Education

Availability of digital simulation resources for teaching abstract biology concepts in public secondary schools in Baringo North Sub-County, Kenya

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Abstract

Despite the growing integration of digital technologies in education, inadequate access to appropriate digital resources may constrain the teaching of abstract Biology concepts involving processes that are difficult to observe directly. This study investigated the availability of digital simulation resources for teaching abstract Biology concepts in public secondary schools. The study adopted a descriptive survey research design. The target population comprised 50 teachers of Biology and 5,894 Form Three learners in public secondary schools in Baringo North Sub-County, Kenya. A sample of 45 Biology teachers and 350 Form Three learners participated in the study. Data were collected using a teachers' questionnaire and an observation checklist. Quantitative data were analyzed using SPSS Version 27. Descriptive statistics, including frequencies, percentages, means and standard deviations, were used to summarize the data, while a one-sample chi-square goodness-of-fit test determined whether observed availability differed significantly from the expected 50.0% distribution. The findings indicated that digital simulation resources were moderately available, with 60.0% of the observed resource indicators available. This proportion was significantly higher than the expected 50.0%, $\chi^2(1) = 36.00$, $p < .001$. However, important gaps persisted in Biology-specific simulation software, curriculum-aligned digital content, adequate computers, learner access, backup power, ICT technical support and classroom utilization of digital simulations. The study concluded that effective integration requires more than basic ICT infrastructure and recommends strengthening access to functional devices, curriculum-aligned simulations, technical support, reliable power and continuous teacher training to promote equitable and sustained use of digital simulations in teaching abstract Biology concepts.

Keywords: Abstract Biology concepts, Biology education, Digital resources, Digital simulations, Secondary schools

1. Introduction

Globally, digital simulation-based instruction has increasingly been recognized as an effective approach for improving the teaching and learning of complex biology concepts. In America [4], found that digital simulations improved high school students' understanding of complex biology concepts, test performance, engagement and interest compared with traditional instruction. Similarly [25], reported that simulations enhanced learning in under-resourced public schools, although inadequate infrastructure and limited teacher training constrained their effectiveness [3]. Further established that simulation-based collaborative learning strengthened students' critical thinking, problem-solving, communication and teamwork skills.

In Britain, [5] reported that digital simulations enhanced students' understanding of complex biological processes, although disparities in technological resources and teacher training resulted in unequal implementation [13]. Found that simulations improved conceptual understanding by enabling students to visualize and manipulate biological processes, but emphasized the importance of quality digital content and adequate teacher support. Similarly [24], identified inadequate technological resources and limited professional development as major barriers to the effective implementation of simulation-based instruction.

In Asia [12], found that digital simulations improved students' understanding and retention of abstract biology concepts by enabling them to visualize and manipulate biological systems. In China [14], reported improved biology achievement and student engagement among learners who used virtual laboratories and simulations [28]. Similarly found that digital simulations enhanced students' ability to apply biological concepts, develop problem-solving skills and establish connections between theoretical knowledge and practical learning.

In Africa [1], found that digital simulations improved students' understanding of complex biology concepts in Nigerian schools, although rural schools experienced challenges related to limited technological resources and teacher-training opportunities. In Ethiopia [26], reported that inadequate resources, limited technical support and insufficient teacher training constrained implementation, particularly in rural schools [17]. Further established that simulations effectively illustrated abstract biological concepts and promoted interactive learning. In Uganda [8], found that schools using digital simulations recorded improved student engagement and comprehension, although adoption remained uneven.

In Kenya [19], found that the use of digital simulations improved students' understanding of complex biological processes, although implementation varied according to school infrastructure and resource availability [22]. Similarly reported improved understanding of difficult biology concepts through interactive visualization, while emphasizing the importance of teachers' technological competence and effective integration of simulations into lessons.

According to [11], limited funding, inadequate teacher training and inconsistent digital infrastructure remain major barriers to the adoption of digital simulations. These findings highlighted the potential of simulation-based instruction to improve biology learning while demonstrating that its effectiveness depends on adequate infrastructure, teacher preparedness, appropriate digital content and institutional support.

