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Enhancing secondary school students' knowledge and reflective thinking in genetics concepts using socio-scientific issue-based strategy

Ayodeji Temitope Ojo [1]*, Temisan Angela Ige [1]

[1] Department of Science and Technology Education, University of Ibadan, Ibadan, Oyo State, NIGERIA
***Corresponding Author:** at.ojo@ui.edu.ng

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ABSTRACT

Genetics concepts (GCs) are taught to equip students with relevant knowledge and skills. However, reports have shown that students exhibited poor knowledge and reflective thinking in GCs. Therefore, this study, determined the effect of socio-scientific issue-based strategy (SsIbS) and scientific reasoning ability (SRA) on students' content knowledge and reflective thinking in GCs in Oyo State, Nigeria. The pretest-posttest control group quasi-experimental design was used. 240 students participated in the study. Five instruments were used, while analysis of covariance was used to analyze collected data at $p < 0.05$. Main effect of treatment on student' knowledge ($F_{[1;339]} = 16.96$; partial $\eta^2 = 0.07$) and reflective thinking ($F_{[1;339]} = 10.17$; partial $\eta^2 = 0.04$) was significant. SRA had significant main effect on students' knowledge ($F_{[2;338]} = 4.84$; partial $\eta^2 = 0.04$) and reflective thinking ($F_{[2;338]} = 5.01$; partial $\eta^2 = 0.04$). The SsIbS improved students' learning outcomes in secondary school GCs in Oyo State, Nigeria. Biology teachers should adopt these strategies to teach GCs.

Keywords: content knowledge and reflective thinking in genetics concepts, socio-scientific issue-based strategy, scientific reasoning ability

INTRODUCTION

Genetics, one of the biology concepts taught at secondary school, often called biology of hereditary, is the study of inheritance. Through the knowledge of this concept, human life has improved considerably through its applications in the areas of gene therapy for genetic diseases, improved crop and animal species, crime investigations and development of medical practices, and these add value to the wellbeing of humans. In spite of the benefits of genetics, many controversies surround it; relating to culture; sex determination, DNA paternity testing, marriage counselling, among others. As a result, genetics has become the subject of moral and ethical discussions in contemporary society.

The rapid developments in genetics studies, the topic's popularity, and the important role of the topic in human wellbeing and reproduction, as well as its controversial nature, makes it a biology concept that students need to understand (Maigoro et al., 2017). Genetics literacy is described as having the necessary or requisite knowledge and skills in genetics and related concepts and effectively applying these to participate in and reach reasonable conclusions on related issues arising from the advancements in genetics for personal well-being (Kampourakis, 2014). While the application of the gained genetics knowledge and skills in area of decision making at sustaining personal well-being and effective participation in social decisions on genetic issues, on the other hand, necessitates a sufficient understanding of genetics concepts (GCs) (Abrams et al., 2015). As a result, it's important to raise genetics-literate students who can use their knowledge of genetics to reach a reasonable conclusion about genetics as well as related issues and understand problems that are genetic in nature rather than relying on superstition and other mystical explanations.

Studies have shown that students failed to grasp GCs taught in secondary school biology classrooms (Little et al., 2022; Ojo, 2024). This lack of understanding has been translated to their inability to apply knowledge acquired in genetics to their everyday lives and related issues that arise, and to actively participate in social-related issues debates in this concept (Ojo, 2024). The West African Examination Council (WAEC) chief examiner's report on biology indicated that among the biology questions, genetics questions were unpopular among the candidates, and very few candidates attempted them. It is reported that those who attempted them did not respond well to the questions and did poorly. For instance, in 2017, the genetics question says that if a child belongs to blood group O and the mother belongs to group B. With the aid of a genetic cross, state the possible blood groups of the father. It was reported that the candidates were unable to state the possible blood groups of the father (WAEC, 2017).

Likewise in 2019, the candidates were asked to briefly explain the reason why a Rhesus negative woman who married to a Rhesus positive man might lose her second pregnancy. It was reported that they failed to explain the reason (WAEC, 2019).

