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Equity in Science Education: A Comparative Analysis of Biology Laboratory Management in Urban and Rural Public Senior High Schools in Sumedang Regency

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Abstract

Educational equity in biology education requires not only the formal availability of laboratories but also students' access to functional equipment, safe practicum environments, institutional support, and opportunities to conduct inquiry-based activities. This exploratory comparative case study examined biology laboratory management in two A-accredited public senior high schools in Sumedang Regency, West Java: SMAN 1 Sumedang as an urban school and SMAN Rancakalong as a rural school. Data were collected from April to May 2026 through structured observation, semi-structured interviews, and document analysis. The interview component involved ten purposively selected participants consisting of two school administrators, two biology teachers who also served as laboratory managers, and six Grade XI students. The observation instrument included 48 indicators across 11 aspects of laboratory management. Data were analyzed thematically using Bafadal's four management functions: planning, organizing, implementation, and supervision. The findings show that both schools experienced serious operational weaknesses despite their A accreditation status. Written laboratory schedules were absent, laboratory work programs were either unavailable or blank, no trained laboratory technician was assigned, only about six of 34 microscopes in the urban school and seven of 20 microscopes in the rural school were functional, laboratory documentation was outdated or unused, and occupational health and safety compliance reached only approximately 25%. The urban school had relatively better physical infrastructure, whereas the rural school experienced more severe limitations in students' independent access to microscopes and authentic practicum activities. The study contributes case-based evidence that accreditation status may mask operational weaknesses in laboratory functionality and inequitable practicum access. Strengthening laboratory personnel, equipment maintenance, documentation, safety facilities, and accreditation indicators based on actual laboratory use is essential for improving equity in science education.

Keywords: Biology laboratory management; Educational equity; Urban-rural disparity; Science learning; School accreditation; Practicum access

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INTRODUCTION

This study uses educational equity to mean the fair opportunity of all students to participate in meaningful science learning, regardless of school location, resource capacity, or institutional context. In biology education, equity is not achieved merely when a school formally owns a laboratory; it is achieved when students can use functional instruments, conduct practicum activities safely, receive teacher and institutional support, and engage directly with evidence. This definition is important because many biology concepts, including cells, tissues, microorganisms, physiology, and ecological processes, cannot be fully understood through verbal explanation alone. Students need opportunities to observe specimens, manipulate instruments, interpret data, and connect empirical evidence with scientific concepts. International frameworks for science education emphasize students' engagement in scientific practices, including asking questions, planning investigations, analyzing data, and constructing explanations (National Research Council, 2012). Therefore, a biology laboratory should be understood as a pedagogical condition for equitable participation in science learning, not simply as a physical facility.

The equity issue becomes more urgent when laboratory access is uneven. UNESCO (2020) frames educational inclusion as the removal of barriers that prevent learners from meaningful participation in education, while the Programme for International Student Assessment shows that Indonesian students' average science performance in 2022 remained far below the OECD average (OECD, 2023). Although PISA scores cannot be attributed to laboratory access alone, they highlight the need to strengthen learning opportunities that develop scientific literacy and inquiry skills. Laboratory-based learning has long been recognized as a distinctive component of science education because it can support conceptual understanding, science process skills, evidence-based reasoning, and positive attitudes toward science when it is planned and managed effectively (Hofstein & Lunetta, 2004; Abrahams & Millar, 2008). Recent studies also show that guided inquiry, practical work, and laboratory engagement can strengthen students' science process skills, conceptual learning, and critical thinking (Rahmadani et al., 2025; Tuaputty et al., 2023; Tadesse et al., 2025).

The logical chain underlying this study is as follows: weak laboratory management restricts practicum access; restricted practicum access reduces students' opportunities to develop inquiry skills and scientific literacy; unequal access to authentic practicum experiences creates inequity in science education; and accreditation status may fail to reveal this problem when it emphasizes formal documentation rather than actual laboratory use. This chain shows why laboratory management is not merely an administrative issue. It directly affects whether students can experience biology as an empirical science.

The instructional value of laboratory work depends strongly on management. Laboratories that are formally available but poorly planned, understaffed, unsafe, or filled with non-functional equipment cannot provide the learning experiences expected by the curriculum. Bafadal's (2008) framework explains educational facility management through four interrelated functions: planning, organizing, implementation, and supervision. In biology laboratories, planning concerns work programs, practicum schedules, procurement, and maintenance preparation; organizing concerns personnel, role distribution, and technical responsibility; implementation concerns the actual use of rooms, instruments, materials, and practicum procedures; and supervision concerns documentation, safety monitoring, inventory control, and follow-up. These functions are mutually dependent because weakness in one function can undermine the entire laboratory system.

Previous Indonesian studies have documented recurring weaknesses in school laboratory management. Mohzana et al. (2023) found that laboratory management in senior high schools often remains weak because planning programs are not consistently implemented and practical activities are constrained by equipment and material shortages. Suharyanto et al. (2020) reported that planning, organizing, implementation, and supervision in science laboratories are rarely optimized simultaneously. Rahmawati et al. (2024a) identified gaps between national laboratory standards and actual school conditions, particularly in equipment completeness, administration, and utilization. These studies confirm that the physical presence of a laboratory does not automatically indicate functional laboratory-based learning.

Urban-rural disparities add another layer to this issue. Rural schools may face constraints in resource allocation, maintenance support, personnel availability, transportation access, and institutional networks. In biology learning, these constraints may appear as fewer functional instruments, weaker safety systems, limited consumable materials, and reduced opportunities for independent student experimentation. However, urban schools may also fail to provide effective laboratory learning when planning, documentation, maintenance, and personnel systems are weak. Therefore, an urban-rural comparison should not assume that urban schools are automatically effective and rural schools are automatically ineffective. A sharper equity analysis must identify which problems are shared across contexts and which problems intensify inequitable student experiences.

The relationship between school accreditation and actual laboratory functionality is also critical. Accreditation is expected to function as an external quality assurance mechanism that reflects school eligibility and performance. Indonesia's IASP 2020 accreditation paradigm emphasizes graduate quality, learning process, teacher quality, and school or madrasah management, while the current national facility standard is regulated through Permendikbudristek No. 22 of 2023. Nevertheless, studies suggest that accreditation and quality assurance practices may still emphasize administrative compliance more than continuous operational quality (Irawan et al., 2020; Kartiniasih et al., 2017; Thobi, 2022). This raises an important question for science education: can schools with the same high accreditation status still provide different and inadequate access to authentic biology laboratory learning?

Although previous studies have examined laboratory facilities and laboratory management in Indonesian schools, four gaps remain. First, many studies emphasize facility completeness without analyzing planning, organizing, implementation, and supervision as an integrated management system. Second, many studies examine a single school context and do not directly compare urban and rural schools within the same administrative region. Third, accreditation status is often treated as a background characteristic rather than as a possible mechanism that may obscure operational weaknesses. Fourth, students' actual practicum experiences, including independent access to instruments and perceptions of safety, are often treated as secondary evidence rather than central indicators of equity.