Therefore, the current study sought to assess the availability of digital simulation resources for teaching abstract Biology concepts in public secondary schools in Baringo North Sub-County, Kenya, as a basis for identifying existing resource gaps, informing strategies for effective integration of digital simulations, strengthening teachers' capacity to use technology-supported instructional approaches, and promoting equitable and sustained teaching and learning of abstract Biology concepts.

2. Materials and Methods

2.1 Research design

The study adopted a descriptive survey design to assess the availability of digital simulation resources and challenges faced by teachers of Biology.

2.2 Study area

The study was conducted in Baringo North Sub-County, one of the seven sub-counties in Baringo County, Kenya. Administratively, it comprises four divisions, five wards, 14 locations, 44 sub-locations and 355 villages. The sub-county covers 1,703.50 km², with an altitude of 1,000-2,200 m above sea level, a population of 104,871 and 23,500 households [2, 10]. The main livelihoods are agro-pastoralism, pastoralism, irrigated and mixed farming. Temperatures range from 15-32°C, with bimodal rainfall occurring mainly in March-June and September-November. Soils are predominantly sandy clay loam with alluvial deposits, while land is communally or individually owned. Economic activities mainly comprise farming and Jua kali enterprises, with limited industrial development and poor feeder-road connectivity.

2.3 Target population

The target population of this study was forming three students of biology in public secondary schools since the school's showed homogeneity in infrastructure depending on the school category. The Sub-County has form three student population of 5, 894 and 50 teachers of Biology. In the sub county, there are four Extra County and three county schools that have computers that learners can use for learning (Table 1). Therefore, form three students in these schools constituted the accessible population. Most schools do subject selection in form three which is affected by student's interest and academic achievement [6] hence the choice of form three students.

Table 1: Target population

School Type	Target Population		
	Number	Teachers of Biology	Students
Extra county	4	28	3480
County	3	22	2414
Totals	7	50	5,894

2.4 Sample size and sampling procedures

2.4.1 Sample size

For learner population, a sample size of 361 while 50 teachers of Biology were utilized for the study. The sample size for learner population was derived using Krejcie and Morgan's table for determining the sample size. Therefore, the entire study sample size was 411 respondents as shown in Table 2.

Table 2: Sampling frame

School Type	Sample Population		
	No. of Schools	Teacher	Students
Extra county	4	28	213 (59.0%)
County	3	22	148 (41.0%)
Totals	7	50	361

2.4.2 Sampling procedures

Sampling denotes a method of choosing a variety of people or items from a definite population in order to guarantee that the chosen cluster encompasses part representation of the physiognomies constituted within the whole cluster [18].

2.4.2.1 Sampling of schools

The sampling frame comprised all public secondary schools in Baringo North Sub-County. The researcher used purposive sampling to select seven (7) secondary schools that will participate in the study. The schools were selected based on similar characteristics such as availability of learning resources (for example computers), comparable entry behavior, relatively similar academic performance trends in the Kenya Certificate of Secondary Education (K.C.S.E.), and students drawn from varied socio-economic backgrounds. The selected schools included four Extra-County schools and three County schools, as indicated in Table 2. These schools formed the study sites from which teachers and learners were sampled.

2.4.2.2 Sampling of teachers

The study used purposive sampling to select teachers of Biology from the sampled secondary schools. All teachers handling Biology in the selected schools were identified with the assistance of the school administration. A total of fifty (50) teachers of Biology were included in the study. Since Biology teachers possess specific subject knowledge relevant to the study, purposive sampling was appropriate to ensure that only those directly involved in teaching Biology participated. Where a school has more than the required number of Biology teachers, proportionate allocation will be applied to ensure fair representation across the seven schools.

2.4.2.3 Sampling of learners

Learners were proportionately sampled from the seven selected secondary schools and Form Three classes to obtain the required sample of 361 respondents. Within each school, simple random sampling was used to select participating streams and learners. Learners picked folded papers marked “Yes” or “No” from a container after thorough mixing, with the number of “Yes” papers corresponding to the required sample. Those who selected “Yes” constituted the sample. The procedure was repeated across the sampled schools until all 361 respondents were obtained.