It is important that students are provided with the appropriate genetics content in biology. However, it is also important to realize that this knowledge may not be enough to make rational decisions. For secondary school students to comprehend GCs in biology, effective use of reflective skills is of great importance. This can help students to make connections, develop ideas and apply what they have learned for better understanding. Reflective thinking is generally known as the process of making well-informed and rational decisions on academic matters, then evaluating the results of those decisions by reasoning, reflecting, and predicting questions and issues. Moreover, literature has shown that an improved reflective thinking may lead to improve comprehension of concepts in science lessons (Zhai et al., 2023). In spite of this importance, studies have shown that students at senior secondary level have low reflective thinking ability (Salido & Dasari, 2019), and they also find it difficult to reflect in both abstract and concrete terms.

Acquisition of relevant knowledge and reflective thinking in GCs are important steps in addressing the various issues related to GCs. To address these aforementioned challenges in students' knowledge and reflective thinking, there is a need for appropriate strategies that support students' active participation and at the same time incorporate related issues into the learning of genetics. A variety of innovative active learning strategies that can enhance students' cognitive, affective, and psychomotor domains in GCs and related issues have been proposed by several scholars in field of biology education, such as, computer simulation and game puzzle packages, problem-solving and discovery strategies, 5E learning, and problem-solving and discussion among others. In spite of this, the poor achievement and inability to reflect in genetics classroom still persist. The researchers attributed these to the fact that most of these strategies did not have the element of reflection, relate socio-scientific issues in genetics to the teaching and learning of GCs as well as the application of the gained knowledge in GCs. Among the strategies that incorporate the socio-scientific issues into genetics learning and provide an opportunity to apply the gained knowledge by reflection is socio-scientific issue-based strategy (SsIbS).

The SsIbS is an issue-based strategy that places the learning of science content within a social context in a way that gives students motivation and ownership of their learning as emphasized by the situated learning theory by Lave and Wenger (1991). The aim of an SsIbS is to bring about the understanding of science contents by incorporating science issues that are of societal interest but have the added features of involving moral reasoning or the assessment of ethical considerations in the course of making decisions on how to resolve those issues. The key to effective SsIbS implementation is to identify current socio-scientific problems that are important and related to the topic to be taught in the class, as well as to connect contents of the topic to the behavioral objectives (Mohammed, 2016). By bringing SsIbS into the Nigerian secondary school biology classroom, the researchers hope to engage students in authentic tasks that involve problem solving whereby the knowledge of genetics as well as students' thinking are brought to bear when they are discussing and making decisions about issues that are directly important to their lives and day-to-day activities.

Some inhibiting factors moderating the effectiveness of adopted strategies have been identified by researchers in biology education, these include gender, learning styles, verbal ability, scientific reasoning ability (SRA) and self-efficacy among others. SRA has become prominent and is highly emphasized in the new science education standards (Zhou et al., 2016). According to Boon et al. (2022), SRA is a collection of fundamental abilities needed by students to construct new knowledge and learn science through observation, evaluation, interpretation, and theoretical explanation. These abilities include the ability to investigate a problem, formulate and test theories, control and manipulate data, observe and assess the results. Previous research works have indicated that SRA is one of the factors that contribute to students understanding of GCs (Kılıç & Sağlam, 2014) and also has the potential to stimulate students to reason scientifically. In this study SRA was examined and categorized into three; concrete, transitional and formal.

Biology educators emphasized that if biology is poorly taught and poorly learned, students will be unable to comprehend what is expected of them, which may result in poor achievement and poor skill manipulation. Therefore, there is a need for viable strategies such as SsIbS that may give students the opportunities to build and develop reflective thinking along with the real-world application of the knowledge and skills, as supported by literature that may improve the knowledge, reflective thinking and development of positive attitude to GCs and related issues at the secondary school level.

Hypotheses

The following hypotheses were formulated and tested at 0.05 level of significance:

Ho1. There is no significant main effect of treatment on students'

(1) knowledge of GCs

(2) reflective thinking in GCs

Ho2. There is no significant main effect of SRA on students'

(1) knowledge of GCs

(2) reflective thinking in GCs

Ho3. There is no significant interaction effect of treatment and SRA on students'

(1) knowledge of GCs

(2) reflective thinking in GCs

METHOD

Research Design

The mixed methods of research design adopted the pre-/post-test control group quasi-experimental design.

