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Animation-Based Instruction to Eliminate the Misconception of Students in Learning Biology: An Action Research

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Abstract

Animation-Based Instruction is one of the innovative teaching approaches incorporated in the classroom using animated videos as a visual aid to assist learning and improve academic achievement. This study, conducted in 2022, investigated the effectiveness of Animation-Based Instruction in Biology for improving students' academic achievement and eliminating misconceptions, particularly in abstract topics such as meiosis. A sample of 35 students from Class 10 of Tang Central School was randomly selected for the study. The research employed a mixed-methods approach, utilising a One-group Pretest–Posttest research design, 5-point Likert scale survey questionnaires for quantitative data, and semi-structured interviews for qualitative data collection. A dependent sample t-test at the 95% confidence level revealed a significant difference between pre-test (M = 5.2, SD = 2.2) and post-test scores (M = 7.9, SD = 1.8), with a mean increase of 2.7 ($p = 0.001$). Analysis showed a 70% improvement in conceptual understanding, with misconceptions reduced from 52% to a minimal level. Subscale analyses indicated significant gains in the general concept of meiosis ($p = 0.006$), chromosome number ($p = 0.001$), and stages of meiosis ($p = 0.003$). Post-intervention drawing analysis revealed 55% of students produced comprehensive representational drawings, compared to 95% producing non-representational drawings before intervention. Students' perception ratings were consistently high (overall $M \geq 3.77$), with the highest rating for the ability to pause and replay videos (M = 4.59). The study revealed that Animation-Based Instruction is an effective teaching-learning approach to enhance students' academic achievement in Biology and reduce misconceptions. The study recommends that teachers adopt Animation-Based Instruction to improve academic performance, foster lifelong learning, and promote a meaningful teaching-learning process.

Keywords: Animation-Based Instruction, academic performance, meiosis, misconception

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Introduction

Educational pedagogy is at the centre of the paradigm shift in the 21st century, aiming to enhance the academic performance of learners. The Ministry of Education initiated the 21st-century transformative pedagogy professional development across the nation to upscale teachers' pedagogical practices and enhance students' academic performance. However, the analysis conducted by the Bhutan Council for School Examinations and Assessment (BCSEA) indicated poor academic performance in Biology. Similarly, the analysis of Class Nine Science results for 2021 at Tang Central School revealed poor performance. To address this, the study employed animation-based instruction (ABI), integrating Information and Communication Technology (ICT) to help eliminate students' misconceptions in Biology

The study explored the benefits of the integration of ICT in teaching, learning, and assessment. It also explored other alternatives for using digital platforms in the classroom. Science curriculum must provide learners an opportunity to explore digital resources, manipulate and handle physical ICT-related tools, design and create solutions using relevant ICT tools (software or apps), and promote environmental, socio-economic, and cultural values through ICT. Therefore, ABI was employed to teach the students about cell division, focusing on the topic "Meiosis". Through this, the effectiveness of ABI in improving understanding and reducing misconceptions about meiosis was evaluated.

However, in the Bhutanese classrooms, many schools do not have computers in the classes to support learning, even though their use is mandated by the instructional guide of the National School Curriculum (NSC). Students are also not allowed to use smartphones in the classrooms. Computers in the ICT laboratory are used for ICT classes, creating a digital divide for other subjects. In such a situation, it is challenging to practice blended learning in the classroom. This contributes to a lack of skills and experience needed to continue learning during a pandemic, impeding academic performance. Therefore, to equip learners with ICT skills and experience, the conceptual framework "How Meiosis Works," which was designed by Michael McKinley and O'Loughlin (2006), was adapted and integrated into the meiosis lessons to provide an opportunity to learn the 21st-century skills required for enhancing academic performance in Biology.

A study conducted by the Royal Education Council (2009) on *The Quality of School Education in Bhutan Reality and Opportunities*, revealed that Bhutanese classroom practices are based on the conventional method, the lecture method, which results in students' low level of learning. With the demand for 21st-century schooling, to improve the quality of education in the country, it has become necessary to shift the pedagogical trend from teacher-centered teaching to learner-centered teaching (Rabgay, 2018). This study aimed to validate the applicability of ABI in Bhutanese classrooms to examine its effectiveness in studying Biology by students in Class 10.

Objectives

1. To identify the misconceptions about meiosis held by Class 10A students.

2. To evaluate the effectiveness of Animation-Based Instruction in enhancing Class 10 students' conceptual understanding of meiosis.
3. To explore the extent to which Animation-Based Instruction mitigates students' misconceptions regarding the stages and processes of meiosis.