2.5 Research instruments

The study used questionnaire to measure availability of digital simulation resources, frequency of use, competence/training and also perceived challenges. Additionally, an observation schedule was also used to obtain data on availability of the digital-simulation resources.

2.6 Data collection

The researcher visited the sampled schools to assess the availability of digital simulation resources for Biology instruction. Using a digital simulation resource checklist, the researcher physically verified and recorded the availability of computers, tablets, projectors, internet connectivity, simulation software and other relevant devices. Teachers’ questionnaires were also administered to obtain information on resource accessibility and usability. Completed instruments were checked, coded and entered into SPSS Version 27 for analysis.

2.7 Data analysis

Collected data were analysed using descriptive statistics (frequencies and percentages), to summarize the availability of digital simulation resources. A one-sample chi-square goodness-of-fit test was used to determine whether the observed responses differed significantly from the expected distribution at the 5% significance level ($\alpha = 0.05$). The resources assessed included simulation software, computers, projectors, internet connectivity, electricity, ICT laboratories, technical support, and digital Biology content.

3. Results

3.1 Learners’ responses on availability of digital simulation resources for teaching abstract biology concepts in public secondary schools

The findings indicate generally positive but varied perceptions of digital simulation resources (Table 3). Overall, 59.7% of learners reported resource availability, 60.0% perceived teachers as adequately trained, and 52.8% had sufficient access to technological devices. The highest rating (68.0%) concerned simulations’ contribution to understanding complex transport concepts, while technical support and infrastructure received the lowest rating (50.0%). Administrative support was moderately positive at 55.7%.

Table 3: Learners’ responses on availability of digital simulation resources for teaching abstract biology concepts in public secondary schools

Statement	Strongly agree		Agree		Neutral		Disagree		Strongly disagree		Totals	
	Freq	Perc	Freq	Perc	Freq	Perc	Freq	Perc	Freq	Perc	Freq	Perc
Digital simulation resources (such as virtual labs and animations) are readily available for teaching abstract biology concepts related to transport in plants and animals.	85	24.3	124	35.4	74	21.1	46	13.1	21	6.0	350	100
Biology teachers in our school are trained and proficient in using digital simulation resources to teach topics related to the transport system, such as blood circulation, heart function, and translocation in plants.	79	22.6	131	37.4	71	20.3	49	14.0	20	5.7	350	100
Students have adequate access to the necessary technological devices (computers, tablets, projectors) to effectively interact with digital simulations of the human circulatory system and plant transport systems.	68	19.4	117	33.4	87	24.9	55	15.7	23	6.6	350	100
The use of digital simulation resources has significantly improved students' understanding of complex concepts in the transport system, including blood flow, double circulation, transpiration stream, and xylem-phloem transport.	102	29.1	136	38.9	56	16.0	38	10.9	18	5.1	350	100
There is sufficient technical support and infrastructure (e.g., reliable internet connection and electricity supply) to effectively use digital simulation tools when teaching the transport system in biology.	62	17.7	113	32.3	91	26.0	61	17.4	23	6.6	350	100
The school administration prioritizes the integration of digital resources in teaching the transport system, including the purchase, updating, and maintenance of relevant digital tools and simulation software.	74	21.1	121	34.6	82	23.4	50	14.3	23	6.6	350	100

Source: Researcher, (2026)

3.2 Chi-square test of learners’ responses

A one-sample chi-square goodness-of-fit test was conducted to determine whether the observed response distributions differed significantly from an equal distribution across the five response categories. As presented in Table 4, statistically significant differences were obtained for all six statements: availability of digital simulation resources, $\chi^2(4) = 87.629$, $p < .001$; teacher competence, $\chi^2(4) = 96.343$, $p < .001$; access to technological devices, $\chi^2(4) = 70.514$, $p < .001$; improved understanding of complex transport-system concepts, $\chi^2(4) = 132.914$, $p < .001$; technical support and infrastructure, $\chi^2(4) = 66.343$, $p < .001$; and administrative prioritization, $\chi^2(4) = 76.714$, $p < .001$.

