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The effects of using animation on high school students' comprehension of chemical digestion in the human digestive system

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Abstract

This study employs a pretest–post-test quasi-experimental design to examine the effects of animation on students' comprehension of chemical digestion within the human digestive system. The sample comprised 50, Grade 10 high school students (16-17 years old), selected as intact groups, with 25 assigned to the Experimental Group and 25 to the Control Group. The Experimental Group received instruction supported by animation during the chemical digestion lesson for four weeks, whereas the Control Group was taught using conventional methods, relying solely on static diagrams and the lecture method. Quantitative data were collected through pretests and post-tests, while qualitative data were obtained from student interviews regarding their learning experiences with both instructional approaches. The findings of the ANCOVA test indicate that the use of animation significantly enhanced students' performance in answering multiple choice questions, structured questions and essay questions on chemical digestion. Moreover, students in the Experimental Group reported positive learning experiences, describing the lessons as engaging and enjoyable. These results hold important pedagogical implications, suggesting that animation is an effective instructional strategy for teaching complex biological processes such as the human digestive system.

Keywords: Animation, Comprehension, Conventional method, Experience, High school students, Human digestive system, Human health, Quality education.

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1. Introduction

Biology is a branch of science concerned with the systematic study of life and living organisms [1]. The term *biology* is derived from the Greek words *bios* (life) and *logos* (study). It encompasses a wide range of topics, including nutrition, health, reproduction, and inheritance. In Malaysian high school Biology subject consists of many topics and concepts that must be comprehended by the students. According to Koehler [2] the study of biology at the secondary school level provides several benefits, including fostering an understanding of the fundamental principles of life, encouraging scientific inquiry, promoting health literacy, and enhancing environmental awareness. Prior studies on school-based pedagogical interventions, such as the use of reading strategies to enhance comprehension in secondary schools, Naushan, et al. [3] further emphasize the importance of adopting innovative teaching approaches to improve student learning outcomes.

Biology is an essential subject, especially the topic of human digestive system [4]. It is crucial for students to have knowledge of their bodies in order to stay healthy and lead a better life. This knowledge is also beneficial for their future career paths. Students are required not only to understand the topic of the human digestive system, but they are also expected to analyze the relationship between digestive organs and nutrition, and bioprocesses, as this is an important principle in human physiology [5].

A study by Salleh, et al. [6] revealed that students experienced difficulties in learning the topics of Nutrition, Cell Division, and Chemical Composition in Cells. In contrast, teachers identified Cell Division, Respiration, and Nutrition as the three most challenging topics to teach. These discrepancies suggest that issues in the teaching and learning of these areas may significantly contribute to students' difficulties in biology. Consequently, the researchers recommended that teachers adopt effective pedagogical strategies and utilize appropriate instructional tools to support students' learning. Within this context, the human digestive system represents a particularly complex biological system, responsible for breaking down food into simpler substances that can be absorbed and used by the body for growth, cellular repair, and energy production [7]. A core component of high school biology is understanding the process of chemical digestion within this system. However, students frequently struggle to comprehend these biochemical processes, as they find it difficult to visualize and apply them to real-world contexts [4].

1.1. Problem Statement

A study by Indrajatun and Desstya [8] highlights that students frequently encounter difficulties in understanding the concept of digestive organs, which can negatively impact their learning outcomes. Traditional methods of teaching are often perceived as ineffective and monotonous by students. Consequently, it is essential to adopt more effective instructional approaches, such as the use of learning media and animations, to improve students' comprehension of the human digestive system.

Students tend to learn biology by rote memorization, resulting in monotonous learning [9]. (With animation as a teaching tool, students will mentally animate the concept, leading to a better understanding of the dynamic processes. Animation can bring complex, abstract biology concepts to life, providing insight into the events that static graphics from books cannot achieve [10].

Certain biology concepts, such as the human digestive system, cell division, plant nutrition, and the reproductive system which involve many unfamiliar terms and dynamic processes, create confusion, and hard to visualize, presenting problems when they are taught using traditional methods [6]. Biology involves learning visually about the abstract phenomena. According to a study from Reinoso-Tapia, et al. [11] learning solely from teaching materials such as books may not help students understand biological concepts easily. Students often face difficulties in understanding and visualizing the processes effectively. Some also have difficulties in grasping cellular and molecular concepts of digestion. The teachers in the research by Salleh, et al. [6] observed that students only memorize the concepts but could not grasp the concepts behind due to the overload of terminology and complex biological concepts.