Research Question

1. What misconceptions about meiosis are held by Class 10A students?
2. To what extent has ABI improved students' conceptual understanding of meiosis?

Situational Analysis

Tang Central School, located 296 km from Bhutan's capital and 27 km from the Bumthang District Administration Office, is one of the remotest schools with limited internet connectivity and digital resources. However, recent improvements in ICT infrastructure have enhanced teaching and learning opportunities. The topic "meiosis" was chosen because it is abstract and challenging for students, who often struggle to visualise the stages of cell division, resulting in persistent misconceptions (Dikmenli, 2010; Kindfield, 1991). Traditional lecture-based methods have proven insufficient, as abstract topics like meiosis contribute to low academic performance (Fisher, 1985; Tekkaya, 2002). ABI using simulations allows students to visualise chromosome movement, interact with the process, and replay stages until the concept is fully understood, thereby improving conceptual clarity and reducing misconceptions (Çimer, 2012; Saka & Cerrah, 2004). Global research similarly highlights widespread misconceptions about meiosis, recognised as one of the most complex topics in Biology (Brown,1995; Oztap et al., 2003; Yip, 1998). Research also shows that interactive technologies such as animations can promote a deeper understanding of dynamic biological processes like chromosomal crossover and cell division (Falvo, 2008). ABI was chosen because, among various pedagogical approaches, it uniquely allows students to interact with abstract concepts visually and dynamically, enabling them to replay and manipulate processes like meiosis until fully understood, something traditional methods cannot achieve. Recent studies have demonstrated that well-designed animations can help students focus on underlying principles and processes in biology, rather than relying on rote memorisation, thereby enhancing conceptual understanding and reducing misconceptions (Kalimuthu, 2017; Oztap et al., 2003).

Competence

With funding support from the Royal Government of Bhutan, I pursued professional development at Samtse College of Education, where I completed a dissertation titled *Flipped Classroom Approach in Teaching Biology: Assessing Students' Academic Achievement and Perceptions toward Biology*. Two manuscripts were produced from this research, one of which was published in the *International Journal of Applied Chemical and Biological Sciences* (IJACBS; ISSN: 2582-788X), and another was recently published in the *Journal of Pedagogical Sociology* *and Psychology*. In addition, I co-authored a study examining challenges in Biology laboratory work in Trongsa District. My understanding of action research was further strengthened through the Advanced Study (ADS 602) module during my Master of Education programme. At Tang Central School, a team of experienced educators contributes both expertise and research experience, enabling the school to undertake action research as well as conventional research effectively.

Literature Review

Effective pedagogy is central to enhancing learning outcomes, particularly in science education, where abstract concepts often challenge students' understanding. Pedagogy involves the strategies, methods, and approaches that teachers use to facilitate meaningful learning experiences, fostering critical thinking, motivation, and engagement (Darling-Hammond et al., 2020). Over time, pedagogical practices have shifted globally from teacher-centered, lecture-based instruction toward learner-centered approaches that prioritise active, interactive, and technology-supported learning. In the Bhutanese context, educators have increasingly recognised the need for pedagogical approaches that go beyond rote memorisation to develop 21st-century competencies in students. In response to concerns over curriculum fragmentation and lack of continuity across grades, a comprehensive PP–XII science curriculum reform was initiated in 2008 (Royal Education Council [REC], 2022). Parallel to this, the Ministry of Education (MoE) commissioned a nationwide needs assessment in 2007. As a result, the reformed science curriculum was implemented in stages, beginning with Grades IV to VI in 2013 and Grades X to XII in 2017 (REC, 2022). Recognising the global shift from traditional lecture-based methods to integrative STEM education, the Royal Education Council launched further curriculum reforms in late 2019. These reforms aimed to embed 21st-century competencies by integrating science, technology, engineering, and mathematics (STEM). STEM education is expected to foster a deeper understanding of both local and global challenges by situating learning in authentic contexts and emphasizing real-world applications (NRC, 2013, 2014). Despite limited access to digital resources in many Bhutanese classrooms, educators continue to explore innovative pedagogical approaches to optimise student learning. For instance, studies by Dorji and Dorji (2022) and Jurmey et al. (2019) showed that flipped classroom strategies significantly enhance student motivation, confidence, academic performance, and engagement in Bhutanese settings. The flipped classroom leverages technology to shift content delivery outside the classroom, allowing more interactive and personalised learning during class time. In a similar vein, ABI combines interactive learning principles with computer-based animations to support science instruction. According to Ozmen (2008), ABI increases students' motivation and enables self-paced learning, particularly when dealing with abstract scientific concepts. Through computer-assisted simulations, ABI helps clarify complex topics that students may struggle to understand through traditional instruction. Moreover, ABI actively engages students in constructing knowledge, thereby improving their academic outcomes. In this study, ABI is utilised to illustrate the process of meiosis, including its various stages, chromosome formation, cytokinesis, and telophase.

