https://doi.org/10.15625/2615-8965/22410403

Addressing Misconceptions in Photosynthesis and Genetics through Interactive Video Lessons in Bhutanese Secondary Biology Classrooms

Kinzang Dorji[1✉], **Bal Bahadur Mongar**[2], **Kinley**[3], **Ran Singh Tamang**[4], **Tandin Zam**[5]

[1] kdorji.sce.sce@rub.edu.bt
Samtse College of Education
(Bhutan)
[2] bbmongar.sce@rub.edu.bt
Samtse College of Education
(Bhutan)
[3] kinley.sce@rub.edu.bt
Samtse College of Education
(Bhutan)
[4] rstamang.sce@rub.edu.bt
Samtse College of Education
(Bhutan)
[5] tandin.zam@education.gov.bt
Samtse High School
(Bhutan)

ABSTRACT: *Misconceptions in Biology present persistent challenges to effective Biology education, limiting students' acquisition of accurate knowledge and scientific literacy. This study investigated the effectiveness of interactive video lessons in addressing and correcting biological misconceptions of photosynthesis, genes and chromosomes among high school students in Bhutan. Employing a quasi-experimental design, the study engaged 228 students who participated in pre-tests, interventions, post-tests, and post-retention tests. The prevalence of misconceptions prior to the intervention highlighted the urgent need for more effective instructional strategies. Statistical analyses indicated significant improvement t(114) = -8.451, p < .001) in the experimental group's performance compared to the control group. Moreover, the sustained nature of this improvement was evident from the minimal differences observed between post-test and post-retention scores t(114) = .139, p > .05) within the treatment group. This suggests that the interactive video lessons were not only effective in correcting misconceptions but also in promoting long-term understanding and retention of fundamental biological concepts. The findings underscore the importance of integrating evidence-based instructional tools, such as interactive videos, to enhance conceptual clarity and student engagement. The study provides actionable recommendations to help improve Biology teaching and reduce persistent misconceptions among students through effective classroom and policy-level interventions.*

KEYWORDS: **misconceptions, pre-post-test, photosynthesis, genes, chromosomes, dark reaction, intervention, interactive videos.**

➔ Received 07/06/2024 ➔ Revised manuscript received 02/12/2024 ➔ Published 30/12/2024.

1. Introduction

Misconceptions in biology present persistent challenges to effective biology education, limiting students' acquisition of accurate knowledge and scientific literacy. This study investigated the effectiveness of interactive video lessons in addressing and correcting biological misconceptions about photosynthesis, genes, and chromosomes among high school students in Bhutan. Employing a quasi-experimental design, the study engaged 228 students who participated in pre-tests, interventions, post-tests, and post-retention tests. The prevalence of misconceptions prior to the intervention highlighted the urgent need for more effective instructional strategies. Statistical analyses indicated significant improvement, $t(114) = -8.451$, $p < .001$, in the experimental group's performance compared to the control group. Moreover, the sustained nature of this improvement was evident from the minimal differences observed between post-test and post-retention scores, $t(114) = .139$, $p > .05$, within the treatment group. This suggests that the interactive video lessons were not only effective in correcting misconceptions but also in promoting long-term understanding and retention of fundamental biological concepts. The findings underscore the importance of integrating evidence-based instructional tools, such as interactive videos, to enhance conceptual clarity and student engagement. The study provides actionable recommendations to help improve biology teaching and reduce persistent misconceptions among students through effective classroom and policy-level interventions.

Misconceptions, also referred to as preconceptions or alternative conceptions, present a significant challenge within biology education. These inaccurate ideas are often unintentionally adopted by students and interfere with their ability to develop a scientifically accurate understanding of biological concepts (Marisda & Handayani, 2020). In biology, such misconceptions commonly arise from intuitive reasoning, incorrect analogies, oversimplified prior explanations, or outdated and misleading information found in textbooks and other media sources (Wahyono & Susetyarini, 2021).

For example, Yuliasari and colleagues (2023) identified a widespread misunderstanding regarding photosynthesis: students frequently believe that dark reactions occur only at night. This misconception stems from confusion over the terminology used to describe the two phases of photosynthesis. The terms “light reactions” and “dark reactions” refer to biochemical processes that differ in their dependence on light, rather than specific times of day. This misunderstanding reinforces the erroneous notion that photosynthesis only happens in the presence of sunlight.

Similarly, Ibourk and colleagues (2018) reported that many secondary biology students confuse genes with chromosomes, treating them as synonymous and failing to comprehend their distinct biological functions. Although such misconceptions are well documented in research, they are also regularly observed in classroom settings and teaching practice, including in the authors’ own experience.

It is crucial to identify and address these misconceptions to support effective biology instruction. If left unresolved, they may persist and limit students’ academic progress as well as their ability to apply biological knowledge in real-world contexts. Therefore, early detection and correction of these misunderstandings are essential for fostering accurate conceptual development and promoting scientific literacy in biology.

