proper use of constructivist and student-centered instructional strategies would bring about a corresponding unit of improvement in how students tackle higher-order thinking questions. This was because allowing the students to interact with learning materials in a progressive manner of brainstorming with questions individually and in conjunction with teacher-worked examples enabled them to think about several ways of tackling problems. Doing this allows the learner to exercise patience and surmount courage to proceed in several ways to resolve any problem they may encounter.

However, the findings of this study contradicted that of Kani and shahrill (2015), who discovered no statistically significant difference in the achievement of students taught using a problem-solving approach. This is at variance with the present study, as we found that students treated with problem-solving strategy significantly outshined their counterparts in the control group. The variance could result from differences in the research procedure and data collection method. While the present study explored problem-solving strategy to promote students' ability to tackle higher-order thinking tasks in biology, theirs looked into students' problem-solving behaviour and think-aloud pair problem-solving (TAPPS) strategy. Research question 2: What is the gender difference in students' response to higher-order thinking tasks in genetics?

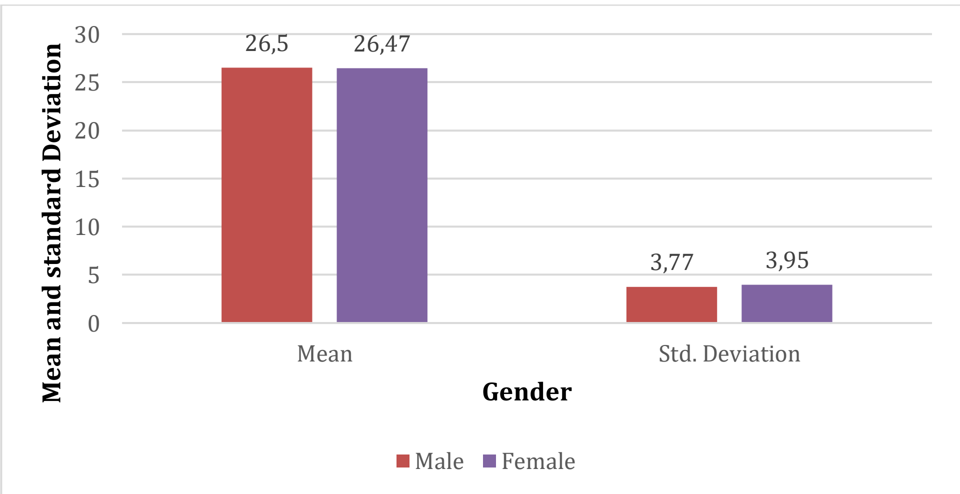

Figure 6. Mean and Standard Deviation of Gender Ability to Tackle Higher-Order Thinking Tasks in Problem–Solving Strategy

Figure 6 shows the mean and standard deviation scores of males (M = 26.59; S = 3.77); females (M = 26.47; S = 3.95) of gender response to higher-order thinking tasks in biolog

$Ho_{2:}$ There is no statistically significant gender difference in response to higher-order thinking tasks in genetics

Table 2. ANCOVA- Post-Test Gender Response to Higher Order Thinking Tasks in Genetics

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	97.820[a]	2	48.910	3.723	.030	.119
Intercept	1957.859	1	1957.859	149.036	.000	.730
Pretest	97.662	1	97.662	7.434	.009	.119
Gender	.002	1	.002	.000	.991	.000
Error	722.525	55	13.137			
Total	41710.000	58				
Corrected Total	820.345	57				

a. R Squared = .119 (Adjusted R Squared = .087)

As indicated in table 2 there is no statistically significant effect of gender on students' response to higher-order thinking tasks in biology F [(1,57) = .00; p > .05]. Therefore, the null hypothesis of no statistically significant gender difference in response to higher-order thinking tasks in genetics is not rejected. This finding aligns with the finding of previous studies (Danmole & Lameed, 2014; Mashebe & Zulu, 2022; Adam et al., 2022; Ekineh & Adolphhus, 2019). The similarity between these studies could be because a problem-solving strategy is a gender-friendly approach to teaching, and it was able to arouse the learners' interest, engage them in active participation, and engender individual learning. This indicates that problem-solving strategy desirably impacts students learning senior secondary biology. Conversely, the finding negates (Jegede & Olu-Ajayi, 2017; Isaak, Kleinert & Wilde, 2022), who discovered significant effects of gender on students' performance. For instance, Isaak et al. (2022) reported a significant effect of gender on students' use of learning strategies such as (rehearsal, organisation, effort, and time management). The difference between the present study with the previous one could be due to differences in scope, population, concepts, and location. When gender-friendly strategies are employed for biology instruction, gender barriers will dismiss. Hence male and female participants or learners will learn optimally and attain or achieve desirably in science. The implication is that appropriate instructional strategies helped students maximise learning and bridge gender gaps, particularly in difficult concepts.