Animation simulates each phase, offering a visual and dynamic explanation of processes typically confined to static textbook illustrations. Therefore, ABI serves as a powerful tool to simplify the complexities of meiosis by allowing students to visualise, pause, and revisit each stage of the process, capabilities not achievable through conventional textbooks alone.

Methods and Materials

A mixed-methods research design was employed to collect both quantitative and qualitative data. The study employed a one-group pretest-posttest design using researcher-designed tests, a structured questionnaire on ABI, and semi-structured interviews. For the quantitative component, purposive sampling was used to select Section A of Class 10. The collected data were analysed using SPSS version 22.0 and Microsoft Excel 2013. For the qualitative component, semi-structured interviews were analysed through a coding process, which involved categorising participant responses into emerging themes.

Intervention Strategies

One-group Pretest-posttest Research Design

A one-group pretest-posttest design was used to address misconceptions in learning meiosis. Due to scheduling conflicts, the intervention was extended from one week to two weeks. A Meiosis Concept Test (MCT) was administered before and after the intervention, consisting of multiple-choice questions and an open-ended question. The MCT covered key concepts like cell cycle, meiosis, homologous chromosomes, and crossing over. The intervention, ABI, was delivered through Google Classroom. Students attended one-hour sessions in the ICT lab, where they explored meiosis using interactive animations. The teacher provided guidance and explained how ABI could enhance learning and correct misconceptions. After the intervention, a post-test was conducted via Google Forms, and students were asked to draw and label the stages of meiosis. The drawing responses were analysed using a coding framework (Kose, 2008) to assess their understanding.

Closed-ended Survey Questionnaire

The closed-ended survey questionnaire was adapted from Dorji and Dorji (2022), which was framed using a five-point Likert scale. It was administered to a sample of 22 students after the post-test to examine the degree of perception level of the respondents' attitude towards ABI in learning Biology. A five-point Likert Scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree) was used to measure the level of participants' perception.

Semi-structured Interview

For a qualitative study, after the intervention, four students were selected using a random sampling for a semi-structured interview to collect the qualitative data (see Table 1). The semi-structured interview questions, based on the topic of cell division, were adapted from Dorji and Dorji (2022) and BCSEA (2014-2018). The semi-structured interview examined students' in-depth conceptual understanding of the topic and their perceptions of ABI in the Biology classroom. The use of such an instrument helped the researchers to triangulate the data and make the findings more valid.

Table 1

Sampling Size for Semi-structured Interview

Group	Male	Female	Total
One-grouped Pretest-posttest	2	2	4

Data Analysis

Quantitative data from the one-group pretest-posttest design were analysed using SPSS 22.0 and MS Excel 2013. Drawing responses were evaluated using Kose's (2008) coding framework, and perception survey data were interpreted using Brown's Model (2010) as shown in Table 2. Qualitative data from interviews were analysed thematically.

Table 2

Interpretation of Students' Perception Mean Scores with Reference to the Brown Model

Mean values	Agreement	Level of perception
4.51-5.00	Strongly agree	Highest
3.51-4.50	Agree	High
2.51-3.50	Neutral	Moderate
1.51-2.50	Poor	Low
1.00-1.50	Very poor	Lowest

Note. Adapted from *ANR Program evaluation*, by S. Brown, 2010, p.1

Quantitative Data Findings

One-group Pretest-posttest Research Design

A dependent sample t-test at the 95% confidence level revealed a significant difference between pre-test and post-test scores ($p = 0.001$), with a mean increase of 2.7 (see Table 3). Students' performance improved from ($M = 5.2$, $SD = 2.2$) to ($M = 7.9$, $SD = 1.8$), indicating that the use of ABI effectively reduced misconceptions and enhanced academic achievement in meiosis.