This study aimed to identify the prevalence of misconceptions among high school students using a 3-tier diagnostic test and to address these misconceptions through interactive video lessons. Given this context, the specific objectives include: (1) to identify the prevalence of misconceptions about biological concepts, especially photosynthesis and genes/chromosomes, among high school students; (2) to assess the effectiveness of interactive videos in correcting students’ misconceptions about photosynthesis and genes/chromosomes; (3) to assess the long-term retention of corrected knowledge on photosynthesis and genes/chromosomes in students after they have been exposed to instructional interactive videos; and (4) to compare the knowledge retention rates between the treatment and control groups using a post-retention test administered two months after the intervention. In line with these aims, the study seeks to answer the main research question: What is the impact of instructional interactive video on high school students’ long-term retention and correction of misconceptions related to photosynthesis, genes, and chromosomes, compared to students who did not receive the intervention? This question is further specified through the following sub-questions: (1) What are the prevailing misconceptions among high school students concerning photosynthesis, genes, and chromosomes? (2) Does a significant difference exist in academic performance between the treatment group and the control group? (3) How proficiently do students retain corrected knowledge about photosynthesis and genes/chromosomes over extended periods following the intervention? and (4) Is there a significant difference in knowledge retention rates between the experimental group and the control group?

2. Literature review

Plant photosynthesis and genetics are fundamental topics in biology education, yet students often hold misconceptions that hinder their understanding of these complex processes. This literature review aims to explore the prevalence of students’ misconceptions, specifically in the light and dark reactions

https://doi.org/10.15625/2615-8965/22410403

of photosynthesis, as well as in genes and chromosomes.

Misconceptions correspond to concepts that have peculiar interpretations and meanings in students' articulations that are not scientifically accurate (Bahar, 2003). Further, Kumandas (2015) defines misconceptions as incorrect ideas that are distant from the actual scientific phenomena. Butler et al. (2015) revealed the presence of an unacceptably high level of misconceptions and uncovered flaws in students' and teachers' understanding of ecological concepts, as diagnosed through tests of biology students and pre-service teachers in Ireland. According to Chophel (2022), most of the misconceptions that students possess are rooted in their inability to understand chemical concepts from macroscopic, sub-microscopic, and symbolic perspectives. He claimed that teaching chemistry with video animations helps students develop canonical scientific knowledge. Likewise, Marisda and Hangayani (2020) concluded that providing Macromedia Flash learning media simulations can minimise misconceptions in science. In physics, misconceptions about the concept of free-fall motion were reduced by using narrative feedback and realistic video (Halim et al., 2021).

2.1. Misconceptions in plant photosynthesis

The differentiation between light and dark reactions in photosynthesis poses a common hurdle for students, leading to prevalent misconceptions. One widespread misunderstanding is the belief that the entire photosynthesis process unfolds exclusively in the presence of light, neglecting the essential distinction between light and dark reactions as two distinct phases. Yuliasari et al. (2023) highlighted a noteworthy misperception: the misconception that dark reactions invariably occur during the night. This arises from the biological terminology, where "light reactions" and "dark reactions" signify distinct phases of photosynthesis rather than specific times of day. This confusion compounds another misconception—the notion that photosynthesis exclusively occurs during daylight hours. Overlooking the flexibility of photosynthesis, students may erroneously assume that sunlight is the sole prerequisite. Darko et al. (2014) emphasized that this misconception obstructs a comprehensive understanding, as students fail to recognize that plants can undergo photosynthesis under artificial light sources. This lack of comprehension underscores the necessity for a broader understanding of the factors influencing photosynthesis beyond natural sunlight.

2.2. Genes/chromosome misconceptions

In the realm of genetics, students frequently struggle with misconceptions related to genes and chromosomes. Ibourk et al. (2018) revealed that students commonly confuse genes with chromosomes, treating them as interchangeable terms and failing to recognize their distinct roles. For instance, students may inaccurately perceive genes as discrete entities within chromosomes without understanding the dynamic interplay between genes and their locations on chromosomes. Building on this, Gusmalini and Wulandari (2020) reported that 42.1% of high school students experienced misconceptions related to genes and chromosomes, with the primary cause rooted in the complexity of genetic concepts. Misconceptions in biology education present a significant challenge, hindering students' grasp of fundamental concepts in various areas, including photosynthesis and genetics.

Misconceptions in biology education represent a critical challenge hindering students' mastery of fundamental concepts. Recognizing the prevalence of these misconceptions is essential for educators and curriculum developers to design effective instructional strategies and timely interventions that foster a more accurate and comprehensive understanding of biological concepts among students. This review underscores the necessity for customised instructional approaches in plant photosynthesis and genetics.

3. Methodology

3.1. Research design

This study employed a quantitative approach, allowing for statistical analysis to reveal patterns and trends across a large sample. A quasi-experimental design involving treatment and control groups was used, comprising a pre-test, intervention, post-test, and post-retention test. This design allowed the researcher to assess the effectiveness of the intervention in addressing misconceptions identified through a three-tier diagnostic test. Constructivism guided the study, given its emphasis on cognitive development and the active restructuring of misconceptions through learner-centred experiences.

3.2. Population and sample

The study targeted secondary school students studying biology in Samtse District, Bhutan. A purposive sampling method was employed to select five schools, ensuring a diverse and representative sample. From these schools, 228 students from Grades IX to XI were selected in consultation with school heads and biology teachers, ensuring a balanced distribution of students across the treatment and control groups. This sampling method was justified based on the need to select participants with similar curricular exposure and to include schools willing and able to support a structured intervention schedule. The chosen grade levels are pedagogically significant, as students at this stage engage with core biological concepts such as photosynthesis and genetics, where misconceptions are commonly documented.

3.3. Research instruments: three-tier diagnostic test

To identify and track misconceptions, a validated three-tier diagnostic test was developed by a panel of experienced biology educators:

- Tier One assessed factual content knowledge through multiple-choice questions.
- Tier Two probed students' reasoning behind their chosen answers.
- Tier Three captured students' confidence in their responses.