The human digestive system is inherently complex, as it involves abstract concepts that describe how digestive organs function to break down food into nutrients, which are subsequently absorbed and converted into energy. Teachers often struggle to explain these processes effectively, and misconceptions among students are common [12]. (

According to Kınık [13] many students struggle to visualize chemical digestion because they are unable to observe the process directly and lack knowledge about the enzymes involved. As a result, they often fail to grasp the idea of molecules being broken down into smaller substances, since the concept remains abstract. Misconceptions in biology may also arise from cultural beliefs or prior experiences that conflict with scientific terminology and explanations, leading to misunderstandings. For instance, some students mistakenly equate respiration with breathing. Verma and Choudhuri [14] further note that biology, as a scientific discipline, can be conceptually challenging for students, which often results in rote memorization rather than genuine understanding.

Animation provides clear visual representations that help students simplify abstract ideas and understand complex biological concepts. This is supported by Valeeva, et al. [15] who found that using models such as animations enhances students' comprehension, particularly when dealing with abstract concepts and processes. Students demonstrated fewer misconceptions and a deeper understanding after viewing illustrations of molecular processes, as animation enables them to visualize phenomena that are not observable with the naked eye [16]. Compared to traditional teaching methods, studies indicate that animation-based techniques can result in higher academic performance [17].

According to Tindan and Chrisantus [18] traditional teaching without technological aids or teachers lacking pedagogical skills restricts students' engagement and understanding. Based on the results of their research, it is found that students suggest that biology should be taught using visual materials to enhance learning. Therefore, there is a critical

need to improve teaching strategies, including multimedia methods, to increase the understanding of complex biological processes, such as chemical digestion in the human digestive system.

In the context of 21st-century learning, animation has emerged as a valuable pedagogical tool for enhancing science education. It has gained prominence by transforming traditional text-based learning into dynamic and engaging learning experiences. As a form of visual aid, animation integrates both visual and auditory elements to effectively convey information, ideas, and complex concepts. Technically, it involves the display of a sequence of images on a screen or other media to create the illusion of continuous movement.

Empirical evidence supports the effectiveness of animation in science education. For instance, Fauziah, et al. [4] demonstrated that the use of animation in biology lessons significantly enhances students' comprehension of complex concepts, including those related to the human digestive system. In particular, the use of animation in teaching chemical digestion provides a complementary advantage over static graphics or media. Given that chemical digestion is a time-dependent process, animations are uniquely capable of illustrating dynamic changes over time, such as enzyme–substrate interactions [19].

The use of animation in teaching high school biology has become a widely recognized instructional practice. As a visual and auditory aid, animation enhances both teaching and learning and is increasingly adopted by high school teachers. However, Adeika, et al. [20] highlight that reliance on traditional teaching methods negatively affects students' performance and motivation to learn. Despite this, traditional approaches remain common in biology classrooms, even though psychologists have long emphasized the benefits of animation [21]. Dual Coding Theory and Sweller [22]. Cognitive Load Theory, suggest that incorporating animation into secondary biology instruction enhances comprehension and retention, particularly for complex and abstract concepts such as chemical digestion in the human digestive system. These insights underscore the importance of equipping educators with the skills to plan, design, and implement animations effectively, in line with the principles of the Dual Coding Theory of Visualization and the Cognitive Theory of Multimedia Learning [15].

Research on the use of animation in teaching high school biology in Malaysia remains limited. Therefore, this study investigates the effects of animation on students' comprehension of chemical digestion in the human digestive system. As a quasi-experimental study, it seeks to address the existing gap in the literature on the application of animation in high school biology instruction.

1.2. Research Questions

Four research questions are formulated for this study:

1. Is there a significant difference between the Experimental Group (using animation) and the Control Group (using the conventional method) in their mean score for multiple-choice questions in the post-test?
2. Is there a significant difference between the Experimental Group (using animation) and the Control Group (using the conventional method) in their mean score for structured questions in the post-test?
3. Is there a significant difference between the Experimental Group (using animation) and the Control Group (using the conventional method) in their mean score for essay questions in the post-test?
4. What are students' perceptions of using animation as a teaching tool in learning the human digestive system compared to the conventional teaching method?