Table 3

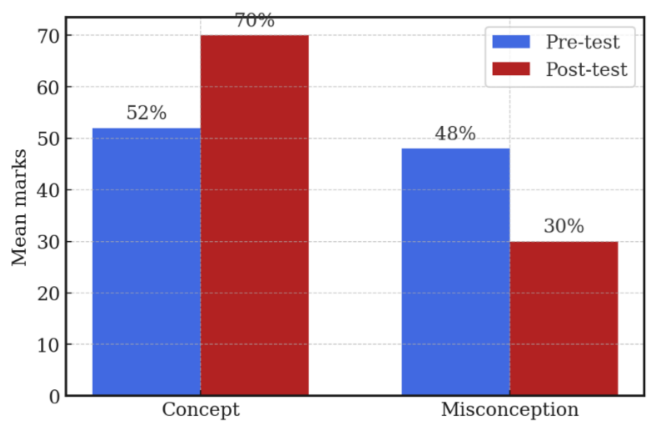
Comparison of the Overall Pre-test and Post-test Mean Scores

Test	N	Mean	Minimum	Maximum	SD	*p*-Value
Pre-test	35	5.2	1	8	2.2	0.001
Post-test	35	7.9	4	10	1.8	

Analysis based on percentages showed that ABI supported learning of the abstract topic of meiosis. In the pre-test, 52% of students showed misconceptions, while post-test results indicated a 70% improvement in conceptual understanding (see Figure 1).

Figure 1

Graph Showing Percentage Differences Between Pre-test and Post-test



Findings Based on the Three Subscales (General concept of Meiosis, Chromosome Number, and Stages of Meiosis)

Descriptive Tables 4, 5, and 6 indicate the differences in the pre-test and post-test mean scores based on three subscales. Similar to the outcome of the overall results of Table 3, there was an increase–in students' conceptual understanding of the topic of meiosis. As shown in Table 4, students gained a conceptual understanding of general concepts of the meiosis subscale with a difference of mean value 1.1 from the pretest (M = 1.3, SD = 0.8) to the post-test (M = 2.4, SD = 0.7). Therefore, there was a statistically significant improvement in this subscale with a ($p=0.006$).

Table 4

Comparison of Pre-test and Post-test Mean Scores of General Concepts of Meiosis

Test	N	Mean	Minimum	Maximum	SD	*p*-Value
Pre-test	35	1.3	0	3	0.8	0.006
Post-test	35	2.4	2	3	0.7	

As indicated in Table 5, the scores for the chromosome number in this subscale, the post-test mean score was higher (M = 2.1, SD = 0.8) than the pre-test mean score (M = 0.9, SD 0.5). An independent sample *t*-test was performed at the 95% confidence level, indicating statistically significant differences between the mean scores of the pre-test and post-test (p=0.001).

Table 5
Comparison of Pre-test and Post-test Mean Scores of Chromosome Number of Meiosis

Test	N	Mean	Minimum	Maximum	SD	*p*-Value
Pre-test	35	0.9	0	2	0.5	0.001
Post-test	35	2.1	1	3	0.8	

As depicted in Table 6, there was a substantial difference between the pre-test and post-test mean scores for the stages of meiosis. In this subscale, students' conceptions of meiosis increased from the pre-test (M = 2.8, SD = 1.3) to the post-test (M = 3.8, SD = 0.9). The differences between the test scores in this subscale appeared to be statistically significant at ($p=0.003$) at the 95% confidence level.

Table 6
Comparison of Pre-test and Post-test Mean Scores of Stages of Meiosis

Test	N	Mean	Minimum	Maximum	SD	*p*-Value
Pre-test	35	2.8	0	4	1.3	0.003
Post-test	35	3.8	1	4	0.9	

Table 7 shows a reduction in student misconceptions from the pre-test to the post-test after using ABI to teach meiosis, which indicates that ABI effectively improved students' understanding. Items 1, 2, and 3 assessed general concepts of meiosis, with Homologous chromosome (Item 1) showing the highest pre-test misconceptions at 23 students. Following the intervention, a marked decrease in misconceptions was observed across most concepts. For instance, misconceptions regarding separating sister chromatid (Item 8) dropped dramatically from 28 students to just 4, and for the general concept of chromosomes (Item 5), misconceptions decreased from 28 to 8. The number of students with a misconception of the chromosome number in prophase I (Item 6) also fell significantly from 33 to 15. The data indicate that while some concepts, like identifying cytokinesis (Item 7), were well-understood even before the intervention, the use of ABI was particularly effective in addressing complex student misconceptions.

