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Examining the Influence of Virtual Laboratory Resources on the Acquisition of Basic and Integrated Science Process Skills Among Senior High School Students

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ABSTRACT

This study investigated the effect of virtual laboratory resources integrated with flipped classroom instruction on Senior High School students' acquisition of basic and integrated science process skills at Winneba Senior High School, Ghana. A mixed-method action research design was employed involving 51 purposively selected Form Two General Science students. Data were collected through questionnaires, pre- and post-intervention assessments, observations, interviews, and achievement tests. The intervention required students to engage with pre-recorded instructional videos and virtual laboratory simulations before participating in guided classroom discussions and practical activities. Pre-intervention findings revealed that students experienced considerable difficulties in science process skills, particularly observation (86.3%), data interpretation (78.4%), defining variables operationally (70.6%), and controlling variables (62.7%). Pre-intervention mean scores ranged from 4.38 to 5.38 (SD = 0.92–1.69), indicating low proficiency in science process skills. Following the intervention, post-intervention mean scores increased substantially, ranging from 9.63 to 10.50 (SD = 2.33–2.95). The improvement was statistically significant across all groups ($p < 0.001$, df = 50), demonstrating the positive effect of virtual laboratory resources and flipped classroom instruction on students' acquisition of both basic and integrated science process skills. Students showed notable improvements in observation, measurement, communication, classification, prediction, experimentation, hypothesis formulation, variable control, and data interpretation. The novelty of this study lies in integrating virtual laboratory resources and flipped classroom pedagogy within a resource-constrained Ghanaian secondary school context. Despite limitations relating to sample size, purposive sampling, and the absence of a control group, the findings suggest that technology-enhanced, learner-centered instructional strategies can effectively strengthen practical science learning, student engagement, and science process skill development.

INTRODUCTION

Process Skills

Governments all over the world, including the Ghanaian government, recognize the importance of science, mathematics, and technology education in achieving the nation's development goals. The Ghana government's recognition of this fact has resulted in science and mathematics being identified as one of the pillars of national development (SEIP, 2014). To achieve this, the Government of Ghana has initiated some interventions and injected incentive schemes aimed at improving students' participation and achievement in science and mathematics, particularly at the secondary education level since the 1990s. Some of these interventions and incentive schemes are, the Science Resource Centre Project, Ghana Investment Fund for Electronic Communication (GIFEC), information and communication technology (ICT)-related projects, Mathematics, Science and Technology Scholarship Scheme (MASTERS), and Secondary Education Improvement Project (SEIP) are but some of these interventions (GIFEC, 2020; MOE, 2015). .

Boakye (2010) underpinned that, learning and teaching of science is challenging in Ghana owing to some reasons, which comprise: resources required, human as well as material resources; and lack of effective practical work ethics. It must be stated that the practical work done in science in most Ghanaian senior high schools is often not interesting for students, and neither is it effective in improving learning (Comah, 2016).

In the introductory page of the Ghana Education Service Integrated Science syllabus currently in the Senior High Schools, the dimensions for teaching and learning the subject have been weighed as follows:

Remembering and understanding	20%
Applying knowledge	40%
Practical and experimental skills	40%

The general expectation was that with the syllabus prescription on increased emphasis on practical and experimental skills, during lessons increases in students' performance in integrated science (however modest) would have been recorded. These expectations have not matched the results, and this is reflected in the poor students' performance in integrated science as noted by chief examiner's report (West African Examinations Council [WAEC], 2019, 2020, 2021).

The unanswered question is whether the Senior High School Integrated Science teachers are sufficiently knowledgeable in the basic and integrated process skills to be able to impart these skills to the students

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during lessons. Findings reported by other educational researchers (Afoaya, 2016; Agbenyo, 2017; Harrison, 2018; Dzeketay, 2017; Yeboah-Mensah, 2014) indicate in totality that the Senior High School integrated science teachers sampled in the various institutions lacked the skills required to organize workable practical activities.

