Parabolum Publishing

Journal of Teacher and Student Hands-on Activities

Vol. 1 (1), pp. 1-11, 2026

Doi: 10.58197/9e44ex74

Available online at http://www.parabolumpublishing.org/

Type of article: Research Article

Laboratory-Based Practical Work and Students' Achievement in Secondary School Biology: A School-Based Study in Rwanda

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Abstract

This study examined the contribution of laboratory-based practical work to students' achievement in Biology at Groupe Scolaire Mahembe in Ngororero District, Rwanda. It also explored constraints affecting the implementation of Biology experiments and strategies that could strengthen practical science teaching. The project reports a school-based mixed-methods case study involving a stated sample of 46 participants drawn purposively from a population of 280. Two learner groups studied the same food-testing topic using different approaches: 21 learners received traditional instruction and 23 participated in laboratory-based practical instruction. The reported pass rates were 33.3% (7/21) in the traditional-instruction group and 91.3% (21/23) in the practical-work group, a descriptive difference of approximately 58 percentage points. Qualitative findings identified inadequate laboratory infrastructure, shortages of apparatus and chemicals, limited teacher expertise in conducting practical activities, and insufficient instructional time as key constraints. Suggested responses included improving laboratory provision, strengthening teacher professional development, improvising appropriate low-cost materials, and allocating adequate time for practical lessons. The pattern is consistent with scholarship emphasizing that well-designed practical work can support conceptual understanding and scientific engagement. However, because the study involved one school, one topic, small instructional groups, and an incompletely documented comparison procedure, the observed difference should not be interpreted as definitive causal evidence. The study highlights the importance of purposeful, adequately resourced and teacher-supported practical work in Biology education in resource-constrained school settings.

Keywords: Biology education; laboratory practical work; academic achievement; secondary education; Rwanda; science teaching

Article information

Received: 28/12/2025;

Reviewed: 22/01/2026;

Revised: 26/06/2026;

Accepted: 11/07/2026

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How to cite this article: Byukusenge, C., Tuyisenge, J.D'A., Manishimwe, H. (2026) 'Laboratory-Based Practical Work and Students' Achievement in Secondary School Biology: A School-Based Study in Rwanda', *Journal of Teacher and Student Hands-on Activities*, 1(1), pp. 1–11. Doi: https://doi.org/10.58197/9e44ex74

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1. Introduction

1.1 Background

Practical work is a distinctive component of science education because it gives learners opportunities to observe phenomena, manipulate materials, collect evidence and connect scientific explanations with observable events (Lesetja, 2025). In Biology, laboratory activities can make unfamiliar concepts more accessible by enabling learners to investigate biological processes directly. They may also provide opportunities to develop observation, measurement, classification, interpretation and evidence-based reasoning skills. Nevertheless, the educational value of laboratory activity depends not simply on whether learners enter a laboratory, but on task design, teacher guidance and the extent to which practical observations are connected explicitly to scientific ideas (Hofstein & Lunetta, 2004).

Research cautions against assuming that practical work automatically produces deeper learning. Abrahams and Millar (2008), for example, found that practical activities can successfully engage students with physical objects while being less effective in helping them connect observations to underlying scientific concepts. Practical lessons therefore need clear learning purposes, carefully sequenced procedures, opportunities for discussion and structured reflection.

This issue is particularly relevant where schools face constraints in laboratory infrastructure, equipment, consumables and teacher preparation. Rwanda's competence-based curriculum emphasises the application of knowledge, skills and attitudes, making practical learning an important pedagogical consideration (Rwanda Education Board, 2015). However, successful implementation requires adequate resources and teachers who can plan, facilitate and assess experimental activities. Research in Rwanda has documented challenges in Biology teachers' practical-work knowledge and skills, alongside the need for professional development and improved access to equipment and reagents (Mbonimpaye et al., 2023).

Other Rwandan studies have reported positive outcomes associated with practical science instruction. Ntawuhiganayo and Nsanganwimana (2022) reported higher Biology achievement among learners who participated in laboratory practical activities than among learners taught through teacher-centred approaches. In Chemistry, Kaneza et al. (2024) found that both student hands-on experiments and teacher demonstrations produced stronger achievement outcomes than traditional teaching for a unit on solutions and titration. These studies provide a relevant empirical basis for examining practical work in Biology at school level.