Table 7

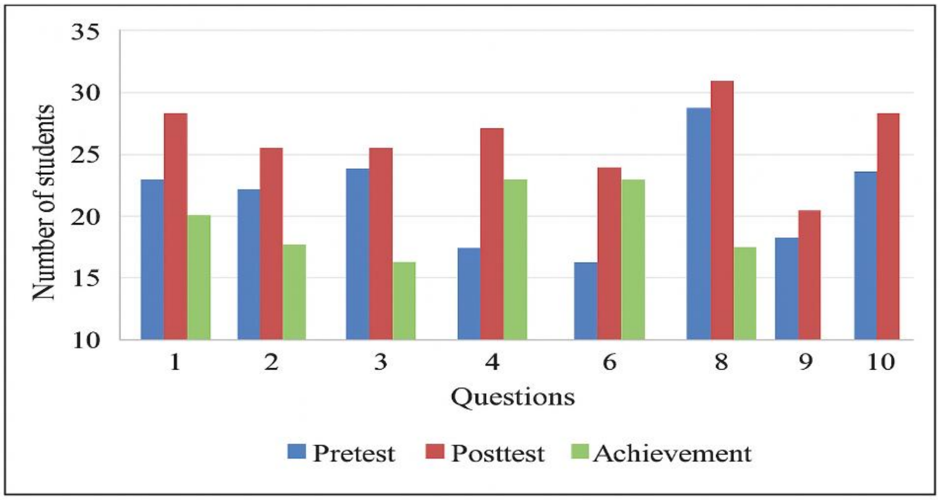
Number of Students with Scientifically Acceptable Understanding and Misconceptions

		Pre-test (N = 35)		**Post-test (N = 35)**	
Items	**Concepts**	**Scientifically accepted concepts**	**Misconceptions**	**Scientifically accepted concepts**	**Misconceptions**
General concepts					
1	Homologous chromosome	12	23	30	5
2	Gamete production	15	20	27	8
3	General characteristics of meiosis	20	15	23	12
Number of chromosomes					
4	Number of chromosomes in somatic cell	22	13	23	12
5	General concept of chromosomes	7	28	27	8
6	Chromosome number in prophase I	2	33	20	15
Stages of meiosis					
7	Identifying cytokinesis	28	7	31	4
8	Separating sister chromatid	7	28	31	4
9	Sequencing phases	19	16	27	8
10	Naming phases	23	12	30	5

Figure 2 shows the achievement level based on each question after the intervention employing the ABI. Therefore, in each question, there was a shift in the understanding of the concept on the topic of meiosis. Overall, Table 7 and Figure 2 show that ABI has eliminated the misconception of the students. However, the post-test results show that there are a few misconceptions among some of the students, as indicated in Table 7.

Figure 2

Comparison of the Number of Students who Answered Questions Correctly



Analysis of Drawing (Section C)

Table 8 shows a significant improvement in students' understanding of meiosis stages through drawing tasks after ABI. In the pre-test, 95% produced non-representational drawings, indicating misconceptions. Post-test results showed 55% comprehensive drawings, 21% partial, and only 14% with misconceptions, confirming ABI's effectiveness in improving conceptual understanding.

Table 8

Analysis of Students' Drawing (N=35)

Levels	Responses	Pre-test (%)	Post-test (%)
1	No drawing	0	0
2	Non-representational drawings	95	0
3	Drawings with misconceptions	5	14
4	Partial drawings	0	21
5	Comprehensive representational drawings	0	55

Students' Perception towards Animation-Based Instruction

Table 9 shows that students had a highly positive perception of ABI in learning meiosis, with most items rated "High" on the Likert scale. Key items like pausing and replaying videos (M=4.59) and overall enjoyment of ABI (M=4.50) highlight its flexibility and effectiveness. Even lower-rated items still met the "High" threshold, indicating ABI's strong potential to enhance understanding and academic performance in abstract Biology topics.