The null hypothesis of an equal distribution of responses was therefore rejected for all six statements. The significant results indicate that learners' responses were not evenly distributed across the five response categories. However, the chi-square results should be interpreted together with the descriptive percentages because statistical significance alone does not establish that a resource was adequate. For example, technical support and infrastructure had a significant response distribution despite only 50.0% of learners expressing agreement.

Table 4: Chi-square goodness-of-fit test of learners' responses on availability of digital simulation resources

Statement	χ^2	Df	*p*-value	Decision
Digital simulation resources such as virtual laboratories and animations are readily available for teaching abstract biology concepts related to transport in plants and animals.	87.629	4	<.001	Reject H_0
Biology teachers are trained and proficient in using digital simulation resources to teach topics related to the transport system.	96.343	4	<.001	Reject H_0
Students have adequate access to technological devices such as computers, tablets and projectors to interact with digital simulations.	70.514	4	<.001	Reject H_0
Use of digital simulation resources has significantly improved students' understanding of complex transport-system concepts.	132.91	4	<.001	Reject H_0
There are sufficient technical support and infrastructure, including reliable internet connectivity and electricity, to use digital simulation tools.	66.343	4	<.001	Reject H_0
School administration prioritizes integration, updating and maintenance of digital resources and simulation software.	76.714	4	<.001	Reject H_0

Source: Researcher, (2026)

3.3 Teachers' responses on availability of digital simulation resources for teaching abstract biology concepts in public secondary schools

The findings indicate that 66.7% of teachers strongly agreed or agreed that digital simulation resources such as virtual laboratories and animations were readily available (Table 5). In addition, 60.0% reported that Biology teachers were trained and proficient in using digital simulations. However, only 53.4% indicated that students had adequate access to technological devices. The perceived contribution of digital simulations to learners' understanding of complex transport-system concepts received the highest positive response, with 75.5% of teachers strongly agreeing or agreeing. Technical support and infrastructure received a comparatively lower positive response, with 53.3% of teachers agreeing or strongly agreeing that adequate support, internet connectivity and electricity were available. Administrative prioritization was reported by 60.0% of teachers.

Table 5: Teachers' responses on availability of digital simulation resources for teaching abstract biology concepts in public secondary schools

Statement	Strongly agree		Agree		Neutral		Disagree		Strongly disagree		Totals	
	Freq	Perc	Freq	Perc	Freq	Perc	Freq	Perc	Freq	Perc	Freq	Perc
Digital simulation resources (such as virtual labs and animations) are readily available for teaching abstract biology concepts related to transport in plants and animals.	12	26.7	18	40.0	7	20.0	4	8.9	2	4.4	45	100
Biology teachers in our school are trained and proficient in using digital simulation resources to teach topics related to the transport system, such as blood circulation, heart function, and translocation in plants.	10	22.2	17	37.8	11	24.4	5	11.1	2	4.4	45	100
Students have adequate access to the necessary technological devices (computers, tablets, projectors) to effectively interact with digital simulations of the human circulatory system and plant transport systems.	8	17.8	16	35.6	13	28.9	6	13.3	2	4.4	45	100
The use of digital simulation resources has significantly improved students' understanding of complex concepts in the transport system, including blood flow, double circulation, transpiration stream, and xylem-phloem transport.	15	33.3	19	42.2	7	15.6	2	4.4	2	4.4	45	100
There is sufficient technical support and infrastructure (e.g., reliable internet connection and electricity supply) to effectively use digital simulation tools when teaching the transport system in biology.	9	20.0	15	33.3	12	26.7	6	13.3	3	6.7	45	100
The school administration prioritizes the integration of digital resources in teaching the transport system, including the purchase, updating, and maintenance of relevant digital tools and simulation software.	11	24.4	16	35.6	10	22.2	5	11.1	3	6.7	45	100

Source: Researcher, (2026)

3.4 Chi-square test of teachers' responses

The one-sample chi-square goodness-of-fit test showed statistically significant differences in teachers' responses across all six statements (Table 6). The results were $\chi^2(4) = 18.667$, $p < .001$ for availability of digital simulation resources; $\chi^2(4) = 14.889$, $p = .005$ for teacher competence; $\chi^2(4) = 13.778$, $p = .008$ for access to technological devices; $\chi^2(4) = 26.444$, $p<.001$ for improved understanding of transport-system concepts; $\chi^2(4) = 10.000$, $p = .040$ for technical support and infrastructure; and $\chi^2(4) = 11.778$, $p = .019$ for administrative prioritization.