Selection of Participants

240 senior secondary school 2 students in Oyo State were the participants. One local government area (LGA) was randomly selected from each of the three senatorial districts in Oyo State, for a total of three LGAs. Of the selected LGAs, nine senior secondary schools were chosen at random (that is, three schools from each LGA). An intact class of senior high school 2 students in science class offering biology from the nine schools was randomly assigned to the experimental and control groups.

Research Instruments

Data were collected using the following instruments.

Students' achievement test in genetics concepts

The students' achievement test in genetics concepts (SATGC) was self-constructed by the researchers to assess students' knowledge of GCs. The SATGC is made up of 34 multiple-choice items that were designed to assess students' knowledge of the topics studied. Each item had five options, ranging from A to D, with one correct answer and three distracters. Each correct response received one point, while incorrect answers received zero points, for a total of 34 points available to each participating student. The initial 55 test items were subjected to face and content validity, out of which 11 items were screened out the remaining 44 items. The remaining 44 items was pilot tested on SS 2 students that were not part of the sampled school for the main study. The reliability was determined using Kuder-Richardson–20 (KR 20) which gave 0.78. Out of these 44 items trial tested, 34 items within 0.45-0.65 discrimination index range and difficulty index above 0.25 were found to be good enough for the study.

Lawson's classroom test of scientific reasoning (LCTSR):

The researchers adopted the Lawson's classroom test of scientific reasoning (LCTSR) designed by Lawson (2000) to measure students' scientific reasoning abilities. The LCTSR was created to evaluate scientific reasoning using Bloom's (1956) levels of analysis, synthesis, and evaluation. On a standard two-tier structure, the test consists of 24 items in 12 pairs multiple choice style. In terms of the test's evaluation, points are provided only when both associated tasks are completed correctly for tasks 1 through 22. Only tasks 23 and 24 are self-contained, and as a result, they are scored separately. The maximum obtainable point is 13 marks. 0-4, concrete reasoners; 5-10 transitional; 11-13, formal are the categories utilized in grading.

The instrument's creator recorded KR 20 reliability coefficient of 0.78. The instrument was revalidated by the researchers by trial testing the test items on SS 2 students, who were not participants. Its reliability was determined by KR 20 which gave a coefficient of 0.76.

Reflective thinking questionnaire in genetics concepts

This is a 23-item questionnaire adapted from reflection questionnaire developed by Kember et al. (2008) and the scale of reflection in learning by Sobral (2001) to assess students reflecting thinking in genetics. Kember et al. (2000) instrument contains 16 items on a 5-point of definitely agree, agree with reservation, only to be used if a definite answer is not possible, disagree with reservation and scored as 5, 4, 3, 2, 1. The reliability coefficient was established using Cronbach's alpha which gave 0.62-0.76. Sobral (2000) instrument contains 14 items on 7-point response scale from never to always and scored as 1–never to 7–always with a reliability coefficient of 0.84 (at the start) and 0.86 (at the end of term) was established using Cronbach's alpha. They were modified to a four-point Likert scale with responses rating from strongly agree, agree, disagree, and strongly disagree, while some items were reconstructed to read genetics. These modifications were made in order to assess participant reflective thinking in relation to genetics, and to suit the level of the participants. In scoring, strongly agree = 4, agree = 3, disagree = 2, and strongly disagree = 1, were assigned to statements that are positively stated, while negatively worded statements were reversely scored.

The validity of the RTQCC was ascertained by experts in measurement and evaluation in terms of language construction, precision of focus, clarity of purpose and suitability for the target population. Their comments were used to adjust the instrument. The instrument was trial-tested on SS 2 students that were not among the samples selected to participate in the study to ensure its reliability. The Cronbach's alpha formula was used to establish the instrument's internal consistency which gave 0.81.

Treatment Application

Treatment procedure for experimental group (SsIbS)

The following adapted steps were followed in the SsIbS (Presley et al., 2013):

Step 1. Presentation of the issue

(1) The teacher briefly explained the features of an socio-scientific issue classroom.

(2) Teacher presented the topic and related debatable issues. Teacher can introduce these issues via newspaper/magazine headlines, photographs, and models.