This study addresses these gaps by comparing biology laboratory management in two A-accredited public senior high schools in Sumedang Regency, West Java: SMAN 1 Sumedang as the urban case and SMAN Rancakalong as the rural case. The novelty of the study lies in three contributions. Conceptually, it links laboratory management with science education equity by treating access to functional equipment, independent practicum opportunities, safe learning environments, institutional support, and accreditation fairness as interrelated equity dimensions. Methodologically, it combines structured observation, interviews, and document analysis across two contrasting schools with the same accreditation status, allowing accreditation to function as a contextual control rather than an assumed indicator of quality. Practically, it provides case-based evidence for improving laboratory management and accreditation assessment so that quality assurance systems pay closer attention to actual laboratory use.

Based on this rationale, this study aims to analyze and compare biology laboratory management in urban and rural public senior high schools through the four management functions of planning, organizing, implementation, and supervision. The study is guided by three questions: (1) how are these four management functions implemented in each school; (2) what similarities and differences appear between the urban and rural cases; and (3) how do these conditions shape students' equitable access to meaningful biology practicum learning? The scope of the study is limited to two case schools and does not claim statistical representation of all urban and rural schools in Sumedang Regency or Indonesia. Instead, it provides exploratory, case-based evidence on how laboratory management weaknesses may shape unequal practicum access despite identical accreditation status.

METHOD

Research Design

This study employed a descriptive qualitative approach with an exploratory comparative multi-site case study design. A qualitative design was selected because the study examined laboratory management practices in their natural institutional settings and sought to understand how formal management arrangements were translated into everyday laboratory use (Waruwu, 2023). A comparative case study was appropriate because the research compared two schools that shared the same A accreditation status but differed in geographical and institutional context. This design enabled the study to examine whether similar formal quality recognition corresponded with similar laboratory functionality and student practicum access. The study does not aim to generalize statistically, but to generate analytical insights from two carefully selected cases.

Study Sites and Case Selection

The study was conducted from April to May 2026 in Sumedang Regency, West Java, Indonesia. SMAN 1 Sumedang was selected to represent the urban case because it is located in the regency's urban center and has relatively greater access to public services, transportation, and institutional facilities. SMAN Rancakalong was selected to represent the rural case because it is located outside the regency's urban center and serves students in a more peripheral geographical setting. The urban-rural classification was operationalized through location, accessibility, and school service context rather than through a broad demographic claim. Both schools were selected purposively because they are public senior high schools with A accreditation status, allowing the study to compare laboratory management under similar formal quality recognition while observing differences in operational functionality.

Participants and Sampling

Participants were selected purposively based on their direct involvement in laboratory management or biology practicum learning. The interview component involved ten participants: two school administrators responsible for facilities, infrastructure, or laboratory policy; two biology teachers who also performed laboratory management duties; and six Grade XI students, with three students from each school. Grade XI students were selected because they had experienced biology learning across several topics and could describe practicum access during senior high school. To protect confidentiality, direct quotations identify participants by role and school context rather than by personal name.

Table 1. Participant Profile and Sampling Distribution

School	Context	Institutional Informant	Biology Teacher/ Lab. Manager	Grade XI Students	Total
SMAN 1 Sumedang	Urban public senior high school; A accreditation	1 vice principal for facilities and infrastructure	1 biology teacher	3 students	5
SMAN Rancakalong	Rural public senior high school; A accreditation	1 principal/school administrator	1 biology teacher	3 students	5
Total	-	2	2	6	10

Instruments and Data Collection

Data were collected through structured observation, semi-structured interviews, and document analysis using a triangulation approach (Sugiyono, 2022). The observation instrument consisted of 48 indicators across 11 aspects of laboratory management: laboratory room condition, furniture, equipment availability, equipment functionality, storage and maintenance, administrative documents, laboratory utilization, organizational structure, safety facilities, waste management, and alignment with national facility expectations. The instrument was developed by combining Bafadal's (2008) management functions, the study's equity indicators, Permendikbudristek No. 22 of 2023 as the current national standard for educational facilities, and item-level benchmarks from earlier laboratory facility references, including Permendiknas No. 24 of 2007, where relevant for comparison with previous studies. Semi-structured interviews explored planning, organizing, implementation, supervision, laboratory access, equipment use, safety, administrative practices, and perceived barriers. Interviews were recorded in field notes and, where permitted, audio recordings, then transcribed for analysis.

Document analysis examined laboratory inventory books, usage records, work programs, lesson plans or teaching modules, laboratory regulations, equipment condition records, and safety-related documents.

Data Analysis

Data analysis used thematic analysis guided by Bafadal's (2008) four management functions: planning, organizing, implementation, and supervision. The analysis began with data familiarization through repeated reading of observation notes, interview transcripts, and documents. Deductive codes were derived from the four management functions, while inductive codes were generated from recurring empirical patterns, including technician absence, equipment deterioration, safety gaps, informal practicum substitution, accreditation mismatch, and student access limitations. The codes were then grouped into categories and compared across schools using a cross-case matrix. The analysis distinguished between findings that appeared in both cases and findings that reflected urban-rural differences. Equity implications were interpreted through five dimensions: access to laboratory rooms, access to functional equipment, opportunity for independent practicum, access to safe learning environments, and institutional support for laboratory learning.

Trustworthiness and Ethical Considerations

Credibility was strengthened through triangulation among observation, interview, and document data (Miles et al., 2014). Key findings were checked against documentary evidence and clarified through follow-up confirmation with relevant school informants when necessary. Researcher discussion was used to review coding consistency and reduce individual interpretive bias. The study was conducted after obtaining permission from the participating schools. Adult participants were informed about the study purpose, voluntary participation, and the academic use of interview excerpts. Student participation was conducted with school authorization and student assent under school-approved procedures. No sensitive personal data were collected. Participants were allowed to decline questions, and student quotations are reported without personal identifiers. The school names are retained because the study was designed as a contextual institutional case study and institutional identification was authorized at the school level.

Data were collected through observation, in-depth interviews, and document analysis using a triangulation approach (Sugiyono, 2022). Direct observation employed a structured observation instrument consisting of 48 indicators covering 11 aspects of laboratory management, including physical facilities, laboratory equipment, administrative standards, safety facilities, organizational structure, laboratory utilization, and compliance with national laboratory standards. Semi-structured interviews were conducted based on the management functions proposed by Bafadal (2008), namely planning, organizing, implementation, and supervision. Document analysis included laboratory inventory books, laboratory usage records, work programs, lesson plans, laboratory regulations, and equipment condition reports. Data analysis used thematic analysis guided by the four management functions of planning, organizing, implementation, and supervision (Bafadal, 2008). The analysis involved data reduction, categorization, comparison across research sites, and interpretation of findings to identify similarities and differences in biology laboratory management between urban and rural schools. Data credibility was strengthened through triangulation of observation results, interview findings, and documentary evidence (Miles et al., 2014).