The null hypothesis of equal response distribution was rejected for all six statements at $\alpha = .05$. The findings demonstrate that teachers' responses were significantly concentrated in particular response categories rather than being evenly distributed. Nevertheless, the descriptive results provide the substantive indication of the direction of these responses and show that perceived availability and usefulness were stronger than perceived access to devices and infrastructure.

Table 6: Chi-square goodness-of-fit test of teachers' responses on availability of digital simulation resources

Statement	χ^2	Df	*p*-value	Decision at $\alpha = .05$
Digital simulation resources such as virtual laboratories and animations are readily available for teaching abstract biology concepts related to transport in plants and animals	19.44	4	<.001	Significant
Biology teachers are trained and proficient in using digital simulation resources to teach topics related to the transport system	14.89	4	<.005	Significant
Students have adequate access to technological devices such as computers, tablets and projectors to interact with digital simulations	13.78	4	<.008	Significant
Use of digital simulation resources has significantly improved students' understanding of complex transport-system concepts	26.44	4	<.001	Significant
There are sufficient technical support and infrastructure, including reliable internet connectivity and electricity, to use digital simulation tools	10.00	4	<.040	Significant
School administration prioritizes integration, updating and maintenance of digital resources and simulation software	11.78	4	<.019	Significant

Source: Researcher, (2026)

3.5 Observation checklist on the availability of digital simulation resources for teaching abstract biology concepts

Reliable electricity was the most widely available resource, occurring in 41 schools (91.1%), followed by desktop/laptop computers in 39 schools (86.7%), computer laboratories in 37 schools (82.2%), and suitable ICT laboratories in 35 schools (77.8%) as illustrated in Table 7. ICT equipment maintenance was observed in 32 schools (71.1%), while internet connectivity was available in 31 schools (68.9%). The availability of Biology-specific digital simulation resources was comparatively lower. Biology simulation software was available in 25 schools (55.6%), open-source simulation software in 29 schools (64.4%), curriculum-aligned simulations in 23 schools (51.1%), and digital Biology content in 26 schools (57.8%). Teacher access was observed in 30 schools (66.7%), whereas student access was observed in only 21 schools (46.7%). Several resources were particularly limited. Interactive whiteboards were available in only 7 schools (15.6%), adequate computers in 19 schools (42.2%), backup power in 18 schools (40.0%), ICT technicians in 22 schools (48.9%), and evidence of classroom use in 20 schools (44.4%). Thus, the observation data indicate a distinction between the availability of general ICT infrastructure and the availability and classroom utilization of Biology-specific digital simulation resources.

Table 7: Observation checklist on the availability of digital simulation resources for teaching abstract biology concepts

Resource	Availability		Functionality	
	Frequency	Percentage	Frequency	Percentage
Desktop/Laptop computers	39	86.7	35	89.7
Multimedia projector	33	73.3	29	87.9
Interactive whiteboard	7	15.6	5	71.4
Internet connectivity	31	68.9	27	87.1
Biology simulation software	25	55.6	22	88.0
Open-source simulation software	29	64.4	27	93.1
Computer laboratory	37	82.2	35	94.6
Reliable electricity	41	91.1	40	97.6
LCD screen/TV	28	62.2	25	89.3
Audio facilities	24	53.3	22	91.7
Adequate computers	19	42.2	17	89.5
Curriculum-aligned simulations	23	51.1	21	91.3
Digital biology content	26	57.8	24	92.3
Teacher access	30	66.7	29	96.7
Student access	21	46.7	20	95.2
ICT equipment maintained	32	71.1	30	93.8
Suitable ICT laboratory	35	77.8	33	94.3

Backup power	18	40.0	17	94.4
ICT technician	22	48.9	21	95.5
Evidence of classroom use	20	44.4	19	95.0

Source: Researcher, (2026)