Against this background, the present study examines the contribution of laboratory-based practical work to students' achievement in Biology at Groupe Scolaire Mahembe in Ngororero District. It focuses on a food-testing lesson and considers school-level constraints that affect the regular use of laboratory experiments.

1.2 Literature Review and Theoretical Orientation

The meaning and educational purposes of laboratory practical work

Laboratory practical work refers to planned learning activities in which learners engage with materials, equipment, specimens or experimental procedures to observe phenomena, generate or examine evidence, and relate their observations to scientific explanations (Gericke, et.al., 2023). In Biology education, such activities may include microscopy, food tests, dissection where ethically and safely appropriate, ecological sampling, and investigations of physiological or biological processes. Practical work is not a single teaching method: it may range from teacher demonstrations and highly structured verification exercises to guided investigations in which learners formulate questions, make predictions, collect data and interpret results.

The educational value of an activity therefore depends on the learning purpose and the degree of intellectual engagement it creates, rather than on the presence of apparatus alone (Gericke et al., 2023).

Practical work, conceptual understanding and academic achievement

Laboratory activities can make abstract biological ideas more tangible by enabling learners to observe phenomena and connect theoretical explanations with empirical evidence (Tibell & Harms, 2017). For example, food tests provide visible reactions that can help learners relate the presence of starch, reducing sugars, proteins or lipids to the chemical composition of food. Such experiences may support conceptual understanding when learners are asked to predict outcomes, record observations accurately, explain colour changes and connect results to the underlying biological concepts. Hofstein and Lunetta (2004) argue that the laboratory can contribute to meaningful science learning when practical experiences are integrated with classroom teaching, reflection and assessment. A systematic review by Gericke et al. (2023), covering secondary-school laboratory research, similarly identifies conceptual learning and the development of scientific practices as important but distinct goals of laboratory instruction.

Evidence also cautions against assuming that hands-on activity automatically improves understanding or achievement. Abrahams and Millar (2008) found that learners may successfully manipulate materials and produce observations without necessarily making the intended conceptual connections. This distinction is especially important in food-testing lessons: completing a procedure and observing a colour change do not, by themselves, demonstrate that learners understand what the result means or why the test works. Teachers therefore need to make the relationship between the practical task and the scientific explanation explicit. Well-designed practical work should include preparation, guided activity, interpretation and post-practical discussion.

Development of scientific process skills and learner engagement

Beyond content knowledge, laboratory work can support scientific process skills such as observing, classifying, measuring, handling apparatus, following safety procedures, recording results, interpreting evidence and communicating conclusions (Lunetta et al., 2013). These competencies are central to learning how science is practised. Gericke et al. (2023) distinguish between learning science concepts and learning to do science through investigative practices. These goals can complement one another, but they should be deliberately planned and assessed. In a food-test investigation, for instance, learners may develop procedural competence by handling reagents safely and recording results, while also developing reasoning skills by comparing samples and drawing evidence-based conclusions.

Practical work may also increase learner participation and interest by giving students an active role in the learning process. Nevertheless, engagement should not be equated only with physical activity. Learners may be busy carrying out steps without thinking deeply about the biological problem. Seery et al. (2024) emphasise that effective laboratory learning requires alignment among learning outcomes, task design, teaching support and assessment. Activities should therefore provide opportunities for learners to explain decisions, discuss unexpected observations and reflect on the reliability and meaning of evidence.

Teacher guidance and the design of effective practical lessons

The effectiveness of laboratory work is influenced by how teachers structure and facilitate the activity. Highly prescriptive, 'cookbook' procedures may be useful when learners are first developing basic laboratory skills or when safety requires close direction (Kanter et al., 2003). However, if practical work is limited to following instructions, learners may have few opportunities to formulate questions, make decisions or interpret evidence independently. Conversely, completely open investigations may overwhelm

learners who lack the prior knowledge or procedural skills needed to work safely and productively. Gericke et al. (2023) conclude that the level of inquiry and teacher guidance should be matched to the intended learning goals and learners' experience.