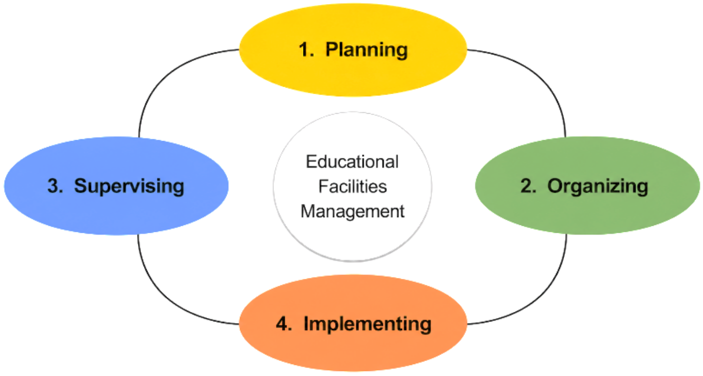

Figure 1. Four Management Functions Framework of Bafadal (2008) Applied to Biology Laboratory Management

The framework guided data collection, categorization, and thematic analysis covering planning, organizing, implementing, and supervising functions of biology laboratory management.

RESULTS AND DISCUSSION

Planning of Biology Laboratory Utilization

Findings from observations, interviews, and document analysis consistently indicated that the planning of biology laboratory utilization in both schools had not been implemented systematically. Although both schools formally incorporated practical activities into biology learning documents, the operational planning required to support sustainable laboratory utilization remained limited. At SMAN 1 Sumedang, document analysis revealed that lesson plans and teaching modules formally included laboratory practicum activities. However, direct observation showed the absence of written laboratory schedules, procurement plans for practicum materials, and laboratory work programs. No documented planning system was found regarding laboratory utilization, equipment maintenance, or practicum scheduling. This condition demonstrates that laboratory planning was administratively recognized in instructional documents but was not operationally implemented in daily educational practice.

The vice principal responsible for facilities and infrastructure explained that financial limitations significantly influenced laboratory planning and utilization. According to the informant, laboratory needs had to compete with other institutional priorities within the allocation of School Operational Assistance funds.

> *"We* fully *depend on School Operational Assistance funding. Budget allocation must be prioritized, and laboratory needs have to compete with other institutional demands considered more urgent."* (Vice Principal for Facilities and Infrastructure, SMAN 1 Sumedang, personal communication, April 2026)

This condition directly affected the implementation of biology practicum activities. The biology teacher estimated that less than 30% of the planned practical activities were successfully implemented during the previous academic year. The interview findings were strengthened by students' statements, in which all interviewed eleventh-grade students reported participating in only one or two laboratory sessions since entering senior high school. One student explained that a fermentation practicum assignment had to be conducted independently at home because laboratory access at school was unavailable. These findings indicate that individual student initiatives frequently replaced institutional laboratory planning, reflecting a gap between curriculum expectations and actual implementation.

Similar conditions were identified at SMAN Rancakalong. Document analysis confirmed that a laboratory work program template physically existed; however, the document remained entirely blank without evidence of active implementation. The principal explained that practicum preparation was conducted informally by the biology teacher approximately one week before laboratory activities without formal written planning. Although the biology teacher reported relatively more active practicum implementation for eleventh-grade students, including blood typing tests, urine analysis, and food testing activities, laboratory access for tenth-grade students remained limited.

The biology teacher further explained that practicum activities were often adjusted depending on the availability of materials and equipment. When laboratory resources were unavailable or damaged, alternative learning strategies were implemented.

> *"If materials were unavailable or equipment was damaged, the practicum activities were replaced with alternative methods, such as learning videos or online virtual laboratory simulations."* (Biology Teacher, SMAN Rancakalong, personal communication, April 2026)

Overall, the findings demonstrate that laboratory utilization planning in both schools remained highly dependent on situational decisions rather than systematic managerial planning. Although both schools possessed A accreditation status, the absence of structured laboratory planning limited the consistency and effectiveness of practicum-based biology learning. These findings indicate that formal accreditation status does not necessarily guarantee effective laboratory planning or equitable access to practical science learning experiences.

The findings showed that the planning of biology laboratory utilization in both schools had not been implemented systematically. Although practicum activities were formally included in lesson plans and teaching modules, supporting managerial components such as written laboratory schedules, laboratory work programs, and structured procurement planning were largely absent. At SMAN 1 Sumedang, practicum realization was estimated at less than 30% annually, while students reported experiencing only one or two practicum sessions since Grade X. Similarly, at SMAN Rancakalong, laboratory planning was conducted informally by the biology teacher shortly before practicum activities without formal written planning. These conditions indicate that laboratory planning remained administrative rather than operational in supporting biology learning.

From a management perspective, the findings confirm Bafadal's (2008) proposition that educational facilities can only function effectively when planning processes are implemented systematically and continuously. The absence of structured planning directly affected laboratory utilization and reduced students' opportunities to engage in practical science learning. This finding is consistent with Mohzana et al. (2023), who reported that laboratory management in Indonesian senior high schools frequently fails because planning programs are not implemented consistently and organizational support remains weak. Similar findings were also reported by Suharyanto et al. (2020), who found that planning and implementation functions in school laboratories are often not conducted optimally and simultaneously.

The limited implementation of practicum activities also has important implications for educational equity. Laboratory-based learning is essential for developing scientific literacy, inquiry skills, and conceptual understanding in biology education. Rahmadani et al. (2025) found that effective laboratory utilization significantly improves students' biology learning outcomes, while Palisoa and Lumaela (2022) demonstrated that science process skills are strengthened through direct laboratory engagement. Therefore, limited practicum realization in both schools indicates not only managerial weakness but also unequal access to meaningful science learning experiences, particularly for students in resource-limited contexts.

Although both schools held A accreditation status, the findings demonstrate that accreditation did not necessarily guarantee effective laboratory planning or equitable laboratory access. The urban school showed relatively better infrastructural conditions, yet planning weaknesses still restricted practicum implementation. Meanwhile, the rural school experienced additional limitations related to resource availability and informal management practices. These findings support Irawan et al. (2020), who argued that accreditation systems frequently emphasize administrative compliance rather than operational effectiveness in educational management.

Organizing of Biology Laboratory Management

Findings from observations, interviews, and document analysis revealed that the organizational structure of biology laboratory management in both schools was not adequately established and operated with significant structural limitations. In both schools, laboratory management responsibilities were concentrated on biology teachers without the support of dedicated laboratory personnel, resulting in overlapping duties and ineffective managerial distribution. At SMAN 1 Sumedang, direct observation confirmed the absence of a formally displayed laboratory organizational structure and the unavailability of laboratory work programs specifying task allocation and managerial responsibilities. The biology teacher functioned as the de facto laboratory manager, while administrative staff members informally assisted with equipment preparation without formal job descriptions or technical responsibilities. This situation reflected the lack of institutionalized laboratory management within the school organization.