2. Literature Review

Mayer [23] Cognitive Theory of Multimedia Learning (CTML) provides an important theoretical framework for this study, as it offers a scientifically grounded explanation of how individuals learn from multimedia instructional materials. CTML rests on three core assumptions: (1) learners process information through dual channels—visual and auditory; (2) each channel has a limited capacity; and (3) meaningful learning requires active cognitive processing to select, organize, and integrate information effectively. This framework informs the design of multimedia learning by emphasizing the need to minimize extraneous cognitive load, manage essential processing, and foster generative processing, thereby optimizing learning outcomes.

CTML emphasizes that meaningful learning is most likely to occur when multimedia messages are designed to support and promote active cognitive processes. Accordingly, instructional designers are encouraged to minimize extraneous cognitive load, manage intrinsic cognitive load, and foster germane cognitive load to facilitate deeper understanding and more effective learning [24].

The positive impact of animation on students' learning is evident not only in science education but also across a range of other subjects. For instance, a study by Veerasamy and Ramasamy [25] has been shown animation facilitate the learning of Tamil grammar in secondary schools. Likewise, the use of animation support the acquisition of rare English vocabulary among students [26]. Moreover, its use has also proven effective in enhancing ESL speaking skills among primary school learners [27]. A study by Nair, et al. [28] reveals that the use of multimedia and digital music technology enhances students' aural musical skills and motivation.

Nofitasari, et al. [5] developed an Android application, *My Biology App*, as a learning tool to support senior high school students' understanding of the digestive system. The app was designed to enhance comprehension, reduce misconceptions, and promote motivation and learning outcomes, particularly in addressing the abstract nature of digestive physiology and the challenges students face in visualizing unseen processes. This quasi-experimental study involved 70 students from Semarang City, Indonesia, who were divided into experimental and control groups. The experimental group used *My Biology App*, while the control group received traditional instruction. Data were collected using questionnaires to

assess learning motivation and tests to measure learning outcomes. The findings revealed that *My Biology App* significantly enhanced students' motivation and improved learning outcomes related to the digestive system compared to the control group.

Furthermore, Fauziah, et al. [4] conducted a study to examine the effects of animation media on fifth-grade students' understanding of human digestive system concepts. Based on classroom observations, the researchers noted that traditional teaching methods in science, with limited use of varied media, were insufficient for abstract and complex topics such as the digestive system. To address this gap, they introduced animation as a teaching aid. The study involved 30 students (14 males and 16 females) who completed a pre-test, engaged with an animated video on the human digestive system, and then took a post-test. The results showed a significant improvement in students' understanding, indicating that animation media positively influence conceptual learning. The study further emphasized the importance of using animations and visual aids in biology to help students visualize abstract processes, reduce learning difficulties, and enhance motivation and knowledge retention. Nair, et al. [29] also reinforce the relevance of digital technology to enhance students' learning.

Similarly, Reza and Tambunan [30] conducted a study in Indonesia to examine the influence of an animated video on the human digestive system, developed using the Animaker application, on high school students' performance. The study employed questionnaires to evaluate the viability and effectiveness of the animated video, which was also validated by experts, including subject matter specialists, biology teachers, students, and media experts. The findings indicated that the animated video was an effective teaching tool for enhancing student engagement, enjoyment, and understanding, particularly when addressing complex topics such as the human digestive system in biology education.

Likewise, a study conducted by Alzahrani [31] in Saudi Arabia demonstrated the positive effects of using animation as a learning tool among 110 applied medical sciences students. Participants were randomly assigned to either an animation group or a traditional lecture group and were evaluated through quizzes administered immediately after instruction to assess cognitive skills and knowledge retention. The results revealed that the animation group outperformed the traditional lecture group, with a passing rate of 80% and above compared to 60% and below, respectively. This performance advantage was consistent across academic levels from the second to the fourth year. Notably, fourth-year students achieved the greatest gains in cognitive performance compared to other levels. Overall, the study provided strong evidence that animation can significantly enhance the learning outcomes of applied medical sciences students, particularly in mastering complex cognitive tasks.

Many researchers, such as Lazaris [32] have highlighted the lack of studies exploring the use of animations to enhance visualization skills. The present quasi-experimental research seeks to address this gap by examining how animation can improve students' cognitive abilities, particularly in understanding the process of chemical digestion. In addition, this study investigates how animation influences high school students' comprehension of chemical digestion in the human digestive system and explores their perceptions of using animation as a teaching tool in biology learning.