The diagnostic test was reviewed by subject experts for content validity, and a pilot test was conducted with 30 students (not included in the final study) to ensure clarity and internal consistency. The instrument showed a Cronbach's alpha of 0.84, indicating high reliability.

3.4. Intervention design and development

Based on misconceptions identified during the pre-test, interactive video lessons were custom-developed to target misconceptions in topics such as photosynthesis and chromosomes vs. genes. These lessons incorporated:

- Graphical animations for visualisation of abstract concepts
- Embedded quizzes and drag-and-drop activities
- Clickable segments that allowed students to control the pace of content
- Prompts for self-assessment throughout the video

This multi-modal design aimed to promote cognitive engagement and conceptual restructuring. The videos were reviewed by a team of educators and technology specialists to ensure technical accuracy, content alignment, and interactivity.

3.5. Classroom intervention

Intervention sessions were held during regular class hours in coordination with school authorities and teachers. The treatment group engaged individually with the interactive video lessons, ensuring a personalised pace and focus. Each intervention session lasted 45 minutes, conducted over five consecutive school days. After each session, students participated in structured group discussions led by teachers using prompts designed to encourage reflection, question misconceptions, and promote peer learning. The control group continued with traditional instruction without the video-based component.

3.6. Data collection procedure

- Pre-test: Administered to all participants to identify baseline misconceptions.
- Post-test: Conducted immediately after the intervention using the same diagnostic instrument.
- Post-retention test: Administered two months later to the treatment group to assess long-term retention and conceptual consolidation.

3.7. Data analysis

Data were analysed using SPSS. Descriptive statistics and independent samples *t*-tests were employed to compare performance between treatment and control groups at each test stage. Paired samples *t*-tests were conducted within the treatment group to assess gains from pre-test to post-test and from post-test to post-retention test. This approach ensured robust statistical comparisons and helped confirm the intervention's effectiveness over time.

4. Results

4.1. Participants' demography

The study involved 228 high school students, divided into a treatment group (n = 115) and a control group (n = 113). Table 1 below illustrates the demographic breakdown of research participants by gender in both the treatment and control groups. These demographic statistics indicate a balanced representation of gender within the study groups, thereby establishing a baseline for investigating the impact of the instructional intervention on misconceptions pertaining to photosynthesis, genes, and cell chromosomes among high school students.

Table 1. Demographic information of the participants

Gender	Treatment	Control
Male	62	58
Female	63	55
Total participants	115	113

4.2. Misconceptions prevalence among high school students

The initial data obtained from the three-tier diagnostic survey in the treatment group were categorized into three dimensions. Each concept was assessed through a series of statements, with responses classified as either "Yes" (indicating a correct answer) or "No" (indicating an incorrect answer). Furthermore, this comprehensive analysis incorporated students' reasoning behind their responses, along with their self-rated confidence levels. These analyses provide insights into students' understanding and areas of misconception, guiding targeted educational interventions.

Table 2a provides an overview of the frequency and percentage of correct ("Yes") and incorrect ("No") responses to each survey statement, along with the frequency and percentage of the students' reasoning and confidence levels during the pre-test phase.

4.3. Misconceptions in photosynthesis

In examining students' understanding of plant photosynthesis, several prevalent misconceptions emerged. Firstly, a significant proportion of students (59.1%) inaccurately identified true statements about photosynthesis. This suggests a fundamental misunderstanding of the key principles of the process. Additionally, over half of the students (53.9%) demonstrated a misconception regarding the dark reactions (Calvin cycle) of photosynthesis, indicating confusion about this crucial aspect of the process. Furthermore, a notable percentage (35.7%) inaccurately described the dark reaction in photosynthesis, revealing a lack of comprehension about its mechanisms (see Table 2a).

Another area of misconception relates to the plant parts involved in photosynthesis. A substantial portion of students (21.7%) incorrectly identified these parts, reflecting confusion about the anatomical components crucial for photosynthetic processes. Moreover, an overwhelming majority (67.8%) failed to accurately identify the pigments involved in photosynthesis, indicating a widespread misunderstanding of the molecules responsible for light absorption.

Students also exhibited confusion regarding the relationship between light and dark reactions in photosynthesis. Nearly a third of the participants (27.8%) inaccurately understood this relationship, highlighting a gap in understanding the coordinated processes that drive photosynthetic activity. Additionally, over half of the students (52.2%) incorrectly identified the energy source for plant growth and activities, indicating a misconception about the

https://doi.org/10.15625/2615-8965/22410403

fundamental fuel for photosynthesis.

Furthermore, a considerable proportion of students (39.1%) inaccurately identified the primary purpose of photosynthesis, suggesting a lack of clarity about its role in sustaining life processes. These misconceptions collectively underscore the need for effective educational strategies to enhance students' understanding of photosynthesis and address common points of confusion (see Table 2a).

4.4. Misconceptions in Genes/Chromosomes

In exploring students' understanding of genes and chromosomes, several notable misconceptions surfaced. Firstly, a majority of students (62.6%) incorrectly associated skin cell division with chromosomes, indicating confusion about the role of chromosomes in cellular processes. Additionally, a significant proportion (73.9%) inaccurately understood genetic information during human development, suggesting a misunderstanding of the transmission and expression of genetic material.