The vice principal responsible for facilities and infrastructure acknowledged that regulatory and financial constraints contributed to the organizational limitations of laboratory management.

> "*There are regulatory barriers. Current regulations prohibit the recruitment of new honorary laboratory staff, and this situation is worsened by budget limitations and the elimination of school tuition fees that previously supported school operational activities.*" (Vice Principal for Facilities and Infrastructure, SMAN 1 Sumedang, personal communication, April 2026)

The biology teacher identified the absence of dedicated laboratory personnel as the most significant structural problem affecting laboratory operations. The teacher explained that laboratory management responsibilities, administrative documentation, equipment preparation, and classroom teaching had to be handled simultaneously by a single individual. As a result, laboratory management became highly dependent on personal initiative rather than institutional support. The teacher further reported relying on informal university networks to obtain technical assistance for repairing laboratory equipment because no official technical support system was available within the school structure.

A similar but more complex organizational problem was identified at SMAN Rancakalong. Formally, the school principal held the position of laboratory head for all school laboratories; however, the role functioned only administratively without operational involvement. The formal laboratory head position had been assigned to a civics teacher based on teaching workload distribution rather than laboratory competence or certification. The principal openly acknowledged this condition during the interview.

> *"The current laboratory head position is held by a civics teacher because there is no other option. In this school, laboratory head assignments are usually given to teachers with fewer teaching hours. From a professionalism perspective, this is not ideal, and the assigned teacher also does not have laboratory certification."* (Principal, SMAN Rancakalong, personal communication, April 2026)

In practice, the biology teacher simultaneously managed classroom instruction, laboratory administration, equipment preparation, and laboratory maintenance activities. The teacher described the heavy workload created by the absence of laboratory personnel and technical support.

> *"It is very demanding, but we manage as best as possible. When practicum activities are conducted, I usually ask students for assistance or use my free teaching hours to prepare laboratory equipment. If equipment is damaged, because*

there is no laboratory technician, I first consult with the school administration.” (Biology Teacher, SMAN Rancakalong, personal communication, April 2026)

Both school principals confirmed that formal requests for laboratory technician positions had been submitted repeatedly to the regional education authority but had not received approval due to persistent budget constraints. In addition to personnel limitations, both schools also faced organizational challenges related to large class sizes mandated by provincial policy. The principal of SMAN Rancakalong explained that an effective practicum group ideally consisted of approximately 24 students, while 36 students represented the maximum manageable number for proper supervision. Consequently, classes consisting of approximately 50 students created structural barriers to effective laboratory management and practical learning implementation regardless of equipment availability.

Overall, the findings indicate that the organizing function of laboratory management in both schools remained structurally weak. The absence of certified laboratory personnel, unclear task distribution, overlapping professional responsibilities, and institutional resource limitations significantly reduced the effectiveness of laboratory management. These conditions demonstrate that laboratory organization in both urban and rural schools continued to rely heavily on individual adaptation rather than sustainable institutional systems.

The findings revealed that the organizing function of biology laboratory management in both schools remained structurally weak and highly dependent on individual teacher initiatives. In both schools, biology teachers simultaneously functioned as instructors, laboratory managers, administrative personnel, and equipment handlers due to the absence of dedicated laboratory technicians. At SMAN 1 Sumedang, laboratory responsibilities were informally supported by administrative staff without clear job descriptions or technical competence, while at SMAN Rancakalong, the formal laboratory head position was assigned to a Civics teacher based on teaching load considerations rather than laboratory expertise. These conditions indicate that laboratory organization had not been institutionalized systematically within the school management structure.

From a management perspective, these findings support Bafadal’s (2008) argument that effective educational facility management requires clear organizational structures, defined task distribution, and competent personnel. The absence of dedicated laboratory staff created overlapping responsibilities that reduced the effectiveness of laboratory management and increased dependence on personal adaptation strategies. Similar findings were reported by Mohzana et al. (2023), who found that weak organizational structures and unclear managerial roles frequently hinder laboratory management implementation in Indonesian senior high schools. Suharyanto et al. (2020) also emphasized that ineffective organizational coordination contributes directly to the limited operation of school laboratories.

The organizational burden was particularly severe at SMAN Rancakalong, where a single biology teacher handled teaching, administration, equipment preparation, and laboratory maintenance simultaneously. This finding confirms Sili et al. (2024), who identified the availability of laboratory personnel as a key determinant of laboratory management quality. Furthermore, the large class sizes reported in both schools created additional barriers to effective practicum supervision. The principal of SMAN Rancakalong explained that an ideal practicum group should consist of approximately 24 students, whereas actual classroom conditions reached around 50 students per class. Such conditions limited teachers’ capacity to supervise practicum activities effectively and reduced students’ opportunities for direct laboratory engagement.

The findings also demonstrate important implications for educational equity. Although the urban school demonstrated relatively better institutional support and informal assistance networks, both schools experienced similar structural weaknesses related to personnel shortages and unclear organizational systems. These conditions suggest that laboratory management problems were not solely caused by geographical differences but also by broader structural and policy limitations affecting science education management. The findings further support Efendi and Jayanti (2024), who argued that weak organizational implementation contributes to incomplete laboratory administration and reduced effectiveness of practicum-based learning.

Implementation of Biology Laboratory Equipment Utilization

The implementation of biology laboratory utilization in both schools demonstrated significant disparities between the physical availability of laboratory facilities and their actual operational use in science learning activities. Although both schools possessed laboratory rooms and basic laboratory infrastructure, the effectiveness of equipment utilization remained limited due to equipment damage, inadequate maintenance, and restricted operational capacity.

At SMAN 1 Sumedang, direct observation confirmed that the physical laboratory environment was generally adequate. The laboratory contained 36 chairs, eight laboratory tables, air conditioning, fans, six large windows, eight functioning ceiling lamps, and operational sinks. The laboratory room was also used exclusively for practicum activities and was not converted for non-laboratory purposes. However, serious problems were identified regarding laboratory equipment functionality. Of the 34 microscopes physically available, observations and teacher interviews confirmed that only approximately six microscopes were operational. Several microscopes showed fungal contamination on the lenses, non-responsive mechanical components, and poor storage conditions caused by the absence of silica gel in storage cabinets.

The biology teacher acknowledged that damaged equipment significantly limited practicum implementation.