For this reason, this study was designed to determine the effect of virtual laboratory resources and flipped classroom instruction on Senior High School students' acquisition of the basic and integrated process skills. The virtual laboratory resource was meant to augment the available resource for the full-scale intervention.

The following research questions guided the study:

1. What difficulties do Senior High Hchool students encounter during lessons that require the use of basic and integrated science process skills?
2. To what extent does the utilization of virtual laboratory resources and flipped classroom instructions improve students' competencies in basic and integrated process skills during practical activities?

LITERATURE REVIEW

Theories Underpinning the Research

To construct an ideal-typical model for the development of process skills in science, the Bloom's taxonomy and the Constructivist Learning Theory (CLT) guided the study.

Blooms taxonomy

In our increasingly complex and specialized society, it is becoming imperative that individuals think creatively, critically, and constructively. These attributes constitute higher-order thinking skills (Shuyang, 2023). Ghanizadeh, Al-Hoorie and Jahedizadeh, (2020), included the ability to use reference material and interpret graphs, tables, and maps among the high-order thinking skills. King, Goodson, and Rohani (2018) defined higher-order thinking skills as thinking at the higher levels of the hierarchy of cognitive processing. The concept of higher-order thinking skills became a major educational agenda item with the publications of Bloom's taxonomy of educational objectives (Bloom et. al., 1956). Bloom and his co-workers established a hierarchy of educational objectives, which attempts to divide cognitive objectives into subdivisions, ranging from the simplest intellectual behaviour to the most complex ones. These subdivisions are knowledge, comprehension, application, analysis, synthesis, and evaluation (Ikuenobe, 2003). Of these objectives, application, analysis, synthesis, and evaluation are higher-order thinking skills (Zajda, 2018; Fisher, 2001).

Blooms taxonomy ((Bloom *et al.*, 1956), is perfectly linked to the present study in that the theory focuses on the development of the science process skills in education where students need to create, evaluate, analyze, apply, understand, and remember concepts that lead to the development of good science basic and integrated process skills.

The Constructivist Learning Theory (CLT)

The Constructivist Learning Theory (CLT) guided this study. The theory was developed by Lev Vygotsky, a Russian psychologist (1896-1934) who also came up with the Social Development Theory (SDT) which is applied in education (Bruner, 1966; Johnson, 2017; LeFrancois, 2006).

Constructivism is an active procedure whereby a teacher guides learners to create new information from previous knowledge during learning. The constructed knowledge in this study is procedure, observation, execution, and interpretation skills used in selected tasks that constitute the independent variables while achievement or performance in the skills tested constitutes the dependent variable. This type of learning proposed by Vygotsky is a give-and-take experience for both the teacher and the students. It places emphasis on the affective domain, makes instruction significant to the learner, it also helps learners build up beliefs and attitudes that support both present and lifetime learning, and balances teacher control with personal self-sufficiency in the education environment (Hoese & Casem, 2007).

According to this theory, students construct their knowledge from personal experiences, textbooks, teacher explanations, or any other means of knowing. In attempting to solve problems in novels, there are perceptual or conceptual similarities between knowledge of a new problem and can remind people of what they already know, and how the knowledge will impact the learning process (National Science Board, 2018; Woolfolk, 2020). The theory of constructivism has many elements. These principles outline the theory as a whole and how they affect the learning of the students. The main points are listed below:

- Knowledge is constructed. Each student begins the learning journey with some pre-existing knowledge and then continues to build their understanding on top of that. They select which pieces of the experience to add, making everyone's knowledge unique.
- Learning is a social activity. Interacting with others is vital to constructing knowledge. Group work, discussions, conversations, and interactions are all important to creating understanding. When we reflect on our past experiences, we can see how our relationship with others is directly connected to the information learned.
- Learning is an active process. Students must actively engage in discussions and activities to construct knowledge. Students can't take on a passive role and retain information. To build meaningful ideas, there must be a sensory response.
- Learning is contextual. Isolation is not the best way to retain information. We learn by forging connections between what we believe and the information we have already. Learning also occurs in the situation within the context of our lives, or alongside the rest of our

understanding. We reflect on our lives and classify the new information as it fits into our current perspective.