Moreover, a substantial percentage of students (67.8%) demonstrated a misconception regarding genetic similarity in *Paramecium* reproduction, highlighting a lack of comprehension about genetic inheritance in single-celled organisms. Interestingly, all students (100%) incorrectly understood the genetic composition in different cell types, indicating a pervasive misunderstanding of cellular genetics.

Furthermore, a notable proportion of students (19.1%) inaccurately understood the genetic makeup of twins, suggesting misconceptions about the hereditary basis of twinning. Additionally, nearly half of the participants (47.8%) incorrectly identified structures in a diagram representation, indicating difficulties in interpreting visual representations of genetic concepts (see Table 2a).

Finally, a small percentage of students (10.4%) incorrectly understood the number of kidneys in offspring, revealing misconceptions about genetic inheritance patterns. These findings highlight the prevalence of misconceptions among students regarding genes and chromosomes, emphasising the importance of effective educational interventions to improve understanding in these areas (see Table 2a).

Table 2a. Frequency and Percentage of Responses by the Treatment Group to Pretest Diagnostic Test Statements

Statements	Yes (n=115)	No (n=115)	Yes (%)	No (%)
1. a) The correct sequence of parts in living systems from largest to smallest	7	108	6.1	93.9
1. b) Reason for the answer	80	35	69.6	30.4
1. c) Confidence levels	26	89	22.6	77.4
2. a) Skin cells division and chromosomes	43	72	37.4	62.6
2. b) Reason for the answer	62	53	53.9	46.1
2. c) Confidence levels	68	47	59.1	40.9
3. a) Genetic information during human development	30	85	26.1	73.9
3. b) Reason for the answer	104	11	90.4	9.6
3. c) Confidence levels	52	63	45.2	54.8
4. a) Genetic similarity in Paramecium reproduction	37	78	32.2	67.8
4. b) Reason for the answer	54	61	47	53
4. c) Confidence levels	64	51	55.7	44.3
5. a) Genetic composition in different cell types	0	115	0	100

Statements	Yes (n=115)	No (n=115)	Yes (%)	No (%)
5. b) Reason for the answer	14	101	12.2	87.8
5. c) Confidence levels	75	40	65.2	34.8
6. a) Genetic makeup of twins	93	22	80.9	19.1
6. b) Reason for the answer	0	115	0	100
6. c) Confidence levels	36	79	31.3	68.7
7. a) Structures circled in diagram representation	60	55	52.2	47.8
7. b) Reason for the answer	78	37	67.8	32.2
7. c) Confidence levels	54	61	47	53
8. a) Number of kidneys in offspring	103	12	89.6	10.4
8. b) Reason for the answer	75	40	65.2	34.8
8. c) Confidence levels	48	67	41.7	58.3
9. a) True statements about photosynthesis	47	68	40.9	59.1
9. b) Reason for the answer	40	75	34.8	65.2
9. c) Confidence levels	39	76	33.9	66.1
10. a) Dark reactions (Calvin cycle) of photosynthesis	53	62	46.1	53.9
10. b) Reason for the answer	13	102	11.3	88.7
10. c) Confidence levels	36	79	31.3	68.7
11. a) Description of dark reaction in photosynthesis	74	41	64.3	35.7
11. b) Reason for the answer	62	53	53.9	46.1
11. c) Confidence levels	44	71	38.3	61.7
12. a) Plant parts involved in photosynthesis	90	25	78.3	21.7
12. b) Reason for the answer	87	28	75.7	24.3
12. c) Confidence levels	32	83	27.8	72.2
13. a) Pigments involved in photosynthesis	37	78	32.2	67.8
13. b) Reason for the answer	50	65	43.5	56.5
13. c) Confidence levels	37	78	32.2	67.8
14. a) Relationship between light and dark reactions	83	32	72.2	27.8
14. b) Reason for the answer	93	22	80.9	19.1
14. c) Confidence levels	32	83	27.8	72.2
15. a) Energy source for plant growth and activities	55	60	47.8	52.2
15. b) Reason for the answer	74	41	64.3	35.7
15. c) Confidence levels	32	83	27.8	72.2
16. a) Primary purpose of photosynthesis	70	45	60.9	39.1
16. b) Reason for the answer	53	62	46.1	53.9
16. c) Confidence levels	43	72	37.4	62.6

Following the intervention, there was a notable improvement in students' understanding, as evidenced by a significant increase in the percentage of correct responses across most statements. For example, in statement 1a, the percentage of correct responses increased from 6.1% in the pretest to 85.2% in the posttest, indicating a substantial reduction in misconceptions regarding the correct sequence of parts in living systems. Similarly, statement 10a showed a significant improvement, with 90.4% of students providing the correct response regarding the dark reactions (Calvin cycle) of photosynthesis (see Table 2b).

Table 2b. Frequency and percentage of responses by the treatment group to posttest diagnostic test statements