> *"The condition is exactly like that. Many microscopes are damaged and cannot be used optimally. We hope that after repairs are completed, cell and tissue practicum activities can be conducted properly."* (Biology Teacher, SMAN 1 Sumedang, personal communication, April 2026)

As a consequence of equipment and material shortages, adaptive substitution practices had become normalized within laboratory activities. The biology teacher explained that Betadine was frequently used as a substitute for iodine solution, bottled mineral water replaced distilled water, and personal funds were often used to purchase laboratory materials when school procurement processes were too slow. Students' testimonies reinforced these findings. One eleventh-grade student reported bringing knives and measuring instruments from home during potato-based practicum activities because laboratory equipment was insufficient. This finding indicates that institutional limitations in laboratory management were frequently transferred to students individually, reducing the quality and consistency of practical learning experiences.

At SMAN Rancakalong, the most critical finding related to educational equity concerned students' access to microscope-based practicum activities. Observation confirmed the physical presence of approximately 20 microscopes in the laboratory. However, interviews with teachers and students consistently revealed that none of the interviewed eleventh-grade students had ever independently operated a microscope during their studies at the school. One student explained the situation as follows:

> *"We have never had the opportunity to use microscopes independently because most of them cannot function properly. There is one digital microscope, but the teacher experienced difficulties operating it, so it was not used either."* (Eleventh-Grade Student, SMAN Rancakalong, personal communication, April 2026)

This finding was consistently confirmed by all interviewed students at SMAN Rancakalong. The biology teacher associated the equipment deterioration with environmental damage that occurred after the school renovation process in 2024.

"After the 2024 renovation, laboratory equipment had to be relocated, and the storage conditions became humid. There were even termite problems. Proper maintenance is something that I realistically cannot manage alone." (Biology Teacher, SMAN Rancakalong, personal communication, April 2026)

The teacher further explained that microscope-dependent practicum activities for tenth-grade biology topics, including bacteria and fungi observations, could no longer be conducted directly. Consequently, these learning materials were delivered through instructional videos and virtual laboratory simulations instead of hands-on laboratory practice. Although these substitutions reflected adaptive teaching strategies, they also demonstrated that students at SMAN Rancakalong received science learning experiences that differed substantially from curriculum expectations and national laboratory standards.

Overall, the findings indicate that the implementation of biology laboratory utilization in both schools remained operationally ineffective despite the physical existence of laboratory facilities and accreditation recognition. The limited functionality of laboratory equipment, inadequate maintenance systems, and reliance on substitute learning methods reduced students' opportunities to engage in authentic scientific investigation. These conditions illustrate how inequalities in laboratory implementation contribute directly to disparities in the quality of science learning between urban and rural school contexts.

The findings revealed that the implementation of biology laboratory utilization in both schools remained operationally ineffective despite the physical availability of laboratory facilities and equipment. At SMAN 1 Sumedang, the laboratory environment was physically adequate and exclusively used for practicum activities; however, most optical equipment was non-functional. Of the 34 microscopes available, only approximately six could still operate properly, while the remaining units experienced fungal contamination, damaged mechanical components, and inadequate storage conditions. Similar conditions were identified at SMAN Rancakalong, where only around seven of approximately 20 microscopes remained functional following humidity and termite damage after the 2024 renovation. These findings indicate that the existence of laboratory facilities alone did not guarantee effective laboratory-based learning implementation.

From a management perspective, the findings support Bafadal's (2008) argument that educational facilities require continuous maintenance and operational supervision to function effectively in supporting learning activities. The severe limitations in microscope functionality directly reduced students' opportunities to engage in authentic scientific investigation. These findings are consistent with Rahmawati et al. (2024a), who found significant discrepancies between laboratory equipment availability and actual operational conditions in Indonesian schools. Similar findings were also reported by Rizkiyah et al. (2025), who identified that many laboratory facilities in rural schools formally existed but could not function optimally due to maintenance limitations and inadequate managerial support.

The study also revealed that adaptive substitution practices had become normalized in both schools as responses to equipment and material shortages. At SMAN 1 Sumedang, teachers substituted iodine with Betadine, replaced distilled water with bottled mineral water, and occasionally used personal funds to purchase laboratory materials. Meanwhile, at SMAN Rancakalong, microscope-dependent practicum activities were replaced with virtual laboratory simulations, videos, and demonstration-based instruction. Although these strategies reflected strong teacher commitment, they simultaneously demonstrated systemic institutional limitations in supporting practical science learning. This finding supports Puspita and Wulandari (2026), who emphasized that sustainable laboratory optimization requires systematic institutional support rather than dependence on individual teacher adaptation.

The limitations in laboratory implementation also carried important implications for educational equity. Students at SMAN Rancakalong reported never independently operating microscopes during their studies despite the physical presence of laboratory equipment, while students at SMAN 1 Sumedang experienced limited access due to large-group sharing systems and equipment shortages. These conditions indicate unequal opportunities for developing scientific inquiry skills and practical competencies. Previous studies by Rahmadani et al. (2025) and Tuaputty et al. (2023) demonstrated that effective laboratory-based learning significantly improves conceptual understanding, critical thinking, and science process skills. Therefore, restricted laboratory implementation in both schools represents not only a managerial problem but also a direct limitation on students' access to equitable and meaningful science education.

Supervision and Maintenance of Biology Laboratories

Supervision emerged as the most consistently deficient management function in both schools, with findings from observations, interviews, and document analysis mutually reinforcing one another across nearly all indicators. The findings demonstrated that laboratory supervision and maintenance were not conducted systematically and largely depended on incidental institutional needs rather than continuous managerial practices.

At SMAN 1 Sumedang, physical examination of laboratory administrative records confirmed that the laboratory inventory book had last been updated during the 2013/2014 academic year. No laboratory usage logbooks, written scheduling documents, equipment condition cards, or laboratory work programs were found during the observation process. Standard operating procedure documents had not yet been printed or displayed publicly, although draft laboratory regulations written in Indonesian were identified during document analysis. These findings indicate that laboratory supervision was administratively weak and lacked continuous monitoring mechanisms.

The biology teacher identified bureaucratic and infrastructural barriers as the main causes of the ineffective supervision system.

> *"There are two major obstacles: the initial laboratory condition was extremely disorganized and dirty, and the bureaucratic process for disposing damaged equipment takes a very long time. Without completing that process first, we cannot formally procure replacement equipment."* (Biology Teacher, SMAN 1 Sumedang, personal communication, April 2026)

The findings at SMAN Rancakalong reflected even deeper administrative weaknesses. Document analysis confirmed that templates for inventory books, equipment cards, and laboratory usage records physically existed; however, all documents remained completely blank without evidence of regular administrative implementation. The school principal explained that laboratory documentation activities were generally completed only during supervisory visits or accreditation preparation periods rather than as part of routine operational management.