3.6 Chi-square test of observed resource availability

Table 8 presents the one-sample chi-square goodness-of-fit results comparing observed availability with non-availability using an expected frequency of 22.5 for each category. Availability differed significantly from the expected 50:50 distribution for desktop/laptop computers, $\chi^2(1) = 24.200$, $p < .001$; multimedia projectors, $\chi^2(1) = 9.800$, $p = .002$; interactive whiteboards, $\chi^2(1) = 21.356$, $p < .001$; internet connectivity, $\chi^2(1) = 6.422$, $p = .011$; computer laboratories, $\chi^2(1) = 18.689$, $p < .001$; reliable electricity, $\chi^2(1) = 30.422$, $p < .001$; teacher access, $\chi^2(1) = 5.000$, $p = .025$; maintained ICT equipment, $\chi^2(1) = 8.022$, $p = .005$; and suitable ICT laboratories, $\chi^2(1) = 13.889$, $p < .001$.

Biology simulation software did not differ significantly from the expected 50:50 distribution, $\chi^2(1) = 0.556$, $p = .456$. Similarly, open-source simulation software, LCD screens/TVs, audio facilities, adequate computers, curriculum-aligned simulations, digital Biology content, student access, backup power, ICT technicians and evidence of classroom use did not show statistically significant departures from the specified expected distribution, except where indicated above.

Table 8: One-sample chi-square goodness-of-fit test for availability of digital simulation resources

Resource	Available	Not available	Expected Freq	χ^2	df	*p*-value
Desktop/Laptop computers	39	6	22.5	24.200	1	<.001
Multimedia projector	33	12	22.5	9.800	1	.002
Interactive whiteboard	7	38	22.5	21.356	1	<.001
Internet connectivity	31	14	22.5	6.422	1	.011
Biology simulation software	25	20	22.5	0.556	1	.456
Open-source simulation software	29	16	22.5	3.756	1	.053
Computer laboratory	37	8	22.5	18.689	1	<.001
Reliable electricity	41	4	22.5	30.422	1	<.001
LCD screen/TV	28	17	22.5	2.689	1	.101
Audio facilities	24	21	22.5	0.200	1	.655
Adequate computers	19	26	22.5	1.089	1	.297
Curriculum-aligned simulations	23	22	22.5	0.022	1	.881
Digital biology content	26	19	22.5	1.089	1	.297
Teacher access	30	15	22.5	5.000	1	.025
Student access	21	24	22.5	0.200	1	.655
ICT equipment maintained	32	13	22.5	8.022	1	.005
Suitable ICT laboratory	35	10	22.5	13.889	1	<.001
Backup power	18	27	22.5	1.800	1	.180
ICT technician	22	23	22.5	0.022	1	.881
Evidence of classroom use	20	25	22.5	0.556	1	.456

Source: Researcher, (2026)

3.7 Overall Availability of Digital Simulation Resources

Across the 20 observed resource indicators in the 45 sampled schools, 540 instances of resource availability were recorded out of 900 possible observations, representing an overall availability rate of 60.0%. Non-availability accounted for 360 observations (40.0%). The overall chi-square test indicated a statistically significant difference between availability and non-availability, $\chi^2(1) = 36.000$, $p < .001$. The null hypothesis of equal availability and non-availability was therefore rejected. The findings indicate that digital simulation-related resources were more frequently available than unavailable across the observed schools. However, substantial item-level disparities were evident, particularly for interactive whiteboards, adequate computers, backup power, student access, ICT technical support and evidence of classroom use.

Table 9: Overall inferential test for the availability of digital simulation resources

Overall availability	Observed Freq.	Expected Freq	χ^2	Df	*p*-value
Available	540	450	36.000	1	<.001
Not available	360	450	-	-	-
Total	900	900	36.000	1	<.001

Source: Researcher, (2026)

4. Discussion

4.1 Availability of digital simulation resources based on learners' responses

The finding that 59.7% of learners reported that digital simulation resources were available indicates a moderate level of access to virtual laboratories, animations and related digital resources. This finding is consistent with the growing integration of digital technologies into Biology education, where interactive simulations and virtual models are increasingly being used to represent biological processes that are difficult to observe directly [15]. Noted that interactive simulations, virtual models, virtual reality and augmented reality can provide new ways of representing biological phenomena and can address some limitations associated with conventional Biology teaching materials.