• People learn to learn, as they learn. As each student moves through the learning journey, they get better at selecting and organizing information. They can better classify ideas and create more meaningful systems of thought. They also begin to recognize that they are learning multiple ideas simultaneously, for example, if they are writing an essay on historical events, they are also learning elements of written grammar. If they are learning about important dates, they are also learning how to chronologically organize important information.

• Learning exists in the mind. Hands-on activities and physical experience are not enough to retain knowledge. Active engagement and reflection are critical to the learning journey. To develop a thorough understanding, students must experience activities mentally as well.

• Knowledge is personal. Because every person's perspective is unique, so will be the knowledge gained. Every individual comes into the learning activity with their own experiences and will take away different things as well. The theory of constructivist learning is based entirely on everyone's perspective and experiences.

• Motivation is key to learning. Like active participation, motivation is key to making connections and creating understanding. Students cannot learn if they are unwilling to reflect on pre-existing knowledge and activate their thought processes. Educators must work to motivate their students to engage in the learning journey (Oliver, 2000; Pratiwi et. al., 2025; Woolfolk, 2020).

Constructivist theory provides a theoretical framework that serves as an appropriate model for analyzing the nature of science learning. The National Research Council (2000) stated that, Laboratory activities appeal as a way of allowing students to learn with understanding and, at the same time, engage in a process of constructing knowledge by doing science. Constructivist learning enables students to actively construct knowledge through experience and reflection (Goloi & Osman, 2018).

Information not connected with a learner's previous experiences is rapidly forgotten. In short, the learner must actively enrich the existing information by constructing new additional knowledge for meaningful learning to occur. This is because constructivism views learning as a process in which the student actively constructs or builds new ideas or concepts based on current or past knowledge (Akinbobola, & Afolabi, 2010). Additionally, inquiry-based science teaching, which is grounded in constructivism, enhances meaningful learning and scientific understanding (Mohammed & Luguterah, 2024).

The constructivist theory developed by Lev Vygotsky (1896-1934), whereby teachers guide the learners to create new information from previous knowledge during learning is perfectly linked to this study. This is because the process of constructing knowledge leads to the development of basic and integrated science process skills

MATERIALS AND METHODS

Research Approach

This study adopted a mixed-method approach. Mixed-methods research combines elements of quantitative research and qualitative research to answer research questions. This means a mixed-method approach is characterized by the combination of qualitative and quantitative research components (Creswell & Creswell, 2018). In science research, quantitative research is typically based on positivist assumptions, and qualitative research is based on interpretivist phenomena (Walliman, 2006; Creswell & Creswell, 2018).

Research Design

The action research design was used in this study. The goal of an action research study is to create a framework for future research or to ascertain whether an intervention might help the situation being observed. George (2023) underpinned that Action research is a research design that tries to concurrently investigate and solve an issue. In other words, as its name suggests, action research conducts research and acts at the same time.

An extremely interactional method, action research is frequently used in the social sciences, specifically in educational situations. Predominantly popular with educationalists as a form of systematic inquiry, it prioritizes replication and links the gap connecting theory and practice. Due to the makeup of the research, it is also at times termed a cycle of action or a cycle of inquiry (George, 2023).

Population

The target population of this study consisted of Senior High schools in Winneba, Apam and Kasoa. The accessible population comprised all second-year science students in Winneba Senior High School.

Sampling Techniques and Sample Size

A purposive sampling technique was used to select one class for the study. The selected class consisted of fifty-one (51) students, who formed the sample size.