> *"Laboratory administration still depends entirely on the biology teacher, who also serves as the laboratory manager. In the future, we hope there will be a dedicated laboratory technician so that administrative responsibilities can be managed separately and more appropriately."* (Principal, SMAN Rancakalong, personal communication, April 2026)

Laboratory safety supervision also demonstrated serious deficiencies in both schools. Compliance with occupational health and safety standards reached only approximately 25%, with functioning sinks representing the only consistently available safety facility. Direct observation confirmed the absence of fire extinguishers, properly equipped first-aid kits, and laboratory waste disposal systems at both research locations. Student interviews further revealed awareness of these safety limitations. One eleventh-grade student at SMAN Rancakalong expressed concern regarding the absence of emergency safety equipment.

> *"There is no fire extinguisher and no basic first-aid equipment in the laboratory.*

In my opinion, those facilities are important and should be available.” (Eleventh-Grade Student, SMAN Rancakalong, personal communication, April 2026)

Similar concerns were identified at SMAN 1 Sumedang. Student informants reported that no visible first-aid equipment was available in the laboratory and expressed uncertainty regarding emergency procedures beyond verbally reporting incidents to teachers. The biology teacher explained that saline solution had been prepared as a temporary response for minor injuries and that requests for fire extinguishers had already been formally submitted but had not yet been fulfilled. The vice principal further stated that the current school safety policy prioritized rapid referral to nearby health facilities rather than immediate laboratory-based emergency intervention, following recent guidance from the regional education authority.

Overall, the findings demonstrate that supervision and maintenance systems in both schools remained highly ineffective despite the formal existence of laboratory facilities and accreditation status. Administrative monitoring, equipment maintenance, and occupational safety management were implemented inconsistently and lacked institutional sustainability. These conditions indicate that laboratory supervision in both urban and rural schools continued to function reactively rather than preventively, contributing to the ongoing limitations in the quality and safety of science practicum learning.

The findings revealed that supervision and maintenance represented the weakest management function in both schools. Administrative monitoring, equipment maintenance, and laboratory safety management were implemented inconsistently and depended largely on incidental institutional needs rather than continuous managerial practices. At SMAN 1 Sumedang, laboratory inventory records had not been updated since the 2013/2014 academic year, while laboratory usage logbooks, equipment condition cards, written schedules, and laboratory work programs were absent. Similarly, at SMAN Rancakalong, administrative document templates physically existed but remained completely blank without evidence of regular implementation. These findings indicate that laboratory supervision systems in both schools lacked systematic monitoring and sustainable administrative management.

From a management perspective, these findings confirm Bafadal’s (2008) proposition that supervision functions are essential to ensure the sustainability, effectiveness, and accountability of educational facility management. Weak supervision systems contributed directly to poor laboratory maintenance and administrative disorder in both schools. These findings are consistent with Efendi and Jayanti (2024), who found that ineffective organizational supervision results in incomplete documentation and weak operational follow-up in school laboratories. Similar findings were also reported by Mohzana et al. (2023), who emphasized that weak supervision mechanisms frequently contribute to the deterioration of laboratory facilities and reduced practicum implementation in Indonesian schools.

The study further revealed serious deficiencies in occupational health and safety management. Compliance with laboratory safety standards reached only approximately 25% in both schools, with functioning sinks representing the only consistently available safety facility. Fire extinguishers, complete first-aid kits, and laboratory waste disposal systems were absent in both locations. Students in both schools were aware of these safety limitations and expressed concerns regarding emergency preparedness. These findings support Adam et al. (2026), who identified laboratory safety and equipment functionality as major gaps between students’ expectations and actual laboratory service quality. The absence of adequate safety infrastructure demonstrates that laboratory supervision had not yet prioritized preventive safety management as part of sustainable science learning support systems.

The findings also indicate that ineffective supervision contributed directly to inequalities in science learning quality. In both schools, damaged equipment remained unrepaired for long periods, administrative monitoring was neglected, and laboratory management depended heavily on individual teacher initiatives rather than institutional systems. This condition supports Irawan et al. (2020) and Thobi (2022), who argued that school accreditation systems often emphasize formal compliance rather than continuous operational quality. Although both schools possessed A accreditation status, the supervision and maintenance systems remained weak and reactive, limiting the quality, safety, and sustainability of practicum-based science learning.

The visual summary below is used as an analytical bridge between the qualitative field notes and the cross-case interpretation. By converting the 48 structured observation indicators into condition categories and a readiness index, the figures make visible which weaknesses are incidental and which weaknesses represent systemic laboratory management failure. This visual condensation strengthens data triangulation because observation, interview, and document evidence can be read against the same management dimensions used in the thematic analysis (Bafadal, 2008; Miles et al., 2014).

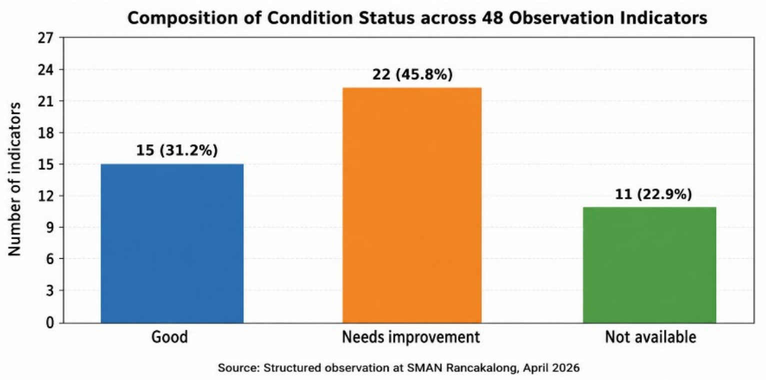

Figure 2. Condition-status composition across 48 structured observation indicators at SMAN Rancakalong

Figure 2 shows that only 15 of 48 indicators (31.2%) were in good condition, while 22 indicators (45.8%) required improvement and 11 indicators (22.9%) were not available. This means that suboptimal or absent components accounted for more than two thirds of the observed laboratory system. The finding is therefore not a minor facility gap; it indicates that the rural laboratory had basic physical presence but lacked sufficient functional readiness to support stable practicum implementation. This pattern supports previous evidence that laboratory availability does not automatically translate into effective laboratory use when planning, maintenance, and equipment functionality are weak (Mohzana et al., 2023; Rahmawati et al., 2024a).