Statements	**Yes (n=115)**	**No (n=115)**	**Yes (%)**	**No (%)**
1. a) The correct sequence of parts in living systems from largest to smallest	98	17	85.2	14.8
1. b) Reason for the answer	91	24	79.1	20.9
1. c) Confidence levels	58	57	50.4	49.6
2. a) Skin cells division and chromosomes	89	26	77.4	22.6
2. b) Reason for the answer	82	33	71.3	28.7
2. c) Confidence levels	60	55	52.2	47.8
3. a) Genetic information during human development	50	65	43.5	56.5
3. b) Reason for the answer	87	28	75.7	24.3
3. c) Confidence levels	52	63	45.2	54.8
4. a) Genetic similarity in Paramecium reproduction	65	50	56.5	43.5
4. b) Reason for the answer	74	41	64.3	35.7
4. c) Confidence levels	56	59	48.7	51.3
5. a) Genetic composition in different cell types	54	61	47	53
5. b) Reason for the answer	49	66	42.6	57.4
5. c) Confidence levels	41	74	35.7	64.3
6. a) Genetic makeup of twins	98	17	85.2	14.8
6. b) Reason for the answer	104	11	90.4	9.6
6. c) Confidence levels	53	62	46.1	53.9
7. a) Structures circled in diagram representation	85	30	73.9	26.1
7. b) Reason for the answer	104	11	90.4	9.6
7. c) Confidence levels	51	64	44.3	55.7
8. a) Number of kidneys in offspring	104	11	90.4	9.6
8. b) Reason for the answer	87	28	75.7	24.3
8. c) Confidence levels	55	60	47.8	52.2
9. a) True statements about photosynthesis	91	24	79.1	20.9
9. b) Reason for the answer	65	50	56.5	43.5
9. c) Confidence levels	59	56	51.3	48.7
10. a) Dark reactions (Calvin cycle) of photosynthesis	104	11	90.4	9.6
10. b) Reason for the answer	43	72	37.4	62.6
10. c) Confidence levels	57	58	49.6	50.4
11. a) Description of dark reaction in photosynthesis	93	22	80.9	19.1
11. b) Reason for the answer	99	16	86.1	13.9
11. c) Confidence levels	60	55	52.2	47.8

https://doi.org/10.15625/2615-8965/22410403

Statements	Yes (n=115)	No (n=115)	Yes (%)	No (%)
12. a) Plant parts involved in photosynthesis	109	6	94.8	5.2
12. b) Reason for the answer	95	20	82.6	17.4
12. c) Confidence levels	62	53	53.9	46.1
13. a) Pigments involved in photosynthesis	97	18	84.3	15.7
13. b) Reason for the answer	81	34	70.4	29.6
13. c) Confidence levels	62	53	53.9	46.1
14. a) Relationship between light and dark reactions	93	22	80.9	19.1
14. b) Reason for the answer	95	20	82.6	17.4
14. c) Confidence levels	56	59	48.7	51.3
15. a) Energy source for plant growth and activities	79	36	68.7	31.3
15. b) Reason for the answer	88	27	76.5	23.5
15. c) Confidence levels	56	59	48.7	51.3
16. a) Primary purpose of photosynthesis	64	51	55.7	44.3
16. b) Reason for the answer	61	54	53	47
16. c) Confidence levels	46	69	40	60

4.5. Comparison of pre-intervention scores between treatment and control groups

The descriptive statistics provided an initial exploration into the central tendency and variability of scores within each group, laying the foundation for subsequent inferential analyses aimed at assessing the statistical significance of differences between the treatment and control groups. Data suggest that there was no significant difference in pretest scores between the treatment and control groups. Both groups exhibited similar mean pretest scores, with the treatment group scoring slightly lower (M = 16.43, SD = 4.66) compared to the control group (M = 16.65, SD = 4.83), with no evidence of a statistically significant difference, $t(226) = -0.357$, $p > .05$ (see Tables 3a and 3b). Furthermore, the standard errors of the means (SEs) were also comparable between the two groups, implying that participants in both groups had similar baseline performance levels prior to any instructional intervention or treatment.

Table 3a. Comparison of pre-test scores between Treatment and Control Groups prior to the intervention

Pre-test scores	Groups	N	Mean	SD	Std. Error Mean
	Treatment	115	16.43	4.66	.435
	Control	113	16.65	4.83	.455

Table 3b. Levene's Test and Independent Samples t-test on pre-test scores (a comparison of treatment and control) prior to the intervention

F		Levene's Test for Equality of Variances		t-test for Equality of Means			
		Sig.	*t*	*df*	*Sig. (2-tailed)*	Mean difference	
Pre-test scores Treatment vs Control	Equal variances assumed	.086	.769	-.357	226	.722	.629
	Equal variances not assumed			-.357	225.329	.722	.629

Additionally, a Levene's test was conducted to evaluate the equality of variances between the treatment and control groups based on pretest scores. The assumption of equal variances was met, as evidenced by a non-significant result, $F(1, 226) = 0.086$, $p > .05$ (see Table 3b), satisfying the assumption requirements of the independent samples *t*-test. Consequently, any discrepancies observed in subsequent analyses or outcomes can be more confidently attributed to the instructional intervention itself rather than initial differences in baseline scores.

The above sequence of analyses provides a comprehensive overview of the pre-intervention scores between the treatment and control groups, establishing a robust foundation for further investigation into the effectiveness of the intervention.

4.6. Comparison of post-intervention scores within the treatment group

A paired-sample *t*-test was performed to evaluate the mean difference between the pretest (M = 51.34, SD = 14.56) and posttest (M = 71.37, SD = 22.19) scores within the treatment group. The results revealed a statistically significant difference, $t(114) = -8.451$, $p < .001$ (see Table 4), indicating that the intervention, which involved interactive video lessons, successfully addressed existing misconceptions among high school students, particularly in the areas of photosynthesis, genes, and chromosomes.