3. Research Methodology

3.1. Research Design

This study employed a quasi-experimental design using quantitative and qualitative data. Quantitative data are used to investigate the effects of animation on students' performance in answering multiple-choice questions, structured questions and essay questions related to chemical digestion in the human digestive system. The qualitative data are used to explore how animation helps the students in comprehending chemical digestion in the human and students' perception of using animation as a learning tool. According to Creswell and Creswell [33] a quasi-experimental design seeks to establish cause and effect between an independent and dependent variable by collecting and statistically analyzing numerical data. While the research itself is quantitative, it may be integrated with qualitative methods in a mixed-methods approach to provide a more comprehensive understanding of the phenomenon being studied.

The sample comprised 50 Grade 10 high school students (24 males and 26 females), aged between 16 and 17, from an international school in Selangor in 2025. This school was purposefully selected because its students had not previously been exposed to animations in learning about chemical digestion in the human digestive system. Most teachers in the school continued to employ conventional teaching methods, making the setting suitable for the study.

The participants were selected as intact groups from two existing classes, as random sampling was not permitted due to potential disruptions to the school timetable. Both groups demonstrated comparable levels of achievement in biology, as indicated by their mid-term examination results. Each group consisted of 25 students. The first group was designated as the Experimental Group, which received instruction on chemical digestion in the human digestive system using animation, while the second group, the Control Group, was taught the same topic using conventional teaching methods.

3.2. Instruments

Two types of instruments were employed in this study: (a) a pre-test and post-test, and (b) four open-ended interview questions for students. The pre-test and post-test were parallel in content and were designed to measure students' conceptual understanding of chemical digestion in the human digestive system. Each test consisted of 10 multiple-choice questions, 5 structured questions, and 1 essay question. The second instrument comprised of four open-ended interview questions, which were designed to capture students' perceptions of learning chemical digestion through different instructional approaches.

To establish content validity, the test items were reviewed by two subject matter experts in biology and one expert in science education, who evaluated the questions for alignment with the learning objectives and curriculum standards.

Minor revisions were made based on their feedback. A pilot test was then conducted with a group of students of similar background to ensure clarity, appropriateness of difficulty level, and timing. The interview questions were also reviewed by experts for clarity and relevance. A pilot interview was also conducted to ensure sufficient qualitative data were collected to answer Research Question 3 and 4.

3.3. Procedures

Before the intervention, both groups were given a pre-test, and after the intervention for four weeks, a post-test was administered to gauge the effectiveness of using animation on students’ performance in answering questions related to chemical digestion in the human digestive system.

Following that, 10 students (5 from the Experimental Group and another 5 from the Control Group) were randomly selected for the focus-group interview. The questions asked in the interview are open-ended, with the objective to encourage the students to reflect and explore various aspects, such as cognitive and affective in learning chemical digestion with animation, which aligns with this research goals and answering Research Question 4

3.4. Data Analysis

The quantitative data from the pre-test and post-test were analyzed using the SPSS program for Windows. An ANCOVA test was employed to address Research Questions 1–3, with the pre-test scores used as a covariate to control for differences between the Experimental and Control Groups prior to the intervention. The students’ interviews were audio-recorded and transcribed verbatim. The transcripts were read multiple times to ensure familiarity with the data. An inductive thematic analysis was then carried out, beginning with open coding to identify recurring words and concepts. Codes were subsequently organized into broader categories and refined into emerging themes. To enhance the trustworthiness of the analysis, peer debriefing was conducted, and coding consistency was cross-checked by multiple researchers.

3.5. Ethical Issues

Informed consent was obtained from both parents and students prior to the commencement of the study, and the school administration granted ethical approval. Additionally, informed consent was secured from the teachers, who voluntarily agreed to participate. The study was carefully designed and rigorously reviewed to ensure that no undue burden was placed on participants. All participants were treated equitably, irrespective of their background or academic performance.

4. Findings

Is there a significant difference between the Experimental Group (using animation) and the Control Group (using the conventional method) in their mean score for multiple-choice questions in the post-test?

Table 1.
Comparing the Mean of the Control Group and The Experimental Group for Multiple Choice Questions in The Pre-Test and Post-Test.