Step 2. Confronting core beliefs

Teacher and students raised debatable questions that challenge students' strongly held core beliefs or views and misconceptions about the issue's social, ethical and moral dimensions.

Step 3. Formal instruction

(1) Teacher explained the topics and terminologies by giving the principles and theories behind the issue.

(2) Students listened attentively and asked questions while the teacher directed them to answers. This could be done through various methods like lectures, demonstrations, and laboratory exercise, etc.

Step 4. Group discourse

(1) Students explored data and evidence related to the topic and issue under investigation. This was done in a collaborative manner.

(2) Students were assigned into groups of four or five member teams based on their SRA and self-efficacy in GCs. The group discourse includes various activities of evaluating claims, analyzing data and evidence, taking positions, making moral decisions and negotiating consensus.

(3) The teacher provided scaffolding whenever it is needed.

Step 5. Presentation of the group agreement

(1) Each group presented their collective findings.

(2) The teacher effectively supervised the group presentations.

Step 6. Class open discussion

(1) Every student was given the opportunity to criticize and evaluate the explanations proposed by groups. Doing so, students will have to present supporting evidence and warrants for their claim.

(2) (Students reviewed their own assumptions. Students can question authority and consider the social, historical and political contexts in which scientific data or information is formed. Teacher encouraged the students to examine moral and ethical aspects behind the issue. Thus, giving students an excellent opportunity to engage in scientific reflective practices.

(3) At the end of this step, teacher refocused students' attention on science behind the issue, elucidate basic GCs and confirms their understandings.

Step 7. Raising real-life questions

(1) Students investigated more real-life issues related to the subject matter they have learned.

(2) Students were instructed to look around their immediate environment and analyze different life situations. The purpose of the investigation is to teach them how to use their reasoning and reflecting abilities, as well as utilizing newly gained knowledge, to resolve controversial problems, dispel false views and change misconceptions.

Step 8. Evaluation

Students were assessed by the teacher using questions.

Methods of Data Analysis

The analysis of covariance was used to analyze data collected. The magnitude of the mean scores of the different groups were determined by the estimated marginal means. All null hypotheses were evaluated at a significance level of 0.05.

RESULTS

Ho1a. There is no significant main effect of treatment on students' knowledge of GC.

In order to test hypothesis 1a, ANCOVA was conducted and the result is presented in **Table 1**.

Table 1. Main and interaction effects of treatment and SRA on post-knowledge in GCs

Source	Type III sum of squares	df	Mean square	F	Significance	Partial eta squared
Corrected model	899.194	6	149.866	10.859	0.000	0.219
Intercept	12,702.793	1	12,702.793	920.435	0.000	0.798
PreKnowledge	38.552	1	38.552	2.793	0.096	0.012
Treatment	233.996	1	233.996	16.955	0.000*	0.068
SRA	133.690	2	66.845	4.844	0.009*	0.040
Treatment × SRA	28.968	2	14.484	1.049	0.352	0.009
Error	3,215.602	233	13.801			
Total	109,661.000	240				
Corrected total	4,114.796	239				

Note.R-squared = 0.22 (adjusted R-squared = 0.20) & *denotes significant p < 0.05

Table 1 indicated a significant main effect of treatment on students' post-knowledge scores in GCs in biology ($F_{[1, 239]} = 16.96$; $p < 0.05$, partial $\eta^2 = 0.07$) after adjusting for pre-knowledge. Thus, the null hypothesis 1a was rejected at the 0.05 level of significance. This means that after being exposed to this treatment, students' post-knowledge mean scores in genetics topics in biology differed significantly. **Table 1** further revealed an effect size of 7.0%, which implies that independent variable alone accounted for 7.0% of the variance in student's adjusted post-knowledge scores in GCs. The degrees of differences in post-knowledge mean scores of students taught with the treatment and control interventions are determined by the estimated marginal means analysis and result presented in **Table 2**.

Table 2. Adjusted post-knowledge in GCs mean performance by treatment and control groups

Treatment	Mean	Standard error	95% confidence interval	
			Lower bound	Upper bound
SsIbS	22.39	0.449	21.50	23.27
CS	19.75	0.454	18.86	20.65

Table 2 indicated that students taught with SsIbS had the higher adjusted post-knowledge mean score in GCs (22.59). While students taught with the conventional strategy (CS) had the lower adjusted post-knowledge in GCs mean score (19.97). This order is presented SsIbS > CS.