4.7. Comparison of post-intervention scores between treatment and control groups

An independent samples *t*-test was conducted to assess the statistical significance of the difference between the treatment and control groups. Levene's test for equality of variances yielded a statistically significant result, $F(1, 226) = 20.31$, $p < .001$, indicating unequal variances between the two groups. Therefore, both equal variances assumed and not assumed analyses were performed. Under the assumption of equal variances, the *t*-test revealed a statistically significant difference between the treatment and control groups, $t(226) = 13.27$, $p < .001$. Similarly, under the assumption of unequal variances, the *t*-test still demonstrated a significant difference, $t(196.84) = 13.33$, $p < .001$ (see Table 5). These results indicate significant differences in both variances and means between the groups, suggesting disparities in the effects of the instructional interventions administered.

4.8. Long-term retention of corrected knowledge

In the comparison of posttest and post-retention test scores within the treatment group, Table 6a presents relevant descriptive statistics. The mean posttest score was M = 22.83 (SD = 7.10), while the mean post-retention test score was slightly lower at M = 22.71 (SD = 7.28). Table 6b displays the outcomes of the paired samples test, examining the difference between posttest and post-retention test scores. The mean

Table 4. Paired Samples t-test (Pre-test score and Post-test score) for the Treatment Group

Paired Samples T-Test		Mean	N	SD	*t*	*df*	*p-value*
Pair 1	Pre-test for the Treatment	51.34	115	14.560	-8.451	114	.000
	Post-test for the Treatment	71.3730	115	22.193			

Table 5. Levene's Test and Independent Samples t-test on post-test scores (a comparison of treatment and control) after the intervention

F		Levene's Test for Equality of Variances		t-test for Equality of Means		
		Sig.	*t*	*df*	*Sig. (2-tailed)*	
Treatment Vs. Control	Equal variances assumed	20.312	.000	13.27	226	.000
	Equal variances not assumed			13.32	196.84	.000

https://doi.org/10.15625/2615-8965/22410403

Table 6a. Comparison of posttest and post retention test scores for treatment group

	Treatment	N	M	SD	Std. Error Mean
Posttest vs. Post retention test	Post test score	115	22.83	7.10	.66
	Post retention test score	115	22.71	7.28	.67

Table 6b. Paired samples test results comparing post-test scores and post-retention test scores

		Mean	SD	*t*	*df*	*Sig. (2-tailed)*
Pair 1	Post-test Scores - Post retention Test Scores	.12174	9.384	.139	114	.89

difference was minimal (M = 0.12, SD = 9.38), and a two-tailed t-test revealed no statistically significant difference, $t(114) = 0.139$, $p > .05$, indicating the retention of knowledge over time. This implies that there was no significant decline in the retention of corrected knowledge among students following the intervention.

5. Discussion

5.1. Prevalence of misconceptions

This study explored the prevalence and nature of misconceptions held by high school students in Bhutan regarding two core biological concepts: photosynthesis and genes/chromosomes. These concepts form foundational pillars of biology education, yet have been consistently reported in both regional and international literature as topics vulnerable to conceptual misunderstanding. In the current study, while some students demonstrated partial understanding of key ideas, a significant proportion displayed conceptual inaccuracies that were both persistent and systematic. These findings strongly support prior research indicating that such misconceptions can act as cognitive barriers, impeding the acquisition of scientifically accurate knowledge and ultimately affecting students' long-term learning trajectories (Bahar, 2003).

Photosynthesis, although often taught in early science education, remains a concept laden with misconceptions. In this study, several students failed to differentiate between light-dependent and light-independent reactions, showing confusion about where and how these processes occur. This pattern of misunderstanding is consistent with the findings of Kumandaş (2015), who reported similar misconceptions among secondary students in other educational contexts. For instance, some students believed that photosynthesis occurs only when sunlight is present, neglecting the fact that the Calvin cycle, which is light-independent, continues without direct light input. This indicates that teaching approaches may not sufficiently emphasize a mechanistic or process-oriented understanding of photosynthesis, leading to surface-level recall without deeper comprehension.

Misconceptions regarding genes and chromosomes were also prominent. Many students incorrectly equated genes with chromosomes or failed to understand their distinct functions in heredity and cell division. A notable proportion of students inaccurately claimed that skin cell division leads to the formation of new chromosomes, reflecting confusion about mitosis and the nature of genetic material in somatic versus reproductive cells. These misconceptions closely resemble those documented by Wahyono and Susetyarini (2021), who emphasized the prevalence of such errors across educational systems. It is likely that traditional didactic teaching methods, which rely heavily on textbook diagrams and rote explanations, fail to convey the dynamic nature of genetic processes, resulting in enduring confusion.

These findings confirm the critical need for instructional strategies that go beyond content delivery and actively address student misconceptions. While many previous studies have emphasized multimedia use in science education, the current study adds to this literature by demonstrating the value of targeted interventions developed from pretest diagnostic results. The customized interactive video lessons created for this study included animations, embedded quizzes, drag-and-drop tasks, and reflective pause segments that encouraged students to engage cognitively and metacognitively with the content. These features are not commonly incorporated into standard multimedia resources and may explain the significant gains observed in this study.

The post-video facilitated group discussions were another key component. By providing students with opportunities to articulate their understanding, confront contradictions, and receive feedback from peers and teachers, these sessions helped reinforce scientifically accurate concepts. According to Susantini et al. (2019), interactive video instruction that includes space for social negotiation of meaning can lead to deeper learning. Our findings support this perspective, as students not only corrected misconceptions but were able to retain corrected knowledge over time, as evidenced by the retention test results.