Effective facilitation includes explaining the purpose of the experiment, activating relevant prior knowledge, modelling safe use of apparatus, prompting predictions, supporting accurate observation, and guiding learners to interpret results (Julien & Lexis, 2015). After the practical activity, teachers should help learners connect empirical observations with concepts and evaluate possible sources of error. This is particularly relevant to the present study because the food-testing comparison should be understood not simply as a contrast between a laboratory and a classroom, but as a contrast between two instructional experiences.

Constraints affecting practical Biology teaching in resource-constrained settings

Practical Biology teaching requires more than a designated laboratory room. It depends on the availability and maintenance of apparatus, chemicals and consumables, safe water and electricity where required, appropriate storage, class size, preparation time and teachers' confidence in conducting investigations (Ndihokubwayo, 2017). Shortages in any of these areas can reduce the frequency, quality or range of practical activities. In addition, practical lessons require time for preparation, distribution of materials, learner activity, cleaning and discussion. When timetables are congested, teachers may prioritise theoretical coverage or demonstrations over learner-centred investigations.

These concerns are reflected in research conducted in Rwanda. Mbonimpaye et al. (2023) examined Biology teachers' knowledge and skills of practical work in 26 secondary schools across three districts in the Western Province. They reported gaps in procedural understanding and subject-specific practical knowledge, and noted that teacher-centred practical approaches were common. Their recommendations included professional development and improved provision of equipment and reagents. This evidence provides an important national context for interpreting the challenges reported at Groupe Scolaire Mahembe. The constraints identified in the present study inadequate laboratory infrastructure, shortages of apparatus and chemicals, limited teacher expertise and insufficient time, are therefore not merely logistical inconveniences; they are interconnected conditions that shape whether practical learning can be implemented meaningfully.

Strategies for strengthening practical Biology instruction

Addressing resource constraints requires coordinated action at classroom, school and system levels. At classroom level, teachers may use safe, locally available materials to support selected activities, adapt group sizes, prepare materials in advance and integrate short investigations into ordinary lessons (Mbonimpaye et al., 2023). Improvisation should not be treated as a substitute for all specialised equipment: materials must be scientifically appropriate, safe and capable of producing interpretable results. At school level, leaders can prioritise essential equipment and consumables, maintain laboratory facilities, organise shared resources and allocate adequate time for practical lessons. At system level, professional development can strengthen teachers' procedural knowledge, subject content knowledge, laboratory safety and ability to design inquiry-oriented activities. Professional development should go beyond one-off demonstrations. Teachers need opportunities to practise experiments, anticipate likely learner difficulties, discuss alternative procedures, develop assessment criteria and reflect on how practical observations can be connected to biological concepts. The findings of Mbonimpaye et al. (2023) reinforce the importance of strengthening both teacher competence and resource provision. Seery et al. (2024) also highlight the need to align laboratory design, teaching and assessment rather than treating practical sessions as isolated events.

Theoretical orientation: Experiential learning theory

The study is informed by Kolb's (1984) experiential learning theory, which conceptualises learning as a cycle involving concrete experience, reflective observation, abstract conceptualisation and active experimentation. In the context of a food-testing lesson, learners first engage in a concrete experience by testing food samples and observing reactions. They then reflect on what they observed, compare results and consider possible explanations. Through abstract conceptualisation, they connect the observed reactions to biological and chemical concepts concerning nutrients. Finally, active experimentation occurs when they apply the knowledge to additional samples, predict outcomes or test their explanations.

This framework helps explain why practical work may support learning: it creates opportunities for learners to move between experience and explanation. However, the cycle is not completed simply by performing an experiment. Reflection and conceptualization are essential. The teacher's role is to help learners interpret the experience and connect it to scientific knowledge. This theoretical orientation is therefore relevant to examining whether laboratory-based instruction is associated with different achievement outcomes in the food-testing topic.

Research gap and contribution of the present study

Existing scholarship recognises the potential of laboratory work to support conceptual learning and scientific practices, while also showing that its effectiveness depends on task design, inquiry level and teacher guidance (Abrahams & Millar, 2008; Gericke et al., 2023; Hofstein & Lunetta, 2004). Research in Rwanda has also identified constraints in teachers' practical-work knowledge and access to resources (Mbonimpaye et al., 2023). Nevertheless, context-specific school-level evidence remains valuable because the availability of resources, organisation of lessons and learner experiences may differ substantially across schools. The present study contributes a case from Groupe Scolaire Mahembe by examining a reported comparison of learner achievement following traditional instruction and laboratory-based instruction on a food-testing topic, alongside perceived implementation challenges and possible responses. Its contribution is exploratory and contextual; given the small groups and incomplete reporting of the comparison procedure, it should not be interpreted as establishing a general causal effect.