Table 9
Students' Towards ABI in Learning Meiosis

Items	N	Mean	Std. Deviation	Level of perception
1. I liked Animation-Based Instruction (ABI).	35	4.50	.51	High
2. I feel that watching animated videos and using simulations contribute efficiently to my learning.	35	4.36	.49	High
3. With ABI, I feel more prepared for my exam.	35	3.95	.65	High
3. I try to learn as much as possible while watching animated videos.	35	4.31	.65	High
4. I wish more teachers would use the ABI.	35	4.13	.83	High
5. I frequently pause or repeat parts of the animated videos to increase my understanding of the content.	35	4.59	.50	Highest
6. ABI encourages me to practice critical and creative thinking.	35	4.18	.39	High
7. ABI attracts my attention to the learning and teaching process.	35	4.04	.84	High
8. ABI can improve interest in exploring topics.	35	4.22	.61	High
9. I feel prepared to complete course tasks in class after watching an animated video on the content.	35	3.95	.56	High
10. ABI is more engaging than the traditional classroom.	35	4.18	.66	High
11. ABI reduces the effort to understand the basic knowledge of the subject matter.	35	3.77	.75	High

12. I am more motivated to learn the concepts of the course via ABI.	35	4.27	.46	High
13. ABI can improve my interest in Biology.	35	4.18	.73	High
14. I got the ability to self-pace my learning with ABI.	35	4.00	.69	High
15. ABI matches my learning style.	35	4.13	.64	High
16. I feel that mastering learning through ABI improved my academic achievement.	35	4.00	.69	High
17. I feel that mastering learning through ABI improved my course understanding.	35	4.18	.394	High
18. I would like to participate in similar classes in the future.	35	4.36	.847	High

Findings Based on Qualitative Data

Semi-structured Interview

To support the quantitative data collected, a semi-structured interview was administered to participants after the intervention. The questions were asked based on two themes (students' perception towards ABI and the general concept of meiosis). Four students took part in the semi-structured interview.

Students' Perception Towards Animation-Based Instruction

Participants have clearly described the digital tools ABI incorporated in the Google Classroom and the sequence followed during the activity. Students were able to navigate through the assigned task of logging into their online classroom and using resources such as playing content videos, simulations, and PowerPoint Presentations individually. The teacher was only required as a guide to support learners in case of technical issues. However, the majority of the respondents complained about disturbances caused by the sound of the content videos played in the common room (ICT lab) whenever they had to view the video lessons. Although the noise was not described as extremely severe, several students emphasised that it disrupted concentration and created discomfort during learning activities. All the respondents perceived learning through ABI as a suitable means to comprehend the content, rather than just relying on teachers' theoretical input in the four corners of the classroom, the conventional method. ABI activities provided learners with opportunities to perceive the biological process (content) through their own senses, with the added advantage of revisiting the content. To this, Student 1 stated:

> ABI activity helps to achieve the lesson goals as we get to explore the process through a visual setting rather than just listening. The concept becomes clearer. For instance, we were able to see how crossing over happens, which would be impossible in a theory class.

Similarly, Student 2 expressed:

> ABI is the best method for students to learn, as we can see the real processes. Moreover, we could watch it repeatedly until we understood. So, I like the idea of learning through ABI as it is interesting and motivating, which will enhance our academic performance.

Therefore, students also wish to avail themselves of such opportunities in other subjects in their daily learning activities to advance their learning and to equip them with the ICT skills needed to navigate the 21st-century pedagogies. However, students had challenges in accessing the ABI, since there weren't earphones to listen to while viewing the video lesson. The videos played by the mates distracted the concentration while accessing the video lessons. For instance, Students 1, 2, and 3 shared: "Video played in the same room with an audio disturbance disturbed the whole class." Despite such problems, students liked ABI and wished to take part in the future as well. This is due to the flexible environment provided by ABI that helps increase their academic performance.

Conceptual Understanding of Meiosis

Semi-structured interviews on the concept of meiosis helped elicit students' misconceptions identified in the pre-test.The information collected from the participants confirmed that there was the elimination of misconceptions they held about the concepts of meiosis, and their academic performance has been enhanced. Moreover, the students in the interview had the opportunity to express why they had selected the correct scientific concepts in the MCT. The qualitative data also confirmed that ABI enhances the academic performance of Grade 10 students in Biology, particularly in understanding cell division. For instance, S1, S3, and S4 stated the definition of the term meiosis in a similar way:

> It is a type of cell division that occurs in the sex cell or gamete cell. It forms four unique daughter cells through four phases. These four daughter cells have haploid chromosomes. Therefore, meiosis is also known as a reduction division.