Group		Pre-test	Post-test
Control Group	Mean	4.07	4.16
	N	25	25
	SD	0.66	0.55
Experimental Group	Mean	4.08	4.56
	N	25	25
	SD	0.57	.51

Findings in Table 1 show that there is not much difference in the mean score of the Control Group (M=4.07, SD=.66) and the Experimental Group (M=4.08, SD=.57) for Multiple Choice Questions in the pre-test. After the intervention, the Experimental Group (M=4.56, SD=.51) outperformed the Control Group (M=4.16, SD=.55).

Table 2.
Results of the ANCOVA test for the Multiple Choice Questions.

Dependent Variable: PostMCQ					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	7.348 ^a	2	3.674	21.131	0.000
Intercept	4.667	1	4.667	26.841	0.000
PreMCQ	5.348	1	5.348	30.760	0.000
Group	2.905	1	2.905	16.709	0.000
Error	8.172	47	0.174		
Total	966.000	50			
Corrected Total	15.520	49			

Note: The level of significance is at p<0.05.

Findings presented in Table 2 reveal that the Experimental Group scored significantly higher than the Control Group on multiple-choice questions following instruction with animation ($F = 16.71, df = 1, p < .000$). These results suggest that the use of animation enhanced students' understanding of chemical digestion in the human digestive system. Accordingly, Research Question 1 is addressed.

- Is there a significant difference between the Experimental Group (using animation) and the Control Group (using the conventional method) in their mean score for structured questions in the post-test?

Table 3.

Comparing the Mean of the Control Group and The Experimental Group for Structured Questions in The Pre-Test and Post-Test .

Group		Pre-test	Post-test
Control Group	Mean	4.32	4.44
	N	25	25
	SD	0.63	0.58
Experimental Group	Mean	4.60	4.96
	N	25	25
	SD	0.50	0.20

Results in Table 3 indicate that there is not much difference in mean score of the Control Group ($M=4.32, SD=.63$) and the Experimental Group ($M=4.60, SD=.50$) for Structured Questions in the pre-test. After the Experimental Group was taught using animation, the mean score was significantly higher ($M = 4.96, SD = .20$) than that of the Control Group ($M = 4.44, SD = .58$).

Table 4.

Results of the ANCOVA test for the Structured Questions in the Post-Test.

Tests of Between-Subjects Effects

Dependent Variable: PostSTRC

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	5.051 ^a	2	2.526	15.937	0.000
Intercept	7.987	1	7.987	50.398	0.000
PreSTRC	1.671	1	1.671	10.546	0.002
Group	2.152	1	2.152	13.578	0.001
Error	7.449	47	.158		
Total	1117.000	50			
Corrected Total	12.500	49			

Note: The level of significance is at $p < 0.05$.

The results of the ANCOVA test presented in Table 4 demonstrate that students in the Experimental Group outperformed their counterparts in the Control Group on structured questions related to the human digestive system ($F = 13.58, df = 1, p = .001$). This outcome is attributed to the use of animation, which actively engaged students in the learning process and supported them in constructing knowledge related to conceptual understanding and the complexity of chemical digestion. These findings provide an answer to Research Question 2.

- Is there a significant difference between the Experimental Group (using animation) and the Control Group (using the conventional method) in their mean score for essay questions in the post-test?

Table 5.

Comparing the Mean of the Control Group and The Experimental Group for Essay Question in the Pre-Test and Post-Test

Group		Pre-test	Post-test
Control Group	Mean	10.28	10.32
	N	25	25
	SD	1.31	1.35
Experimental Group	Mean	10.84	12.88
	N	25	1.20
	SD	0.69	0.20

Findings in Table 5 indicate that there is not much difference in the mean score of the Control Group ($M=10.28, SD=1.31$) and the Experimental Group ($M=10.84, SD=.69$) for the Essay Question in the pre-test. After the Experimental Group was taught using animation, the students' mean score is much higher ($M=12.88, SD=1.20$) than that of the Control Group ($M=10.32, SD=1.35$).

Table 6.

Results of the ANCOVA test for the Structured Questions in the Post-Test.