1.3 Research Objectives

To examine differences in reported achievement between learners taught a food-testing topic through laboratory-based practical work and those taught through traditional instruction.

To identify challenges affecting the implementation of laboratory experiments in Biology at Groupe Scolaire Mahembe.

To identify strategies that may strengthen the use of laboratory practical work in Biology teaching.

2. Research Methodology

2.1 Research design and setting

The source project describes the investigation as using quantitative and qualitative approaches within a descriptive research design, with Groupe Scolaire Mahembe in Sovu Sector, Ngororero District, as the case-study setting. For this article, the design is characterised more precisely as a school-based mixed-methods case study with a non-randomised instructional comparison. This description reflects the reported comparison of two learner groups but does not imply that random allocation or a fully controlled experiment was undertaken.

2.2. Population and participants

The project reports a target population of 280 and a total sample of 46 participants selected purposively. The instructional comparison involved 44 learners: 21 learners in the traditional-instruction group and 23 learners in the laboratory-practical group. The project also reports interview information from teachers and school leaders, although the exact number and roles of these interviewees are not consistently specified. Demographic tables indicate 24 female and 22 male participants; age information is reported for 46 participants, while class-level information is reported for 43 learners. These discrepancies are treated as reporting limitations rather than resolved through assumptions.

2.3. Data collection and analysis

According to the project, the same food-testing topic was taught to two groups using different instructional approaches. One group received traditional instruction, while the other participated in a laboratory experiment. Learner achievement was assessed through a test following the lesson. Questionnaires were used to gather learner information, and interviews with teachers and school leaders explored challenges and possible strategies. The available numerical findings are summarized using frequencies and percentages. Qualitative findings are reported descriptively because the source project does not provide a transparent coding framework, verbatim excerpts or theme frequencies.

3. Results

3.1 Profile of participants

This study reports a total sample of 46 participants. The gender profile comprised 24 female participants (52%) and 22 male participants (48%). In terms of age, 27 participants (59%) were aged 11–15 years, while 19 (41%) were above 15 years. Class-level information was available for 43 participants: 17 (39%) were in Senior Four, 16 (37%) in Senior Five and 10 (24%) in Senior Six. The class-level total is three fewer than the overall sample, and this discrepancy should be clarified if the original records are available.

Table 1. Participant characteristics reported in the project

Characteristic	Category	Frequency	Percentage
Gender	Female	24	52%
Gender	Male	22	48%
Age	11–15 years	27	59%
Age	Above 15 years	19	41%
Class	Senior Four	17	39%
Class	Senior Five	16	37%

3.2. Comparison of achievement following the two instructional approaches

The study compared two groups of learners who studied a food-testing topic through different instructional approaches. In the traditional-instruction group, 7 of 21 learners passed the assessment, representing 33.3%; the remaining 14 learners (66.7%) did not pass. In the laboratory-practical group, 21 of 23 learners passed, representing 91.3%; the remaining 2 learners (8.7%) did not pass. The difference in the reported pass proportions was approximately 58.0 percentage points in favor of the laboratory-practical group.

Table 2. Reported assessment outcomes by instructional approach

Instructional approach	Total learners	Passed n (%)	Did not pass n (%)
Traditional instruction	21	7 (33.3%)	14 (66.7%)
Laboratory practical work	23	21 (91.3%)	2 (8.7%)