Further, all the interviewees were able to explain the relationship between karyokinesis and cytokinesis, with division of the nucleus (karyokinesis) followed by division of cytoplasm (cytokinesis). The significance of crossing over was explained based on the genetic variation. For instance, S2 said, "Significance of crossing over during meiosis helps in the genetic variations, and the daughter cells are not exactly like their parents because of the crossing over". S2 and S3 shared a similar opinion that the most unforgettable experience of ABI was learning by watching videos and playing simulations using ICT and mastering the content through self-paced learning. S1 also expressed a positive perception of ABI:

We like to watch videos, and we feel that we are thoroughly engaged in ABI. We enjoy working within the team, and we feel secure and successful in learning at ABI. Moreover, I am confident that video lessons will help us to recall during our examinations.

Based on the data analysis, it is confirmed that ABI is one of the innovative teaching approaches in learning Biology and enhancing performance. Additionally, students developed ICT skills.

Discussion

The purpose of this study was to examine the effectiveness of ABI in enhancing Class 10 students' conceptual understanding of meiosis and reducing misconceptions. The findings revealed a significant improvement in post-test scores compared to pre-test scores, indicating that ABI supported students in developing clearer and more accurate conceptions of the stages and processes of meiosis. Qualitative data from semi-structured interviews further confirmed that students perceived ABI as engaging, motivating, and helpful in visualising abstract biological processes. Taken together, these results highlight the potential of ABI as an instructional strategy in overcoming learning barriers in complex biological topics. However, the persistence of certain misconceptions suggests that, while effective, ABI cannot fully replace the need for diverse teaching approaches.

One-group Pretest–Posttest Research Design

Overall, the findings based on the quantitative and qualitative results indicated that there was a significant shift in students' conceptual understanding of cell division and the process of meiosis from the pre-test to the post-test. This was evident during interviews as students were able to explain the stages of meiosis and the importance of crossing over in prophase I. The outcome of this study parallels the results found by Dorji and Dorji (2022). According to Stith (2004), students who had the opportunity to learn the content through ABI significantly improved their academic achievement. Similarly, O'Day (2008) indicated that ABI enhances both factual and conceptual understanding. Jurmey et al. (2018) and Dorji and Dorji (2022) further confirmed that video lessons in flipped classroom settings favored experimental groups compared to traditional lecture-based groups. Consistent with Utomo et al. (2020), this study confirmed that the post-test results were significantly higher than the pre-test results, affirming ABI's effectiveness. While these findings strengthen the case for ABI as a pedagogical tool, the use of a one-group pretest–posttest design without a control group poses a limitation. Causal claims about the exclusive impact of ABI must, therefore, be made cautiously. Future studies could adopt experimental or quasi-experimental designs with larger and more diverse samples to validate these outcomes. Nevertheless, as an action research study situated in a classroom context, the design effectively addressed an immediate learning need and provided practical insights for instructional improvement.

Three Subscales (General Concept of Meiosis, Chromosome Number, and Stages of Meiosis)

Analysis across the three subscales revealed that students gained conceptual understanding of the general concept of meiosis, the number of chromosomes, and the stages of meiosis. Although most students developed awareness of the general processes and events occurring during meiosis, some continued to experience difficulties in applying knowledge gained through ABI. For instance, challenges persisted in identifying key characteristics of meiosis, particularly in relation to gamete production and chromosome attributes. This finding echoes Clark and Mathis (2000), who reported that students often fail to integrate cell structure knowledge with its functions. Similarly, Lewis and Wood-Robinson (2000) found that difficulties in understanding genetic information transfer stem from weak foundational knowledge of gene, chromosome, and cell structures.

Among the three subscales, students indicated the highest misconceptions in "Number of Chromosomes." Although there was an overall improvement, persistent difficulties were observed in understanding chromosome numbers in prophase I and in somatic cells. These challenges align with Clark and Mathis's (2000) findings that students often confuse chromatids with chromosomes and struggle to distinguish duplicated from unduplicated chromosomes. In light of these difficulties, integrating diverse teaching aids such as chromosome photographs, videos, simulations, role-play, and physical models may help minimise persistent misconceptions (Özmen, 2008).

Students' understanding of meiotic stages showed the greatest improvement, with fewer misconceptions recorded in the post-test. However, some students still struggled to consistently apply learned concepts when identifying phases and describing events, particularly in prophase I. This finding is consistent with Kindfield (1994), Öztap et al. (2003), and Yip (1998), who highlighted the difficulty of illustrating chromosome movement during meiosis. Hence, employing blended approaches that integrate ABI, flipped classrooms, and ICT-based strategies can enhance conceptual development. Riemeier and Gropengieber (2008) similarly confirmed that well-structured, innovative strategies promote conceptual learning.