Ho1b: There is no significant main effect of treatment on students' reflective thinking in GCs in biology.

ANCOVA was used to test null hypothesis 1b and the result presented in **Table 3**.

Table 3. Main and interaction effects of treatment and SRA on post-reflective thinking in GCs

Source	Type III sum of squares	df	Mean square	F	Significance	Partial eta squared
Corrected model	1,409.873	6	234.979	5.059	0.000	0.115
Intercept	36,646.260	1	36,646.260	788.964	0.000	0.772
PreReflective thinking	388.024	1	388.024	8.354	0.004	0.035
Treatment	472.447	1	472.447	10.171	0.002*	0.042
SRA	465.300	2	232.650	5.009	0.007*	0.041
Treatment × SRA	53.849	2	26.925	0.580	0.561	0.005
Error	10,822.523	233	46.449			
Total	898,575.000	240				
Corrected total	12,232.396	239				

Note.R-squared = 0.11 (adjusted R-squared = 0.09) & *denotes significant p < 0.05

After adjusting for pre-reflective thinking, **Table 3** indicated that treatment had significant main effect on reflective skill scores of secondary school students' GCs in biology ($F_{[1, 239]} = 10.17$; $p < 0.05_{[0.04]}$; partial $\eta^2 = 0.04$). **Table 3** also indicated an effect size of 4.0%, implying that independent variable alone explained 4.0% (0.04) of the variance in student's adjusted post-reflective thinking scores in genetics, while the magnitudes of students' post-reflective thinking mean scores across different treatment conditions are explored by the estimated marginal means in **Table 4**.

Table 4. Adjusted post-reflective thinking in GCs mean performance by treatment and control groups

Treatment	Mean	Standard error	95% confidence interval	
			Lower bound	Upper bound
SsIbS	62.61	0.83	60.97	64.25
CS	58.75	0.85	57.08	60.43

Table 4 revealed that the students exposed to the SsIbS recorded the higher adjusted post-reflective thinking mean score of 62.61 than the students in CS (58.75). This order is presented SsIbS > CS.

Ho2a. There is no significant main effect of SRA on students' knowledge of GC.

To test this hypothesis, ANCOVA was employed, as shown in **Table 1** and the result is interpreted below.

Table 1 revealed a significant main effect of SRA on students' post-knowledge scores in GCs in biology ($F_{[2, 238]} = 4.84$; $p < 0.05$, partial $\eta^2 = 0.04$) after adjusting for pre-knowledge at 0.05 level of significance. This implies that there was a difference in the post-knowledge mean scores of students in GC in biology by their SRA. **Table 1** indicated an effect size of 3.0%, meaning that SRA alone explained 4.0% (0.04) of the variance in students' post-knowledge scores in GCs. In order to explore the magnitudes of the post-knowledge mean scores of the students across SRA levels, the estimated marginal mean analysis was employed and the results presented in **Table 5**.

Table 5. Adjusted post-knowledge in GCs mean performance by SRA

SRA	Mean	Standard error	95% confidence interval	
			Lower bound	Upper bound
Concrete	19.77	0.47	18.84	20.70
Transitional	21.24	0.30	20.65	21.83
Formal	22.20	0.78	20.66	23.74

Table 5 revealed that students with formal SRA recorded the highest adjusted post-knowledge mean (22.20) score. This group was followed by students with transitional scientific reasoning (21.24) ability. While students with concrete SRA recorded the lowest adjusted post-knowledge mean score (19.77). This order is represented as formal > transitional > concrete. **Table 4** lacked the power to show the direction of the differences. In order to explore the direction of this differences, a further analysis using a Bonferroni post-hoc test of multiple comparisons was carried out and the results presented in **Table 6**.