Tests of Between-Subjects Effects

Dependent Variable: PostEssay

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	111.365 ^a	2	55.683	53.811	0.000
Intercept	6.318	1	6.318	6.106	0.017
PreEssay	29.445	1	29.445	28.455	0.000
Group	53.271	1	53.271	51.480	0.000
Error	48.635	47	1.035		
Total	6888.000	50			
Corrected Total	160.000	49			

Note: The level of significance is at p<0.05.

Results of the ANCOVA test presented in Table 6 reveal that, following the use of animation, the Experimental Group performed significantly better in answering the essay question than the Control Group, who were taught using conventional methods such as static diagrams and lectures (F = 51.48, df = 1, p < .000). The use of animation enabled students in the Experimental Group to visualize better chemical digestion in the human digestive system, including enzyme activity in carbohydrate digestion, nutrient absorption, and the processes involved in addressing related misconceptions. These findings answer Research Question 3.

- What are students’ perceptions of students learning the human digestive using animation compared to conventional teaching method?

Table 6.

Perception of the Control Group

Emerging Themes	Quotes from students
Lack of understanding	“Actually I don’t really understand the processes in chemical digestion, it seems too complicated and too many steps to remember.” (P1, Male) “ This topic is difficult for me” (P5, Female) “Very difficult.” (P3, Female)
Less engagement	“I didn’t pay much attention to the lesson because I don’t understand” (P2, Female) “ When the teacher asks, I cannot answer the questions.” (P1, Male)
Low confidence	“I don’t have the confidence to explain to my classmate about chemical digestion because I’m unsure of some parts.” (P5, Female) “ I am not not sure of what I am learning (P4, Male)
Ineffectiveness in learning	“I just memorize from the textbooks, this topic is too confusing for me” (P3, Female) “ I also learn by memorizing” (P2, Female)
Fail to sustain students’ attention	“I feel like I want to give up learning this topic, there are too many names of enzymes.” (P4, Male) “ The lesson is boring.” (P1, Male) “ I cannot follow.” (P3, Female)

Note: P= Participant.

Based on the summary of interviews with five randomly selected high school students from the Control Group (i.e., those not exposed to animation), findings indicate a lack of understanding and evidence of cognitive overload. Participant 1 reported that the chemical digestion process was “too complicated” and involved “too many steps to remember.” Similarly, Participants 3 and 5 described the topic as difficult, suggesting that cognitive overload hindered their ability to fully grasp the concept.

Participant 2 came out with the statement that she couldn’t pay much attention to the lesson because she doesn’t understand and Participant 1 said that he couldn’t answer the questions asked by the the teacher which indicate that that they did not pay much attention to the lesson as they don’t understand which reflects that teaching directly from textbooks leads to confusion, causing disengagement. When they cannot understand the concept learnt, focus declines, which can impede their learning.

Participant 5 stated that she did not feel confident explaining the topic to her classmates, while Participant 4 reported uncertainty about his own learning. These responses indicate that low confidence stemmed from a lack of understanding of the subject matter. Furthermore, Participants 2 and 3 reported relying on memorization rather than conceptual understanding, suggesting that their learning was largely ineffective.

Participant 4 expressed feeling like giving up on learning the topic because of the numerous enzyme names involved. Participant 1 reported finding the lesson boring, while Participant 3 stated that she was unable to follow the lesson. These responses suggest that conventional teaching methods failed to sustain students’ attention.

Interviews with five randomly selected high school students from the Control Group (those not exposed to animation) revealed several recurring themes: lack of understanding, less engagement, low confidence, ineffective learning ,and fail to sustain students’ attention.

Table 7.

Perception of the Experimental Group.

Emerging Themes	Quotes from The Students
Positive experience	"I never thought learning through animation can be so fun, this is my first time I learn using animation." (P6, Male) "I like to learn biology using animation." "(P8, Female) " Using animation is enjoyable, I can understand better" (P10, Male)
Better understanding	"I can now remember the steps better and the names of the enzymes are not so confusing to me" (P7, Male) " I understand better "(Experimental, P8, Female) " It is clear and easy to understand. (P9 Female)
More engaging	"I can grasp the idea better than just reading from books" (P6, Male) "I love learning using animation, because I can understand better how enzymes work in our body, I can visualize how enzymes work" (P9, Female)
Interesting and motivating	"I prefer to learn chemical digestion using animation, because more interesting " (P10, Male) " The lesson is very motivating for me" (P8, Female)
High confidence in learning	" Now I am confident in learning this topic" "(P8, Female) " I can answer the questions and explain to the teacher" (P7, Male) " I can do a presentation in class now on this topic" (P6 Male)

Note: P=Participant.