The finding is also consistent with recent Kenyan evidence [7]. Reported positive outcomes from virtual laboratory-based instruction in Biology in Likuyani, Kakamega County, particularly in learners' conceptual understanding of Biology content. Their study demonstrated that virtual laboratory instruction was associated with substantially higher post-test performance among learners exposed to the intervention. This suggests that the moderate availability observed in the present study provides a potentially useful foundation for simulation-based Biology instruction.

The 68.0% of learners who reported that digital simulations improved their understanding of complex transport-system concepts represents the strongest positive perception among the six learner indicators. This finding is theoretically plausible because simulations can make dynamic and microscopic biological processes visible and manipulable. Transport processes such as blood circulation, double circulation, transpiration and translocation involve sequences and interactions that may be difficult to represent effectively through static diagrams alone. Recent empirical evidence from Kenya supports this interpretation [9]. Found that computer simulations significantly improved learners' academic performance, conceptual understanding and engagement in Biology in Kesses Sub-County. Similarly [16], found stronger learning gains among secondary-school learners taught Biology using computer simulations than among learners receiving conventional instruction.

The present finding should nevertheless be interpreted as a learner perception of improved understanding, rather than direct evidence that simulations caused improved achievement. Since the availability study did not measure achievement gains within this particular analysis, causal conclusions should be avoided. The finding instead demonstrates that learners perceived simulations as useful for making complex Biology concepts easier to understand.

4.1.1 Teacher competence and availability of digital simulation resources

The finding that 60.0% of learners and 60.0% of teachers reported that Biology teachers were trained and proficient in using digital simulation resources indicates a moderately positive level of teacher preparedness. This is important because the availability of hardware and software alone does not guarantee meaningful technology integration. Teachers require the knowledge and pedagogical skills necessary to select appropriate simulations, operate digital tools and connect simulations with curriculum objectives.

This interpretation is supported by [21], who examined teachers' preparedness to integrate three-dimensional computer animation into Biology teaching in Murang'a County. Their study highlighted the importance of teacher preparedness in the integration of digital animation for teaching complex biological concepts. The finding is also consistent with the broader observation by [15] that effective digitalization of Biology education requires appropriate integration of digital tools into teaching rather than simply making technologies available.

In support of these findings [9], recommended teacher training to support meaningful integration of computer simulations into Biology instruction. Therefore, the 60.0% positive perception of teacher competence in the present study is encouraging, but it also suggests that a substantial proportion of learners may still encounter limitations in teachers' ability or confidence to integrate simulations consistently.

4.1.2 Access to technological devices and infrastructure

The relatively low proportion of learners reporting adequate access to technological devices (52.8%) and the corresponding teacher response of 53.4% indicate that access to devices remains an important limitation. The observation data reinforce this finding: although computers were available in 86.7% of schools, adequate computers were observed in only 42.2%, while student access was recorded in 46.7%. This difference suggests that the presence of computers at school level should not be equated with sufficient learner access.

The finding agrees with [20], whose study of public Junior Secondary Schools in Narok County found that inadequate laboratory infrastructure and equipment constrained effective implementation of practical, learner-centred science education. They recommended targeted investment in laboratory infrastructure, virtual laboratories and teacher training. The similarity is particularly relevant because both studies demonstrate that the existence of physical or digital infrastructure does not necessarily translate into effective learner access.

The observation that reliable electricity was available in 91.1% of schools is encouraging. However, backup power was available in only 40.0% of schools. This implies that the high level of basic electricity availability may not guarantee uninterrupted use of digital simulations. Similarly, internet connectivity was available in 68.9% of schools, but this still leaves approximately one-third of schools without observed internet access. UNESCO's DigiSchool Kenya initiative similarly demonstrated the continuing importance of school connectivity, with the second phase of the project expanding broadband connectivity to an additional 21 Kenyan schools and being completed in 2024 [17].