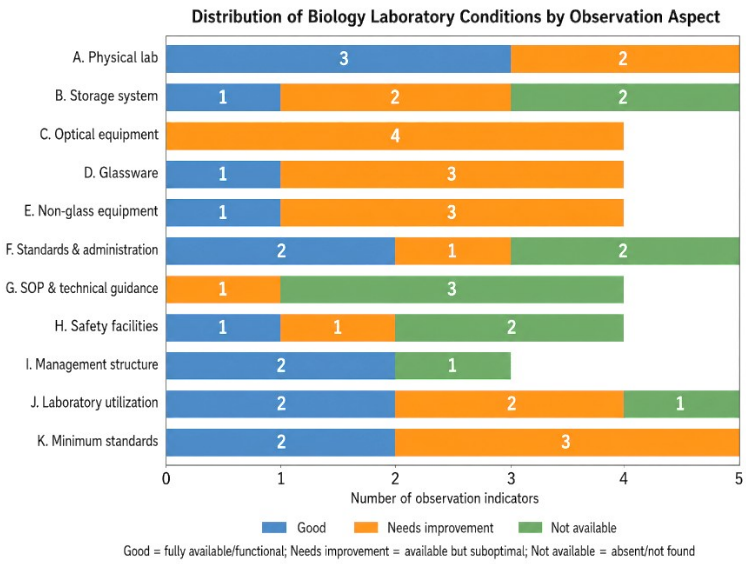

Figure 3. Distribution of condition categories across 11 biology laboratory observation aspects at SMAN Rancakalong

Figure 3 identifies where the management deficit was concentrated. The most critical clusters appeared in SOP and technical guidance, safety facilities, storage systems, optical equipment, and laboratory administration. These aspects are not peripheral because they determine whether students can use equipment safely, repeatedly, and independently. In Bafadal's management framework, these clusters correspond directly to organizing, implementation, and supervision functions; their weakness explains why the presence of laboratory rooms and instruments did not produce equitable practicum access. The safety gap is especially important because inadequate emergency facilities and unclear procedures reduce students' confidence and expose laboratory learning to preventable risks (Bafadal, 2008; Efendi & Jayanti, 2024; Adam et al., 2026).

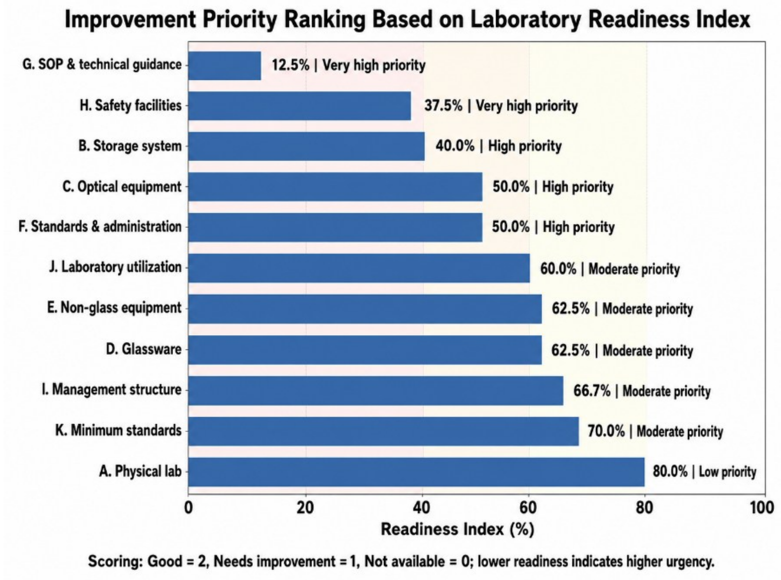

Figure 4. Improvement priority ranking derived from the readiness index for the biology laboratory at SMAN Rancakalong

Figure 4 sharpens the managerial implication by ranking improvement priorities through a readiness index. SOP and technical guidance had the lowest readiness score (12.5%), followed by occupational health and safety facilities (37.5%), storage systems (40.0%), optical equipment (50.0%), and laboratory administration (50.0%). The ranking shows that immediate improvement should not begin with equipment procurement alone. The first intervention should establish procedural governance, visible safety standards, storage control, inventory discipline, and routine maintenance, because these systems protect existing assets and make future procurement sustainable. This interpretation is consistent with studies showing that laboratory optimization depends on continuous management support, not only on the formal availability of tools (Suharyanto et al., 2020; Puspita & Wulandari, 2026).

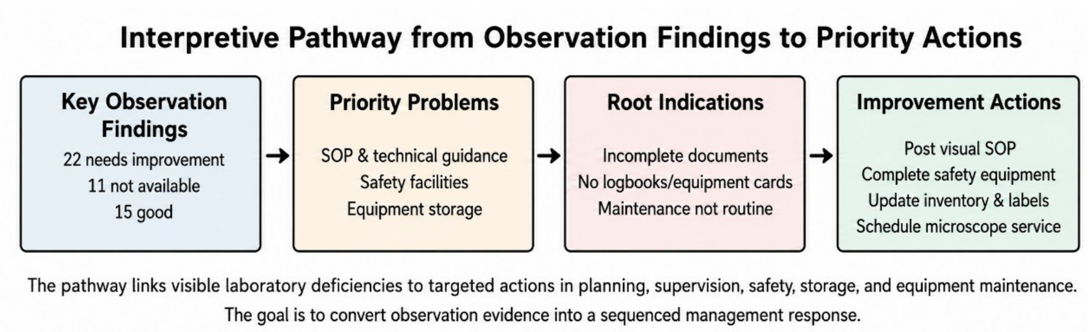

Figure 5. Management pathway linking observation evidence to prioritized improvement actions at SMAN Rancakalong

Figure 5 translates the observation evidence into a sequence of managerial action. The pathway clarifies that visible problems, such as unavailable SOP, weak safety facilities, unsystematic storage, and damaged microscopes, should be treated as symptoms of deeper supervisory and organizational weaknesses. Therefore, the recommended actions must be sequenced: post concise visual SOP and equipment guidance, complete safety infrastructure, label and separate storage areas, update inventory and equipment cards, activate logbooks, and schedule microscope servicing. Such sequencing prevents the school from treating broken equipment as an isolated technical issue and instead positions maintenance, documentation, and safety as integrated conditions for equitable science learning (Bafadal, 2008; Rahmadani et al., 2025; Tadesse et al., 2025).

Taken together, Figures 2–5 sharpen the equity argument of this study. SMAN Rancakalong showed relatively adequate physical-laboratory readiness, but the weakest indicators were located in the invisible systems that make laboratory learning safe, functional, and repeatable: SOP, safety, storage, documentation, equipment maintenance, and technical personnel support. This condition explains why students could be enrolled in an A-accredited school and still lack independent access to microscope-based practicum learning. The figures therefore strengthen the conclusion that accreditation status may conceal operational inequality when quality assurance emphasizes formal possession of facilities more than their actual use in science learning (Hofstein & Lunetta, 2004; Irawan et al., 2020; Thobi, 2022). The comparative findings across the urban and rural cases are presented in Table 1.