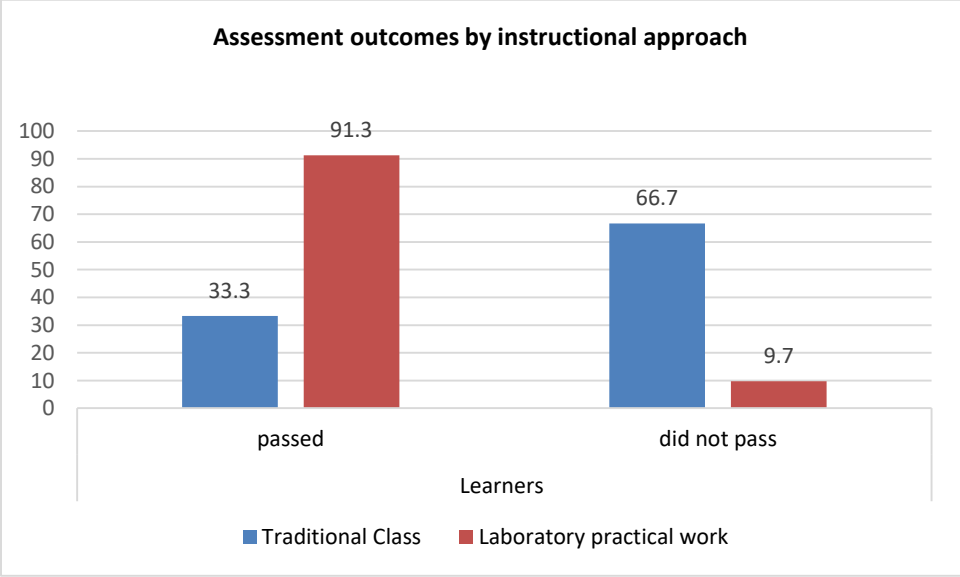

Figure 1. Percentage distribution of assessment outcomes in the two instructional groups.

3.3. Challenges affecting the implementation of laboratory practical work

The findings revealed five major challenges affecting the implementation of laboratory practical work in Biology at Groupe Scolaire Mahembe. These included inadequate or unsuitable laboratory infrastructure, shortages of laboratory apparatus and materials, insufficient chemicals and reagents, limited teacher expertise in conducting laboratory experiments, and insufficient time allocated to practical activities. These challenges emerged as recurring themes across participants' accounts, suggesting that the implementation of laboratory-based Biology teaching was constrained by several interconnected factors.

Inadequate or Unsuitable Laboratory Infrastructure

Participants indicated that the physical condition and availability of laboratory facilities posed a challenge to the effective implementation of practical work. Inadequate laboratory space, unsuitable working conditions, and limited facilities were perceived to affect teachers' ability to organize and conduct practical activities effectively. For instance, teacher 1 said: "Sometimes it is difficult to conduct practical lessons because the laboratory facilities are not adequate to accommodate all the students. This makes it challenging to organize students into groups and ensure that everyone participates."

Shortage of Laboratory Apparatus and Materials

Another challenge identified was the insufficient availability of laboratory apparatus and materials. Participants explained that the shortage of essential equipment limited students' opportunities to engage directly in experiments. In some instances, teachers had to improvise, demonstrate experiments rather than allow students to perform them individually, or teach certain practical concepts theoretically. "We do not have enough apparatus for all students to participate in practical activities. Sometimes, students have to share the available equipment, which reduces their opportunity to handle the materials themselves." Teacher 2 said.

Shortage of Chemicals and Reagents

The findings also highlighted the limited availability of chemicals and reagents required for Biology experiments. Participants suggested that the absence or insufficient quantities of these materials restricted the range of experiments that could be conducted. This challenge particularly affected practical activities requiring specific chemical substances and reagents.

"Even when the apparatus is available, the lack of chemicals sometimes prevents us from carrying out the experiment. We therefore have to explain the expected results to students without allowing them to observe the process themselves." (Teacher 3)

Limited Teacher Expertise in Conducting Laboratory Experiments

Participants also identified limited expertise and confidence in conducting certain laboratory experiments as a challenge. This suggests that the implementation of practical Biology teaching depends not only on the availability of resources but also on teachers' capacity to select, prepare, demonstrate, and supervise laboratory activities. "There are some experiments that require specialized skills and techniques. Without sufficient training and experience, it becomes difficult to prepare and conduct these experiments confidently." Teacher 1 asserted

Insufficient Time for Laboratory Practical Work

Insufficient time was another challenge reported by participants. They explained that the time allocated to Biology lessons was sometimes inadequate for preparing materials, explaining procedures, organizing students, conducting experiments, and discussing observations. Consequently, some practical activities were shortened, postponed, or replaced with theoretical explanations. "Practical lessons require more time than ordinary classroom lessons because students need time to prepare, perform experiments, record observations, and discuss their findings. However, the allocated lesson time is often insufficient." Teacher 3 Another teacher added that Sometimes they cannot complete practical activities within the scheduled lesson period, especially when students are working in groups and need guidance throughout the experiment.