In contrast, students in the Experimental Group (those exposed to animation) reported positive experiences during the interview session. Participant 6 remarked that he had not anticipated that learning through animation would be enjoyable. Participant 8 indicated that she preferred learning biology with the support of animation, while Participant 10 observed that animation made learning more enjoyable and facilitated his understanding.

In addition, students expressed that their understanding improved when the teacher employed animation in instruction. Participant 7 stated that he could recall the steps more effectively and found the names of the enzymes less confusing. Participant 8 also reported that animation enhanced her comprehension, while Participant 9 noted that the material became clearer and easier for her to understand.

Participant 6 commented that animation enabled him to grasp concepts more effectively than by reading from textbooks alone. Participant 9 added that she enjoyed learning through animation, as it allowed her to better understand and visualize how enzymes function in the human body. These remarks suggest that students are more engaged when animation is incorporated into teaching chemical digestion in the human digestive system.

Furthermore, the use of animation made the lessons more interesting and motivating. Participant 10 stated that he preferred learning about chemical digestion through animation because it was more engaging and interesting. Similarly, Participant 8 indicated that she preferred learning the topic with animation, as she found the lessons highly motivating.

Learning through animation also enhanced students' confidence in learning. Participant 8 emphasized that she felt confident in understanding the topic. Participant 7 reported that he was able to answer questions and explain the content to the teacher, while Participant 6 commented that he could deliver a classroom presentation on chemical digestion in the human digestive system.

Learning through animation was found to provide positive experiences to students, and enhance students' understanding. Students also had better engagement with the subject matter. Several participants also reported that animation not only supported their comprehension but also increased their motivation and confidence in learning.

5. Discussion

Findings from quantitative data show that students exposed to animation performed significantly better on multiple-choice, structured, and essay questions. Students in the Experimental Group outperformed those in the Control Group, as the animated video proved to be an effective instructional tool for enhancing engagement, enjoyment, and understanding, particularly when addressing complex topics such as the human digestive system [30, 31]. Moreover, the use of animation was found to influence students' conceptual learning positively. Participants in the Experimental Group reported that animation enabled them to visualize abstract processes, such as the functioning of enzymes in digestion. Consistent with prior research, animation was shown to enhance students' cognitive abilities, facilitate learning, and reduce learning difficulties [32]. Findings of the present study are also parallel to the study by Werner [19] and O'Connor, et al. [34] who stressed that animations are capable of illustrating dynamic changes over time, such as enzyme-substrate interactions in the digestive system.

As emphasized by Fauziah, et al. [4] conventional teaching methods in biology often rely on limited media and are insufficient for conveying complex topics such as the digestive system. The use of static diagrams and lecture-based approaches, which depend heavily on textbooks, tend to make lessons monotonous and less effective. Students in the Control Group also reported that they found the digestive system difficult and confusing, as they struggled to comprehend abstract content and were unable to visualize the underlying chemical reactions [11]. Furthermore, findings by Kınık [13] similarly indicate that students often struggle to visualize chemical digestion because they cannot directly observe the process. Lack sufficient knowledge also leads to misconceptions among students in the Control Group [12].

The qualitative findings from student interviews reinforced the quantitative results, highlighting the effectiveness of animation in supporting learning outcomes. Students in the Experimental Group consistently described animation as a valuable tool for making complex biological processes, such as chemical digestion, more comprehensible and less cognitively demanding, aligning with Valeeva, et al. [15] who emphasized its role in reducing cognitive overload. Beyond improved comprehension, animation also fostered positive learning experiences and deeper conceptual understanding, echoing the observations of Rashid, et al. [17]. Consistent with Reza and Tambunan [30] students in this study reported higher levels of engagement compared to those taught using conventional teaching methods. Moreover, the use of animation not only enhanced comprehension but also strengthened motivation and confidence, reflecting similar findings by Fauziah, et al. [4]. Taken together, these results suggest that animation serves as both a cognitive and affective support in learning biology, bridging gaps left by conventional instruction and enabling students to engage more actively and meaningfully with abstract scientific content.