It is important to note that even with well-designed interventions, misconceptions may persist or re-emerge without continual reinforcement. Halim et al. (2021) emphasized the importance of ongoing formative assessment to track conceptual development. The present study's use of pretests, posttests, and delayed post-retention tests represents an effort to monitor the stability of conceptual change and can serve as a model for future studies.

5.2. Effectiveness of Intervention

The study's results clearly demonstrate the effectiveness of interactive video lessons in addressing biological misconceptions. A paired samples *t*-test revealed a statistically significant difference between the pretest (M = 51.34, SD = 14.56) and posttest (M = 71.37, SD = 22.19) results of the experimental group, $t(114) = -8.451$, $p < .001$. This statistically significant improvement strongly indicates that the intervention had a meaningful effect on student learning. Students who participated in the interactive video lessons not only improved in their posttest performance but also demonstrated enhanced comprehension of key concepts in both photosynthesis and genetics.

What sets this study apart from earlier works is the alignment of instructional content with diagnosed misconceptions from the pretest phase. The interactive videos were not general-purpose but were designed to address specific gaps identified in the baseline assessment. This targeted approach likely contributed to the significant gains observed, as it allowed the intervention to directly confront the faulty reasoning patterns held by students. This reinforces the view that educational technology must be contextually relevant and responsive to learners' needs in order to be truly effective.

Supporting this, an independent samples *t*-test revealed a statistically significant difference between the control and experimental groups, $t(226) = 13.278$, $p < .001$. This indicates that students in the experimental group, who received the interactive video intervention, performed significantly better than those in the control group who received traditional instruction. This finding is in line with prior research (Susantini et al., 2019), which also found that interactive instructional videos enhance conceptual understanding. However, our study extends this literature by showing that the design of the video content, based on diagnostic evidence, plays a critical role in its effectiveness.

The findings also support the broader pedagogical principle that student engagement, interactivity, and personalized pacing are central to meaningful learning. By allowing students to pause, rewind, and interact with the video content at their own pace, the intervention accommodated different learning speeds and styles, fostering individualized comprehension that traditional instruction often fails to provide.

5.3. Sustained Retention of conceptual understanding

A particularly noteworthy finding in this study was the sustained retention of corrected concepts following the intervention. The comparison of posttest and post-retention test scores within the treatment group revealed minimal differences. While the mean posttest score (M = 22.83, SD = 7.10) was slightly higher than the mean post-retention test score (M = 22.71, SD = 7.28), the paired samples test, as presented in the results section (Table 6b), showed no significant difference between the two scores, $t(114) = 0.139$, $p > .05$. This indicates that the conceptual changes achieved through the intervention were not transient but had a lasting effect.

This finding is particularly significant as it suggests that the intervention not only helped students correct their misconceptions but also facilitated the long-term internalization of correct scientific concepts. Such durability in learning is critical, especially in foundational subjects like biology, where early misconceptions can interfere with the understanding of more complex topics in future coursework. This result aligns with previous research by Butler, Simmie, and O'Grady (2015), and Fan, Salleh, and Laxman (2018), who also found that engaging and interactive instruction results in greater knowledge retention.

The sustained performance observed here underscores the effectiveness of the instructional design. The repeated use of interactive prompts, integrated feedback, and post-lesson discussions likely contributed to stronger memory consolidation. It also highlights the value of repeated exposure and multimodal input in reinforcing learning.

6. Conclusions, implications, and and future directions

6.1. Conclusions

This study highlights the prevalence of misconceptions among high school students regarding fundamental biological concepts such as photosynthesis and genes/chromosomes. The findings emphasize the crucial need for effective interventions to rectify these misconceptions, as they can impede students' conceptual understanding and hinder scientific literacy.

The effectiveness of interactive video lessons as an intervention tool was evident in rectifying misconceptions among high school biology students. The significant improvement in posttest scores compared to pretest scores within the experimental group, as well as the higher performance of the experimental group compared to the control group, demonstrates the potential of interactive educational tools in promoting conceptual change and deeper understanding of biological principles.

Furthermore, the study demonstrates the enduring impact of the interactive video intervention, as evidenced by minimal differences between posttest and post-retention test scores within the treatment group. This suggests that the corrected knowledge persisted over time, highlighting the importance of evidence-based instructional strategies in fostering lasting conceptual understanding and alleviating misconceptions in biology education.

In summary, the findings emphasize the significance of leveraging interactive educational tools and evidence-based instructional strategies to address misconceptions and promote accurate understanding of biological concepts among high school students. By doing so, educators can contribute to fostering scientific literacy and facilitating enduring conceptual understanding in biology education.

6.2. Significance of the s tudy

The significance of this study lies in its contribution to the field of education and pedagogy, particularly in addressing a crucial gap in understanding and identifying misconceptions among secondary biology students. By utilizing a three-tier diagnostic test, the research served as a valuable diagnostic tool, refining assessment methods and facilitating a more robust evaluation of students' conceptual understanding. Moreover, the study's emphasis on interactive videos as a corrective measure introduced an innovative remediation approach—especially relevant in the digital age, where technology plays an integral role in education.

https://doi.org/10.15625/2615-8965/22410403

The implications of this research extend beyond the classroom, potentially influencing curriculum development, teacher training, and educational policy. Early identification and rectification of misconceptions in students' academic journeys could contribute to a more solid foundation in biology, with potential long-term improvements in learning outcomes.

Ultimately, the significance of this research lies in its potential to elevate the quality of biology education, shape instructional practices, and contribute to the broader discourse on effective strategies for addressing misconceptions in science education.