Ho_3: There is no statistically significant interaction effect of gender and treatment on students' response to higher-order thinking tasks in genetics.

Table 3. ANCOVA- Interaction Effect of Gender and Treatment on Students' Response To Higher-Order Thinking Tasks in Genetics

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	3211.269[a]	4	802.817	100.114	.000	.780
Intercept	1424.162	1	1424.162	177.597	.000	.611
Pretest	258.721	1	258.721	32.263	.000	.222
Group	2888.830	1	2888.830	360.245	.000	.761
Gender	1.698	1	1.698	.212	.646	.002
Group * Gender	1.952	1	1.952	.243	.623	.002
Error	906.155	113	8.019			
Total	58534.000	118				
Corrected Total	4117.424	117				

a. R Squared = .780 (Adjusted R Squared = .772)

Table 3 shows the result of the interaction effect of gender and problem-solving strategy on students' response to higher-order thinking tasks in genetics F [(1,113) = .24; p > .05]. This shows no statistically significant interaction effect of gender and problem-solving strategy on the ability of students to tackle higher-order thinking tasks in genetics. Regarding whether or not treatment interacts with gender to pronounce effect on students' ability to respond to higher-order thinking tasks in genetics, it was discovered there was no significant interaction effect of treatment and gender on the ability of the students to respond to higher-order thinking tasks in genetics. The study found no significant two-way interaction effect between treatment (teaching strategy) and gender on students' response to higher-order thinking tasks in genetics. This shows that teaching strategy (problem-solving) and gender did not jointly impact senior secondary biology students' ability to answer questions in the analysis, synthesis, and evaluation of cognitive learning in genetics. This finding was attributed to the fact that the strategy employed in this study was able to arouse the learners' interest, engage them in active participation, and engender individual learning. The finding accords with Ajai, Imoko & O'kwu (2013), Aknoğlu & Tandoğan (2007), and Nfon (2013). For instance, Nfon (2013) reported no significant interaction effect between Rusbult's problem-solving strategy and gender on students' achievement in trigonometry. Similarly, Aknoğlu & Tandoğan (2007) reported no significant two-way interaction effect of strategy and gender on 7^{th}-grade students' achievement in science. The implication of this is that the use of appropriate instructional strategies consequently helped students to maximise learning, particularly difficult concepts. Therefore, combining the teaching strategy and gender may not necessarily boost students' achievement and learning of complex concepts in biology but rather the teaching strategies.

4. Conclusion

The study is concerned with improving biology students' performance in the Nigerian secondary school system. The effort was concentrated on a hands-on, student-centered problem-solving strategy and a traditional teaching method in the study. The problem-solving strategy influenced students' higher-order thinking learning ability in biology. The study, therefore, concludes that:

1. Problem-solving strategy effectively promoted students' higher-order thinking ability in biology.
2. Problem-solving strategy enhanced male and female students' ability to solve higher-order thinking tasks in biology, removing gender differences.
3. And that gender does not interact with the problem-solving strategy to enhance students' ability to tackle higher-order thinking tasks rather the strategy-problem solving. The strategy (problem-solving) could thus be regarded as a powerful and appropriate instructional tool to engender meaningful teaching and learning of difficult concepts in biology.

Further studies in other parts of the country and beyond should be carried out with a larger sample in other science subjects. We hope to experiment with problem-solving strategies on other difficult concepts in biology with a broader scope in geographical location, sample size, and expansion of treatment periods. In our future work plan, we hope to engage junior secondary students with problem-solving strategies in basic science and technology concepts to serve as the foundation for science subjects and other STEM education.

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