Table 6. Multiple comparisons of SRA group means by post-knowledge in GCs

(I) SRA	(J) SRA	Mean difference (I-J)	Significance
Concrete	Transitional	-1.473*	0.027
	Formal	-2.432*	0.026
Transitional	Concrete	1.473*	0.027
	Formal	-0.959	0.759
Formal	Concrete	2.432*	0.026
	Transitional	0.959	0.759

Note. *Denotes significant p < 0.05

Table 6 depicted that the differences between concrete and formal, concrete, and transitional scientific reasoning abilities students in their adjusted post-knowledge mean score in GCs were significant but there was no statistically significant difference between formal and transitional scientific reasoning abilities students. This indicates that formal and transitional scientific reasoning abilities were the source of the main effect of SRA in **Table 1**.

Ho2b: There is no significant main effect of SRA on students' reflective thinking in GCs

In order to test the null hypothesis 2b, ANCOVA was employed and presented in **Table 3**.

Table 3 indicated that the main effect of SRA on students' post-reflective thinking score in GCs in biology ($F_{(2, 238)} = 3.33$; $p<0.05$, partial $\eta^2 = 0.02$) was significant. Thus, the null hypothesis 2b was rejected. This result outcome implies that a difference existed among the post-reflective thinking mean scores of students in GCs by their SRA. **Table 3** revealed an effect size of 2.0%, which means that SRA alone explained 2.0% (0.02) of the variance recorded in students adjusted post-reflective thinking scores in GCs. In order to determine the degree of the post-reflective thinking mean scores of the students across SRA levels, **Table 7** presented the estimated marginal means results.

Table 7. Adjusted post-reflective thinking in GCs mean performance SRA

SRA	Mean	Standard error	95% confidence interval	
			Lower bound	Upper bound
Concrete	58.55	0.79	56.99	60.11
Transitional	60.09	0.49	59.14	61.05
Formal	62.87	1.56	59.79	65.94

Table 7 depicted that the highest adjusted post-reflective skill mean score of 62.87 was held by formal SRA students as compared with transitional scientific reasoning students with adjusted post-reflective thinking mean score of 60.09 and students with concrete SRA (58.55) mean score. This order is represented as follows formal > transitional > concrete. In order to explore the direction of this differences, a further analysis using a Bonferroni post-hoc test of multiple comparisons was carried out and the results presented in **Table 8**.

Table 8. Multiple comparisons of SRA group mean by students' post-reflective thinking in GCs

(I) SRA	(J) SRA	Mean difference (I-J)	Significance
Concrete	Transitional	-3.057	0.010
	Formal	-3.794	0.071
Transitional	Concrete	3.057	0.010*
	Formal	-.736	1.000
Formal	Concrete	3.794	0.071
	Transitional	0.736	1.000

Note. *Denotes significant p < 0.05

Table 8 revealed that the differences in the adjusted post-reflective thinking mean scores of students with formal and concrete as well as transitional and formal SRA were not significant. However, the difference between transitional and concrete was statistically significant, implying that the source of the significant effect of SRA in **Table 3** was due to formal SRA group.

Ho3a. There is no significant interaction effect of treatment and SRA on students' knowledge of GC.

In order to test this hypothesis, the tests of between-subjects effects in **Table 1** was explored and the treatment * SRA row is interpreted.

The result of the 2-way interaction effect in **Table 1** depicted no significant interaction effect of treatment and SRA on students' post-knowledge of GCs in biology ($F_{[2, 238]} = 1.05$; $p > 0.05$, partial $\eta^2 = 0.01$). Thus, hypothesis 3a was not rejected. The result indicated that the effect of the treatment on students' post-knowledge of GC in biology after controlling pre-knowledge did not depend on students SRA. This means that students' post-knowledge score in GCs in biology did not vary significantly among concrete, transitional and formal scientific reasoning abilities students after the intervention.

Ho3b. There is no significant interaction effect of treatment and SRA on students' reflective thinking in GC.

To test this null hypothesis, the ANCOVA summary in **Table 3** was explored and the interaction effect of treatment and SRA on reflective thinking is interpreted below.

Table 3 revealed that the interaction effect of treatment and SRA on students' post-reflective thinking of secondary school biology GCs ($F_{[2, 238]} = 0.58$ $p > 0.05$) was not significant. Therefore, the null hypothesis 4b was not rejected. This indicates that the effect of the treatment on students' post-reflective thinking in GCs in biology after controlling pre-knowledge did not depend on students SRA. This means that students' post-reflective thinking score in GC in biology was not significantly sensitive to their SRA (concrete, transitional and formal scientific reasoning) after their exposure to the treatment and control conditions.