6.3. Recommendations

Based on the findings of this study, it is recommended that biology educators incorporate interactive video lessons as a regular instructional strategy to address and rectify students' misconceptions. Teacher professional development programs should include training on the use of diagnostic tools, such as the three-tier diagnostic test, to identify conceptual misunderstandings early. Curriculum developers are encouraged to integrate multimedia resources that are aligned with common student misconceptions, ensuring that content is both engaging and pedagogically sound.

Teacher education institutes should embed training in digital pedagogy and misconception-based instructional planning within their pre-service programs to prepare future educators for conceptually focused and technology-integrated teaching. Additionally, school leaders and policymakers should support the necessary infrastructure—such as access to devices and internet connectivity—to facilitate the effective implementation of technology-enhanced learning. Future research should explore the scalability of such interventions across different subjects and regions to enhance their generalizability and impact.

6.4. Limitations and future directions

Although the findings of this study are promising, several limitations should be acknowledged. First, the use of purposive sampling limits the generalizability of the results. While the sample was drawn from five schools in the Samtse district, it may not be representative of all students in Bhutan. Second, variation in classroom environments, teacher facilitation, and access to resources such as computers or internet may have influenced the consistency of intervention implementation across schools.

Additionally, the study focused on only two conceptual areas within the biology curriculum. While these were chosen due to their foundational importance, the results may not generalize to other topics. Future research should consider extending the intervention model to include additional biology concepts or other science subjects such as physics and chemistry.

Moreover, this study primarily employed quantitative methods. Incorporating qualitative data—such as student interviews, teacher reflections, or classroom observations—would provide richer insights into how students conceptualize and reconstruct their understanding. Future studies could also explore how learner characteristics such as prior academic performance, motivation, or language proficiency affect the effectiveness of interactive video-based learning.

Despite these limitations, the findings of this study offer valuable evidence on the effectiveness of targeted interactive instructional strategies. By identifying and addressing misconceptions through data-informed interventions, educators can play a critical role in improving conceptual understanding and scientific literacy among high school students.

Disclaimers

The views expressed herein do not necessarily represent those of International Development Research Centre or its Board of Governors.

Acknowledgment

This work was supported by the Global Partnership for Education Knowledge and Innovation Exchange, a joint endeavour with the International Development Research Centre, Canada.

References

Bahar, M. (2003). Misconceptions in biology education and conceptual change strategies. *Educational Sciences: Theory & Practice*, *3*(1), 55-64.

Butler, J., Mooney Simmie, G., & O'Grady, A. (2015). An investigation into the prevalence of ecological misconceptions in upper secondary students and implications for pre-service teacher education. *European Journal of Teacher Education*, *38*(3), 300-319.

Chophel, Y. (2022). Remediating misconceptions related to particulate nature of matter using video animation: Action research. *International Research Journal of Science, Technology, Education, and Management*, *2*(1), 65-77.

Darko, E., Heydarizadeh, P., Schoefs, B., & Sabzalian, M. R. (2014). Photosynthesis under artificial light: the shift in primary and secondary metabolism. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *369*(1640), 20130243.

Duda, H. J., Wahyuni, F., & Setyawan, A. E. (2020). Plant biotechnology: Studying the misconception of biology education students. In *AIP Conference Proceedings* (Vol. 2296, No. 1). AIP Publishing.

Fan, L. C., Salleh, S., & Laxman, K. (2018). Embedding video technology in enhancing the understanding of the biology concept of breathing: A Brunei perspective. *E-learning and Digital Media*, *15*(5), 217-234.

Gusmalini, A., & Wulandari, S. (2020). Identification of misconceptions and causes of student misconceptions on genetics concept with CRI method. In *Journal of Physics: Conference Series* (Vol. 1655, No. 1, p. 012053). IOP Publishing.

Halim, A., Mahzum, E., Yacob, M., Irwandi, I., & Halim, L. (2021). The impact of narrative feedback, e-learning modules and realistic video and the reduction of misconception. *Education Sciences*, *11*(4), 158. Publishing.

Ibourk, A., Williams, M., Opperman, A., Cisterna, D., Nazar, C. R., & Xie, Y. (2018). Young students' understanding of the relationship between inheritance and variation of traits using structural equation modeling. *Science Education*, *102*(6), 1201-1238.

Kumandaş, B. (2015). Misconceptions in biology education: a review of relevant research. *PQDT-Global*.

Marisda, D. H., & Handayani, Y. (2020). The combination of interactive conceptual learning models and multimedia interactive to minimize misconceptions on the science content. In *Journal of Physics: Conference Series* (Vol. 1572, No. 1, p. 012069). IOP Publishing.

Susantini, E., Indana, S., Isnawati, I., & Sayitri, S. D. (2019). Developing Instructional Video to EnhanceBiology Pre-Service Teachers' Metacognitive Skills. In *Mathematics, Informatics, Science, and Education International Conference (MISEIC 2019)* (pp. 120-123). Atlantis Press.

Wahyono, P., & Susetyarini, E. (2021). Misconceptions of Biology Education Students in Biochemistry Course during the COVID-19 Pandemic. *Journal of Biological Education Indonesia (Jurnal Pendidikan Biologi Indonesia)*, *7*(2), 104-110.

Yuliasari, A., Hari, D. L. H., & Marianingsih, P. (2023). Identification of students' misconceptions on the photosynthetic and plant respiration concepts using a two-tier diagnostic test. *International Journal of Biology Education Towards Sustainable Development*, *3*(1), 16-23.