On the other hand, students in the Control Group, who were taught exclusively through conventional methods, experienced significant difficulties in understanding the subject matter, as highlighted by Salleh, et al. [6]. Tindan and Chrisantus [18] opined that students' struggles were compounded by limited engagement, which often led them to rely on rote memorization rather than meaningful understanding, consistent with the findings of Verma and Choudhuri [14]. Similarly, Indrajatun and Desstya [8] reported that students encountered challenges in comprehending the functions of digestive organs when instruction relied on traditional teaching methods. These difficulties ultimately contributed to low confidence, ineffective learning, and reduced attention span, further reinforcing the conclusions of Lazaris [32].

In terms of theoretical implications, this study demonstrates that the use of animation significantly enhances high school students' comprehension of chemical digestion. This finding aligns with Mayer [23] and Mayer [24] (Cognitive Theory of Multimedia Learning (CTML)), which posits that learning is more effective when visual and verbal information are combined, thereby fostering deeper understanding.

The study also carries important pedagogical implications. Specifically, it suggests that animation is a highly effective instructional tool for teaching chemical digestion in the human digestive system. By enabling students to visualize complex biological processes, animation not only supports the development of essential visualization skills in biology but also makes learning more engaging and enjoyable. As noted by O'Connor, et al. [34] such approaches can transform the learning experience, particularly when dealing with abstract or intricate scientific concepts.

The qualitative data collected through interviews and observations yielded positive feedback from students who were exposed to animation-based learning. Students reported that animation made the learning process more enjoyable and engaging, which, in turn, fostered greater interest in science education. Moreover, the use of animation encouraged active participation in classroom discussions, thereby promoting a deeper understanding of the topics studied. These findings highlight how animation addresses many of the obstacles and challenges associated with traditional teaching methods.

In particular, animation serves as a valuable alternative to hands-on experimentation for certain biological processes. For example, conducting a practical experiment on chemical digestion in the human digestive system is not feasible, as these processes occur internally within the body. In such contexts, animation provides a safe, time-efficient, and cost-effective means of demonstrating otherwise inaccessible phenomena. By doing so, it equips educators with a powerful tool for delivering comprehensive and conceptually rich content that would otherwise be difficult to teach effectively.

In terms of practical implications, this study further confirmed that animation can be incorporated into teaching biology processes that require high visualization and critical thinking skills in high school students, as argued by Mnguni and Moyo [35]. Curriculum developers and educational policymakers can consider training teachers and trainee teachers on how to adopt animation as teaching tools for teaching biology to further enhance students' learning outcomes. However, further research is needed to investigate methods of implementing animation in teaching complex biological processes like chemical digestion. The Ministry of Education may need to invest a substantial amount of money in implementing animation in biology and providing teachers' training on the use of animated video. Providing equitable learning opportunities to all areas across a nation is important to ensure this teaching tool can benefit and cater to all students across the nation.

6. Conclusion

Results from the post-test revealed that students from the Experimental Group who were taught using animation performed significantly better in answering the multiple choice questions, structured questions and essay question on chemical digestion in the human digestive system than their counterparts who were taught using the conventional method. The data collected from the qualitative approach (interviews and observations) yielded positive feedback from students exposed to animation. They found that learning using animation makes learning more enjoyable and engaging, which can foster greater interest in learning science education.

Students exposed to animation are more likely to participate actively in discussion in the class, thus developing a deeper understanding of the topic learnt. These findings also address the obstacles and challenges found in traditional teaching methods. Animation serves as an alternative to replace hands-on experiments, as seen in the topic studied. It is impossible to conduct a hands-on experiment on chemical digestion in the human digestive system; processes happen inside the body. In this regard, animation serves as a safe, time-efficient, and cost-effective tool for demonstrating otherwise inaccessible biological processes. This approach enables educators to deliver complex content more comprehensively and engagingly.

This study has several limitations that should be acknowledged. First, the sample size was relatively small, consisting of only 50 high school students. Future research should therefore employ a larger sample to enhance the generalizability

of the findings. Second, the study period was limited to four weeks. Extending the intervention to a longer duration (e.g., 8–10 weeks) may yield more robust and reliable results. Third, the study focused exclusively on the topic of chemical digestion in the human digestive system, while other areas of biology were not explored. Future studies should investigate the effectiveness of animation in teaching additional biological topics such as genetic engineering, the reproductive system, and the excretory system; thereby broadening the scope of evidence for animation as an effective learning tool in high school biology.

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