DISCUSSION

Main Effect of Treatment on Secondary School Students' Knowledge of Genetics Concepts

The results of the tested hypothesis 1a revealed that treatment main effect on students' knowledge of GCs was significant. This means that a statistical difference existed in the knowledge mean scores of students in GCs under the socio-scientific issue-based and conventional strategies. It was observed that students in the SsIbS recorded better post-knowledge mean scores in comparison with those in the conventional group.

The efficacy of SsIbS over the CS in enhancing students' knowledge in genetics in biology may be due to the fact that this strategy provided students with learning conditions where they can reflect and relate socio-scientific issues in genetics to real life problems. This may also be due to the fact that this strategy gave students the opportunity to work in groups, critically analysis information, correct any misconceptions, and apply the knowledge gained in genetics in biology through open class and group discourses. This effectiveness of SsIbS in this study agrees with the assumptions of the Lave and Wenger (1991)'s situated learning theory, which holds that learning paradigms are based on knowledge that is connected to a specific contextual environment in which such knowledge is acquired and applied. This could be because SsIbS combines the GCs with challenging societal issues so it becomes a successful tool to engage students in group discussion and reasoning related activities that enhance their abilities in decision making and high order thinking (Christenson et al., 2014) through social interaction, dialoguing, discussion and debate. Also, it integrates genetics content to the social context in a way that give the students the opportunity to own what they learnt by allowing students to relate genetics contents discussed in the classroom with the related societal problem(s) within their environment from different points of view and also motivate them to consider both moral and ethical dilemmas they raised (Hyunok, 2020). It could be inferred that the strategy offers opportunities for students to linking genetics classroom lessons with everyday life and challenging issues.

The earlier studies on the usefulness of a SsIbS in improving knowledge of students' scores support this finding. The findings of Powell (2021); Kärkkäinen et al. (2019) are in line with this finding, that SsIbS had a significantly effect on students' knowledge of climate change, and vitamins and rational use of dietary supplements, respectively. Faelt et al. (2018) who in their study also found that SsIbS is effective in enhancing digestive and cellular respiration content among 10th grade students in biology. This thus suggested that SsIbS appears to be successful in improving understanding of digestive system and cellular respiration concepts in biology. The findings of Zo'bi (2014) also affirmed the current findings, that using a SsIbS helped students to make better decisions about environmental related social problems.

Main Effect of Treatment on Secondary School Students' Reflective Thinking in Genetics Concepts

Findings of the study revealed that the significant main effect of treatment on students' reflective thinking in genetics topics was significant. This indicates that the mean differences of students' post-reflective thinking in GCs in biology across the two strategies (SsIbS and conventional) was statistically significant. The finding revealed that students exposed to SsIbS displayed an increase in adjusted post-reflective mean score, which is higher than what was obtained by those exposed to CS. The effectiveness of SsIbS over the CS in improving students' post-reflective thinking score in GCs in biology may be attributed to the fact that SsIbS does not focus on knowledge acquisition only but bring real world issues that are related to genetics which can trigger students to use their ability to reflect on these issues that are often ill structure and controversial in nature (Rizal et al., 2017) from different perspectives. Thus, leading to the improvement observed in their reflective thinking mean scores. This may also be due to the fact that SsIbS provides a useful opportunity for students in confronting their core beliefs, connecting taught GCs and related issues to authentic situations, improving their understanding of GCs thus allowing them to become more sophisticated in their ability to reflect.

This finding of significant effectiveness of SsIbS on students' reflective thinking in GCs is backed by the finding of van der Leij et al. (2023) that SsIbS can give students the opportunity to contribute to moral and ethical discussions and also reflect on their values. The finding is lent credence to by Pratiwi et al. (2016) that the SsIbS had a significant effect on critical thinking of students in high school.