To determine the reliability of the sample, the margin of error was calculated at a 95% confidence level using the formula:

Where:

$$E = z \times \sqrt{\frac{P(1-P)}{n} \times \frac{N-n}{N-1}}$$

E = margin of error
Z = 1.96 (95% confidence level)
P = 0.5 (assumed proportion)
n = 51 (sample size)
N = 1020 (estimated population size)
Plugging in the numbers, you get:
$E = 1.96\times\sqrt{((0.05(1-0.05))/51\times(1020-1)/(1020-1))}$
$E \approx 13.4\%$
The margin of error was calculated to be approximately

13.4%. This indicates that the results obtained from the sample may differ from the true population values by about 13.4%. Although one class was selected due to time and resource constraints, the relatively high margin of error suggests that the findings may have limited generalizability to the entire population.

Data collection procedure

Both primary and secondary data were collected for the research. These were obtained from libraries of the University of Education, Winneba, and the Winneba Senior High School library. The data collection process comprised Pre-intervention activities, Intervention activities and the post-intervention activities.

The Pre-intervention activities

Pre-intervention activities (Appendix A) were administered to the sampled science students to know their level of knowledge in the basic and integrated process skills acquired from previous topics or concepts taught by their teachers. With permission from the science head of the department, all 51 students selected for the study were made to observe, classify, compare, measure, infer, predict, compare variables, define variables operationally, experiment, formulate hypotheses, formulate models, and interpret data at the biology laboratory during practical sessions. The pre- intervention stage was conducted within four weeks.

Intervention Activities: Using Virtual Laboratory Resources and Flipped Classroom Instruction

The researcher booked appointments with the school's ICT department to use the computer laboratory. The computer application, virtual laboratory, and a pre-recorded video on the selected topics were given to the respondents as they flipped their classes. This is because most of the students selected were boarders and even the day students amongst them did not have the smart phones they could use. The respondents watched the pre-recorded videos on the selected topics and interacted with the virtual laboratories on the computers.

A virtual laboratory resource was on selected topics such as osmosis in living tissues, cells and tissues, food tests, sampling with the quadrat etc. The students observed, communicated, classified, measured, inferred, predicted, controlled variables, defined variables operationally, experimented, formulated hypotheses, formulated models and interpreted data in science on the topics under study. Respondents were observed by the researcher as they worked with the virtual laboratory and as they flipped the class. Observations were recorded and analysed within four weeks.

Post-Intervention Activities: After Using Virtual Laboratory Resources and Flipped Classroom Instruction

Post-intervention activities (Appendix A) were conducted after the students had gone through virtual laboratory resources and flipped classroom instruction. The selected students were made to observe, classify, communicate, measure, infer and predict by answering post-test questions at the biology laboratory in 30 minutes. The researcher observed the students as they worked. An observational checklist (Appendix B) guided the researcher during the observation. All observations were recorded and the sheets for the post-test were collected for observation and analysis. This was to identify the impact of virtual laboratory resources and flipped classroom instruct ion on students.

Presentation of Analyse Data by Research Questions

Research question 1: What difficulties do the Senior High School students encounter during lessons that require the use of basic and integrated process skills?

Table 1 below is a summary of students' responses on the difficulties they encounter in using the basic and

Table1: Students' Reported Difficulties in Basic and Integrated Science Process Skills.

S/N	Science Process Skill	Yes, n (%)	No, n (%)	Total (n)
1	Classifying	24 (47.1)	27 (52.9)	51
2	Measuring	25 (48.1)	26 (51.9)	51
3	Communication	14 (27.5)	37 (72.5)	51
4	Inferring	18 (35.3)	33 (64.7)	51
5	Prediction	25 (48.1)	26 (51.9)	51
6	Observing	44 (86.3)	7 (13.7)	51
7	Controlling variables	32 (62.7)	19 (37.3)	51
8	Defining variables operationally	36 (70.6)	15 (29.4)	51
9	Formulating hypothesis	18 (35.3)	33 (64.7)	51
10	Interpreting data	40 (78.4)	11 (21.6)	51
11	Experimentation	22 (43.1)	29 (56.9)	51
12	Formulating models	27 (52.9)	24 (47.1)	51