3.4. Strategies proposed to address the challenges

The project reports four broad strategies suggested by participants: referring infrastructure needs to district authorities; improvising appropriate materials where feasible; addressing shortages of laboratory chemicals and consumables; and allocating additional time for practical activities. These strategies point to the need for shared responsibility among teachers, school leaders and education authorities. The project also recommends teacher training, advocacy for laboratory equipment and the establishment or improvement of functional laboratory facilities.

4. Discussion

The descriptive comparison indicates a substantially higher reported pass proportion among learners who participated in the laboratory practical lesson than among those taught through traditional instruction. This pattern is consistent with the argument that laboratory activities can help learners connect scientific concepts with observable evidence and develop practical understanding (Hofstein & Lunetta, 2004). It also aligns with findings from Rwanda reported by Ntawuhiganayo and Nsanganwimana (2022) and Kaneza et al. (2024), although the latter study concerned Chemistry.

The findings must nevertheless be interpreted cautiously. The project reports a small comparison involving 44 learners at one school and one food-testing topic. It does not provide sufficient information about group assignment, baseline equivalence, intervention duration and fidelity, test validity and reliability, or the pass threshold. It also does not provide individual scores, means, standard deviations or inferential tests. Consequently, the difference in pass proportions is descriptive and cannot establish that laboratory instruction alone caused the observed difference. Prior achievement, teacher effects, group composition or other contextual factors may have contributed.

The findings also reinforce the point that practical work is not inherently effective simply because learners manipulate materials. Abrahams and Millar (2008) show that learners may complete practical procedures without fully connecting observations to scientific ideas. Teachers should therefore explain the purpose of each experiment, encourage predictions and explanations, facilitate discussion, and connect experimental evidence to biological concepts. In a food-testing lesson, this includes helping learners explain the significance of observed colour changes and relate them to the presence or absence of particular nutrients.

The implementation challenges identified at Groupe Scolaire Mahembe are consistent with Rwandan literature. Mbonimpaye et al. (2023) highlight gaps in Biology teachers' practical-work knowledge and skills

and the importance of professional development and access to materials. Improving practical science teaching therefore requires more than equipment provision: teachers need support in experimental planning, safety, classroom management, assessment of practical competencies and interpretation of results. Where resources are limited, low-cost alternatives may be useful if they are scientifically valid and safe.

From an experiential learning perspective, practical activities should be followed by reflection and conceptual explanation (Kolb, 1984). A complete learning sequence enables learners to engage with a problem, conduct an investigation, record observations, interpret evidence, explain findings and apply knowledge beyond the immediate experiment. This is compatible with the competence-oriented aspirations of Rwanda's curriculum (REB, 2015).

5. Conclusion

This school-based study found a marked descriptive difference in reported pass rates between learners taught a food-testing topic through laboratory practical work and those taught through traditional instruction. It also identified infrastructural, material, human-resource and time-related constraints affecting the implementation of Biology experiments at Groupe Scolaire Mahembe. The findings support the educational relevance of practical Biology activities while underscoring that their value depends on purposeful instructional design, teacher capacity and institutional support. Given the limited sample, single-school setting and incomplete reporting of the comparison procedure, the achievement difference should be treated as indicative rather than conclusive evidence of a causal effect.

Study Recommendations

Biology teachers should plan practical activities around explicit learning outcomes and ensure that learners interpret and explain observations rather than merely follow procedures.

School leaders should prioritise functional laboratory spaces, maintenance of apparatus, and reliable supplies of essential chemicals and consumables.

Professional development should include practical experimentation, laboratory safety, scientifically appropriate improvisation and assessment of practical skills.

Schools should allocate sufficient timetable time for preparation, implementation, discussion and reflection.

District and national education stakeholders should consider targeted support for schools with limited laboratory resources, including resource-sharing arrangements where appropriate.

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