Main Effect of Scientific Reasoning Ability on Secondary School Students' Knowledge of Genetics Concepts

The finding revealed that students' knowledge of GCs and related issues was significantly determined by their SRA in this study. The result also revealed that students with formal SRA had the highest adjusted post-knowledge mean score than their counterparts with transitional and concrete scientific reasoning abilities. The reason for this may be due to the fact that formal SRA students were able to gain highest GCs knowledge by utilizing their already acquired reasoning skills in constructing and interpretating related genetics issues from different evidence.

This significant main effect of SRA on GCs knowledge of students is in line with the results of Sajna and Premachandran (2017), that a positive significant correlation existed between chemistry achievement and SRA of students. Similarly, the result of Kılıç and Sağlam (2014) is in tandem with this current result, who revealed that SRA predict students' knowledge of GCs.

Main Effect of Scientific Reasoning Ability on Secondary School Students' Reflective Skill in Genetics Concepts

Students' post-reflective thinking in GCs in biology was significantly influenced by their SRA. This is to say that students differ significantly in their post-reflective thinking scores in GCs based on their different scientific reasoning abilities. It was also observed from the result that students with formal SRA had the highest adjusted post-reflective thinking mean score in GCs compared to their counterparts with transitional and concrete scientific reasoning abilities, respectively.

The reason for this may be due to the fact that formal SRA students were able to engage in critical reflection, which is required when examining assumptions of various perspectives and their possible outcomes or consequences as they were able to challenge underlying assumptions, values and beliefs of given evidence. This influence of SRA on reflective thinking in GCs is in line with the findings of Tavvl (2014) that incorporating reflective e-journals into the field-based experience process helped pre-service teachers become contributors and efficient, active decision-makers, and confident teachers.

Interaction Effect of Treatment and Scientific Reasoning Ability on Secondary School Students' Knowledge of Genetics Concepts

The treatment and SRA of students had no significant interaction effect on their knowledge of GCs in secondary school biology, indicating that students' knowledge of GCs was not significantly affected by treatment applied and their SRA differences in this study, that is, being formal, transitional or concrete scientific ability has no different effect on the various instructional strategies applied. Moreover, this may be attributed to SRA balance sensitivity in treatment as well as equal opportunity the strategies offered for each SRA group to equally participate during treatment application.

Interaction Effect of Treatment, Scientific Reasoning Ability and Secondary School Students' Reflective Thinking in Genetics Concepts

The treatment and SRA interaction effect on students' reflective thinking in GCs in secondary school biology was found to be not significant. Thus, it indicates that students' reflective thinking in GC did not vary significantly by treatment and SRA of the students. The reason for this may be attributed to the fact that the strategy during the period of application allowed students of vary SRA to work in a small group whereby they were given equal opportunity to take responsibility, actively participate in the process of analyses, reflecting, evaluating different perspectives or information relating to genetics and related issues to reach a reasoned judgment.

CONCLUSION

The study concluded that SsIbS was more efficient in improving students' knowledge and reflective thinking in secondary school biology when compared to CS. Students' SRA influenced students' knowledge and reflective thinking in GCs in biology.

Recommendations

1. There is a need for the adoption of SsIbS by biology teachers in order to improve students' achievement and reflective thinking in genetics classroom.
2. There is a need to explore socio-scientific issues that are related to the needs of GCs learning in biology, especially those that are local and national to our everyday life, needs to be done to enhance students' comprehension of GCs.
3. When implementing SsIbS in the classroom, biology teachers need to consider students SRA as this goes a long way in determine their exploration of issues, reflection on knowledge and academic achievement.

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Ethical statement: The authors stated that the study has been conducted in accordance with the highest ethical standards. Formal ethics approval was waived by the authors' institution. Any personal information that can be used to identify participants was not included on the instruments. A consent letter explaining the purpose and outline of the research was given to the participants. Participation was strictly voluntary. The participants were made aware of the academic benefits of the research, and the confidentiality of the data to be collected. Data collected from the participants was used only for the purpose stated for in this study. The authors further stated that the researcher maintained the databases so that the research could be audited by interested parties. This was done to enable the reader to make independent judgements concerning the qualities of the analysis. Auditability was provided for replication and promotes rigour in both data collection and data analysis. To enable auditability, the documentation was kept confidential and safe, following data collection, thus promoting reliability and validity.

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