Analysis of Drawing

The analysis of students' drawings showed that their conceptual understanding of meiosis was moderately improved after ABI. This finding relates to the first research question, as misconceptions persisted in the post-test, particularly concerning chromosome behavior, chromosome number, organelle changes, meiotic stages, and DNA replication. These results are consistent with earlier studies reporting similar difficulties (Lewis et al., 2000; Lewis & Wood-Robinson, 2000; Riemeier & Gropengieber, 2008; Yesilyurt & Kara, 2007).

Regarding the second research question, the improvement in drawings indicates that ABI enhanced students' ability to represent meiotic stages more clearly. However, deeper misunderstandings, such as crossing over and reduction division, remained. This aligns with Tsui and Treagust (2007), who argued that visual instruction strengthens recognition of processes but does not fully resolve conceptual challenges. Thus, while ABI is a valuable tool, its integration with complementary methods is necessary to address entrenched misconceptions more effectively.

Students' Perception Towards Animation-Based Instruction

The study revealed that students had a highly positive perception of ABI in learning Biology (M = 4.17, SD = 0.62). Interviews further confirmed their enthusiasm for future use of ABI, directly addressing the research question on perception. These findings align with Caviar et al. (2022), who reported that animation-based learning enhances motivation and achievement, and with Devi and Jena (2022), who found improvements in memory and reasoning. Mayer's (2009) cognitive theory of multimedia learning supports this positive response, suggesting that animations reduce cognitive load and facilitate mental model construction, particularly for abstract processes like meiosis.

Students' favourable attitudes indicate that ABI not only enhances understanding but also creates a supportive environment for addressing misconceptions. This is consistent with Tversky et al. (2002), who highlighted the role of animations in clarifying complex temporal and spatial changes. Such positive perceptions also suggest long-term pedagogical potential: students are more likely to remain engaged and motivated when learning tools resonate with their needs. However, reliance on a single instructional method may not be sufficient, and future research should explore how ABI can be integrated with other strategies, such as collaborative learning and inquiry-based approaches, to maximize its impact.

Conclusion

The study confirmed that ABI is an effective approach for teaching abstract biological concepts, particularly meiosis, in secondary schools in Bhutan. Students showed significant improvement in test scores ($p=0.001$) after the intervention, with higher mean scores in the post-test compared to the pre-test. ABI enhanced academic performance and fostered a positive attitude toward Biology. ABI, as a 21st-century pedagogy, supports child-centered, knowledge-based, assessment-based, and community-based learning, making it an effective tool for meaningful teaching. The study recommends that teachers, especially in Biology, adopt ABI in their teaching and that policymakers organize professional development programs for teachers to improve their competency in using ABI. Additionally, providing adequate resources in schools is essential for successful implementation.

Limitations and Recommendations

The findings of this study should be interpreted in light of its inherent limitations.First, the one-group pretest–posttest design limits causal inferences, as no control group was included for comparison. Second, the relatively small sample size of 35 students constrains the generalizability of the findings. Third, although ABI improved students' conceptual understanding of meiosis, some misconceptions persisted, suggesting that ABI alone may not fully address all learning challenges. Nevertheless, as an action research study, it was designed to address immediate classroom-based problems and enhance teaching practices within the local context.

Despite these limitations, the findings highlight the potential of ABI as an effective pedagogical tool for biology education. By providing visual and dynamic representations of complex processes such as meiosis, ABI can enhance student understanding, engagement, motivation, and knowledge retention. To strengthen future research, experimental or quasi-experimental designs with control groups should be employed, and larger sample sizes across multiple classrooms or schools should be considered to improve generalizability. Moreover, integrating ABI with complementary instructional strategies, such as simulations, role-plays, and laboratory-based activities, could further enhance conceptual understanding. Longitudinal studies are recommended to examine the sustained impact of ABI on students' learning outcomes, retention, and motivation over time.

Furthermore, ABI can be extended beyond Biology to other subjects, particularly those involving abstract or complex concepts, where the use of animations, simulations, and videos can support deeper conceptual understanding and improve academic performance. The Ministry of Education and Skills Development could emphasise the adoption of 21st-century innovative pedagogies, such as ABI, to engage learners, foster motivation, and raise academic achievement. Policymakers are also encouraged to support the integration of such technologies into teaching and learning practices by providing adequate resources, training, and professional development opportunities for teachers.

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