4.1.3 Availability of biology-specific simulation resources

The observation that Biology simulation software was available in only 55.6% of schools and curriculum-aligned simulations in 51.1% indicates that the development of general ICT infrastructure has not necessarily been matched by the availability of subject-specific digital resources. This distinction is important because computers and internet connectivity constitute enabling infrastructure, whereas simulations provide the actual pedagogical content through which abstract biological processes can be represented.

The finding is consistent with [15], who emphasized the growing role of interactive simulations and virtual models in Biology education and argued for modernization of Biology teaching materials through digital resources. It is also consistent with the recent Kenyan evidence from [7], whose work demonstrated the instructional value of virtual laboratories for Biology learning. The moderate availability of Biology-specific simulations therefore represents an important gap. Schools may possess computers and laboratories but still lack appropriate curriculum-aligned simulations for topics such as transport in plants and animals. This suggests that technology integration should focus not only on procurement of devices but also on the availability of appropriate digital content aligned with the Biology curriculum.

4.1.4 Classroom utilization and student access

Only 44.4% of schools had evidence of classroom use of digital simulation resources, despite computers being available in 86.7% of schools and computer laboratories in 82.2%. This substantial difference is one of the most important findings of the study. It demonstrates that infrastructure availability does not automatically translate into pedagogical utilization. The finding agrees with [20], who found that infrastructure limitations affected practical and learner-centred curriculum implementation in Kenyan public schools. It also corresponds with recent evidence from [9], which demonstrated that computer simulations can enhance Biology learning when they are actually incorporated into instruction rather than merely being available within schools.

The relatively low level of observed student access (46.7%) provides a further explanation for the limited evidence of classroom use. If digital devices and simulations are primarily controlled by teachers or restricted to particular lessons, learners may have insufficient opportunities for exploration and experimentation. Effective simulation-based instruction therefore requires a combination of functional infrastructure, adequate devices, appropriate software, teacher competence and opportunities for learners to interact directly with simulations.

4.1.5 Overall interpretation of availability

The findings demonstrated that digital simulation resources were moderately available rather than fully adequate in the sampled public secondary schools. The 60.0% overall availability rate provides evidence of a developing digital resource base, but the item-level results reveal substantial disparities. General infrastructure, particularly electricity, computers and computer laboratories, was relatively strong, whereas student access, adequate computers, Biology-specific simulations, backup power, technical support and classroom utilization were weaker. In tandem with these findings [20], found significant infrastructural gaps affecting science curriculum implementation in Narok County, while [7] demonstrated the potential of virtual laboratories to improve Biology learning when such resources are effectively integrated. Recent international scholarship similarly identifies interactive simulations and digital models as increasingly important components of contemporary Biology education, while emphasizing the need for appropriate pedagogical integration [15].

4.1.6 Interpretation of the overall chi-square result

The significant overall chi-square result, $\chi^2(1) = 36.00$, $p < .001$, indicates that the observed counts of available and unavailable resources differed from an assumed 50:50 distribution. However, this result should not be interpreted as evidence that the schools possessed an adequate level of digital simulation resources. The descriptive findings provide the more meaningful substantive interpretation: 60.0% of the recorded resource observations were available, while 40.0% were unavailable. Furthermore, because the 900 observations were derived from 20 resource indicators within the same 45 schools, the observations are not fully independent. Consequently, the pooled chi-square result should be treated as supplementary evidence rather than as the primary basis for concluding that resources were adequate.

5. Conclusion

The study concluded that digital simulation resources were moderately available in public secondary schools in Baringo North Sub-County, with 60.0% of the observed resource indicators available. General ICT infrastructure, particularly electricity, computers and computer laboratories, was relatively well established.

However, Biology-specific simulation software, curriculum-aligned digital content, adequate computers, student access, technical support, backup power and actual classroom utilization remained limited.

6. Recommendations

- Schools should improve access to functional devices and curriculum-aligned Biology simulations.
- Administrations should integrate simulation-based lessons into routine Biology instruction and ensure adequate learner access.
- The Ministry of Education should strengthen ICT infrastructure, internet connectivity, power supply, maintenance, and technical support.
- Curriculum-aligned simulations should be developed to support teaching of difficult and abstract Biology concepts.

7. Conflict of Interest

"The authors declare that there is no conflict of interest." There was no role of the funding sponsors in this study.

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