Note: Values are presented as frequency (percentage). Total sample size (n) = 51. "Yes" indicates students who reported difficulties in each science process skill while "No" indicate those did not. S/N= Serial Number

integrated science process skills during lessons.
Table 1 presents students' reported difficulties in basic and integrated science process skills. The results indicate that a reasonable number of students experience difficulties in several key skills. The greatest difficulty was observed in observing (86.3%), followed by interpreting data (78.4%) and defining variables operationally (70.6%). Also, a considerable number of students reported challenges with controlling variables (62.7%).
On the other hand, fewer students reported difficulties in communication (27.5%), inferring (35.3%), and formulating hypotheses (35.3%). Skills such as measuring (48.1%), prediction (48.1%), and classifying (47.1%) showed nearly equal proportions of students experiencing and not experiencing difficulties.
Overall, the findings suggest that students encounter more difficulties with higher-order science process skills compared to basic skills, indicating a need for improved instructional strategies during practical science lessons.

Research question 2: What are the students' demonstrable process skills capabilities during practical activities?
This question sought to know the skills that students know and exhibit during practical activities.
Table 2 below is a summary of the knowledge students' possess and demonstrates during practical activities.
The results presented in Table 2 provide a comprehensive overview of students' knowledge of basic and integrated science process skills. Overall, the findings reveal a mixed pattern of understanding, with strong competence in some fundamental concepts and notable misconceptions in others.
Students demonstrated a high level of understanding in basic science process skills such as classification, prediction, communication and measurement. For instance, a substantial majority correctly identified classification as the grouping of items based on similarities and differences (76.5% strongly agree, 21.6% agree),

Table 2: Students' Knowledge of the Basic and Integrated Science Process Skills

S/N	STATEMENT	RESPONSES				
			A	U	D	SD
1	Observation is done using five senses.	9 (17.6)	6 (11.8)	6 (11.8)	11 (21.6)	19 (37.3)
2	We infer by explaining and drawing conclusion based on observation	3 (5.9)	2 (3.9)	8 (15.7)	21 (41.2)	17 (33.3)
3	The micrometer screw gauge is used to measure the volume of a substance.	5 (9.8)	2 (3.9)	6 (11.8)	10 (19.6)	28 (54.9)
4	The standard unit for mass is kilogram	29 (56.9)	13 (25.5)	4 (7.8)	1 (2.0)	4 (7.8)
5	The standard unit for volume is meter	12 (23.5)	10 (19.6)	3 (5.9)	10 (19.6)	16 (31.4)
6	The beaker is used to measure volumes of liquids	26 (51.0)	19 (37.3)	1 (2.0)	3 (5.9)	2 (3.9)
7	Communication means to use words or symbols to describe an action, object, or event to other people or readers.	25 (49.0)	18 (35.3)	1 (2.0)	7 (13.7)	0 (0.0)
8	Classification means sorting, grouping and arranging things based on similarities and differences.	39 (76.5)	11 (21.6)	1 (2.0)	0 (0.0	0 (0.0)
9	Prediction means stating the outcome of a future event based on a pattern of evidence.	34 (66.7)	12 (23.5)	2 (3.9)	2 (3.9)	1 (2.0)
10	Controlling variables means to identify variables and keeping them constant during experiments.	20 (39.2)	11 (21.6)	17 (33.3)	2 (3.9)	1 (2.0)
11	Defining variables operationally means to state how to measure a variable in an experiment.	4 (7.8)	2 (3.9)	17 (33.3)	16 (31.4)	12 (23.5)
12	We formulate hypothesis by stating the expected outcome of an experiment.	19 (37.3)	18 (35.3)	10 (19.6)	4 (7.8)	0 (0.0)
13	To experiment means testing by following procedure to produce a verifiable result.	30 (58.8	17 (33.3)	3 (5.9)	1 (2.0)	0 (0.0)
14	We formulate models by creating a mental or physical model of a process or event.	14 (27.5)	13 (25.5)	22 (43.1)	2 (3.9)	0 (0.0)

15	Interpreting data means to organize and explain data to readers.	27 (52.9)	12 (23.5)	9 (17.6)	3 (5.9)	0 (0.0)
16	Biological graphs are easy to plot.	6 (11.8)	13 (25.5)	23 (45.1)	8 (15.7)	1 (2.0)

Note: The table summarizes students' knowledge of basic and integrated science process skills based on their responses to structured questionnaire items. Higher percentages in SA and A indicate good conceptual understanding, while higher percentages in D and SD suggest misconceptions or poor knowledge.

indicating a solid grasp of foundational analytical skills. Similarly, prediction was well understood, with 90.2% of respondents agreeing that it involves stating outcomes based on patterns of evidence. Communication and experimentation also recorded high agreement levels, reflecting that students are relatively comfortable with expressing scientific ideas and following procedures to obtain verifiable results.

In addition, students showed strong knowledge in measurement-related concepts. A significant proportion correctly identified the kilogram as the standard unit of mass (82.4% agreement), and many recognized the role of a beaker in measuring liquid volumes (88.3% agreement). These findings suggest that students are more confident in practical and observable aspects of science.

However, despite these strengths, the data also reveal critical gaps in students' understanding of more complex or abstract science process skills. A large proportion of respondents incorrectly believed that a micrometer screw gauge measures volume, with 74.5% disagreeing with the correct concept, indicating a major misconception in the use of scientific instruments. Similarly, the concept of inference was poorly understood, as over 74% of students disagreed with the correct explanation, suggesting difficulty in linking observations to logical conclusions.

Furthermore, concepts related to experimental design and variable control appear to be problematic. Although some students understood controlling variables (60.8% agreement), a significant proportion remained undecided or incorrect. More notably, defining variables operationally showed weak understanding, with a majority of students either undecided or in disagreement. This suggests that students struggle with higher-order scientific thinking skills required for designing and interpreting experiments.

Another notable area of concern is the misunderstanding of measurement units, as many students incorrectly identified meter as the standard unit of volume. This indicates confusion between different physical quantities and their respective units, pointing to gaps in foundational scientific knowledge.

Additionally, the concept of model formulation was not well comprehended, with the highest percentage (43.1%) falling under undecided responses. This reflects uncertainty and lack of confidence in abstract representation of scientific processes. Similarly, biological graphing skills were weak, as a large proportion of students were undecided or disagreed that such graphs are easy to plot, indicating limited competence in data visualization.

In conclusion, while students exhibit strong understanding of basic and observable science process skills, there are significant deficiencies in integrated and higher-order skills such as inference, operational definition of variables, modeling and data representation. These findings suggest the need for instructional strategies that emphasize practical application, critical thinking and conceptual clarity, particularly in areas requiring deeper cognitive engagement.

Key Findings of the Study

Based on the research questions, the following findings were established:

- Difficulties encountered by students: The study found that most students faced significant challenges in using science process skills, particularly observing, interpreting data, defining variables operationally, and controlling variables. These difficulties were more pronounced in integrated (higher-order) skills than in basic skills.
- Students' process skills capabilities: Although students demonstrated some understanding of basic skills such as classification, communication, prediction, and measurement, there were notable misconceptions and gaps in knowledge, especially in the use of scientific instruments, inference, model formulation, and data representation.
- Effect of virtual laboratory resources and flipped classroom instruction: The findings revealed that the use of virtual laboratory resources and flipped classroom instruction led to significant improvement in students' science process skills. Students showed enhanced ability to observe accurately, measure correctly, communicate effectively, make predictions, classify appropriately, and apply integrated skills during practical activities.

CONCLUSION

Most students initially lacked science process skills. The Traditional teaching methods were ineffective but Virtual labs and flipped classroom instruction made learning: More engaging, more practical and more effective. Overall, the study concludes that innovative teaching approaches significantly enhance students' acquisition of both basic and integrated science process skills. It was recommended that Teachers should use virtual laboratories, Apply flipped classroom methods and also to supervise students during practical work. In addition, students should be motivated to improve their performance in science.

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