Table 1. Comparative Findings of Biology Laboratory Management in Urban and Rural Public Senior High Schools

Function	Indicator	SMAN 1 Sumedang (Urban)	SMAN Rancakalong (Rural)
Planning	Written laboratory usage schedule	Absent (Observation; document analysis)	Absent (Observation; document analysis).
	Laboratory work program	Absent (Document analysis)	Template available but entirely blank (Document analysis).
	Practicum realization rate	<30% annually (Teacher interview)	Approximately 5 sessions per semester for Grade XI; limited in Grade X (Teacher interview).
	Student practicum experience	1–2 sessions since Grade X; one student conducted practicum independently at home (Student interview)	3–5 sessions; no independent microscope use reported (Student interview; observation).
Organizing	Permanent laboratory technician	Absent; administrative staff assist informally (Observation; vice principal interview)	Absent; biology teacher manages all laboratory activities (Observation; principal interview).
	Laboratory head competence	No dedicated laboratory head (Observation)	Laboratory head assigned to Civics teacher without certification (Principal interview).
	Organizational structure displayed	Absent (Observation)	Formally exists but not operationally implemented (Observation; principal interview).
	Class size impact	Approximately 50 students per	Approximately 50

Function	Indicator	SMAN 1 Sumedang (Urban)	SMAN Rancakalong (Rural)
	on practicum	class; no formal adjustment strategy (Observation; interview)	students per class; ideal practicum size stated as 24 students (Principal interview)
Implementing	Functional microscopes	Approximately 6 of 34 operational; fungal contamination and damaged mechanics identified (Observation; teacher interview)	Approximately 7 of 20 operational; humidity and termite damage after renovation (Observation; teacher interview).
	Student microscope access	Shared in large groups and inefficient (Student interview)	No independent microscope use; digital microscope also unused (Student interview; observation).
	Glassware condition	Available; several items contaminated or unused (Observation)	Generally available and functional (Observation).
	Material substitution practices	Betadine and bottled water used as substitutes; teacher used personal funds (Teacher interview)	Eosin substitution, virtual laboratory simulation, and demonstration methods applied (Teacher interview).
	Compliance with Permendiknas No. 24/2007	Partial compliance; major equipment non-functional (Observation; document analysis)	Significant non-compliance; several required items unavailable (Observation; document analysis).
Supervising	Inventory book status	Last updated in 2013/2014 (Document analysis)	Template available but entirely blank (Document analysis).
	Laboratory usage logbook	Absent (Observation; document analysis)	Template available but entirely blank (Document analysis).
	SOP and laboratory regulations	Not displayed; draft available but unprinted (Observation; document analysis)	Not displayed; handwritten notes only (Observation; teacher interview).
	Administrative documentation completeness	0% completeness (Observation; document analysis)	0% completeness (Observation; document analysis).
	Occupational health and safety compliance	Approximately 25%; sink available, no fire extinguisher, incomplete first-aid kit (Observation; interviews)	Approximately 25%; sink available, no fire extinguisher, no first-aid kit (Observation; student interview).

Table 1 indicates that weaknesses in biology laboratory management were consistently identified in both urban and rural schools, although the patterns differed across management functions. While the urban school demonstrated relatively better physical infrastructure and equipment availability, both schools experienced similar problems related to laboratory administration, supervision, safety compliance, and the absence of dedicated laboratory personnel. These findings suggest that accreditation status alone does not necessarily reflect the operational effectiveness of laboratory management or ensure equitable science learning experiences. To further examine the underlying institutional and experiential factors behind these findings, thematic interview analysis across informant categories is presented in Table 2.

Table 2. Thematic Analysis of Interview Findings Across Informant Categories

Theme	**Informant Category**	**SMAN 1 Sumedang (Urban)**	**SMAN Rancakalong (Rural)**
Structural HR gap	Institutional	Regulatory & budget barriers; TU staff as informal substitute; annual technician request denied.	Annual requests to Dinas rejected; Civics teacher as lab head due to surplus hours.
	Biology Teacher	Sole manager of equipment, admin, and instruction; informal university network for equipment repair.	Simultaneously instructor, laboran, technician; burden described as very heavy.
Practicum adaptation	Biology Teacher	Betadine for iodine; Amedis for aquades; personal funds for urgent procurement.	Eosin substitution; virtual labs; demonstration-only when equipment unavailable.
	Students	Brought equipment from home (knife, measuring tools) for potato practicum.	Never independently used microscope; watched teacher demonstration only.
Equipment maintenance failure	Biology Teacher	34 microscopes; only 6 functional; mold on lenses; no silica gel; servicing not funded.	20 microscopes; only 7 functional; termite and humidity damage post-renovation 2024.
Safety awareness gap	Students	Aware of absent APAR; P3K empty; desire written SOP posted on laboratory walls.	Explicitly identified absent APAR and P3K; safety communicated verbally only.
Priority intervention needed	All informants	Permanent lab technician + funded microscope servicing + digital admin system.	Permanent lab technician + functional microscopes + SOP and K3 infrastructure.

Table 2 shows that biology laboratory management problems in both schools were not limited to infrastructure issues but also involved structural human resource limitations, ineffective equipment maintenance, adaptive practicum substitution practices, and weak laboratory safety systems. Interview findings further revealed that both teachers and students experienced the direct consequences of these limitations, particularly restricted practicum access and limited operational support for laboratory activities. To further examine how these conditions affected students' learning experiences, Table 3 presents students' perspectives on biology laboratory learning activities in both schools.

Table 3. Students' Perspectives on Learning Experiences in Biology Laboratories

Aspect	**SMAN 1 Sumedang (Urban)**	**SMAN Rancakalong (Rural)**
Practicum frequency experienced	1–2 sessions since Grade X; osmosis, diffusion, fungi/bacteria observation.	3–5 sessions in Grade XI; blood type, urine test, food test; Grade X rarely accessed lab.
Microscope experience	Used in Grade X; large-group sharing reduces access time; desire more units.	Zero independent use across all three informants; digital microscope also unusable.
Equipment access constraint	Must share 1 microscope per large group; brought personal tools from	Must queue for limited equipment; pipette function

Aspect	SMAN 1 Sumedang (Urban)	SMAN Rancakalong (Rural)
	home for one practicum.	inconsistent; soap absent from sinks.
Safety awareness	Aware of absent APAR; P3K box present but empty; desire SOP poster on wall.	Identified absent APAR and P3K; know to report to teacher; no written emergency guidance.
Primary aspiration	More microscopes; more frequent practicum; written safety procedures visibly posted.	Independent microscope access; additional equipment; air conditioning in laboratory.
Preference for practicum over theory	All three strongly prefer practicum; one completed fermentation practicum at home.	All three prefer practicum; one prefers individual over group work for accountability.

Table 3 shows that students in both schools demonstrated strong interest in practicum-based biology learning despite limited laboratory access and equipment constraints. Students at SMAN 1 Sumedang experienced slightly more direct microscope use, although access remained limited due to large-group sharing and insufficient equipment availability. In contrast, students at SMAN Rancakalong reported never independently operating microscopes, indicating a more substantial limitation in hands-on scientific learning experiences. Students in both schools also expressed awareness of inadequate laboratory safety facilities and emphasized the need for more complete equipment, clearer safety procedures, and more frequent practicum activities. These findings indicate that limitations in laboratory management directly influenced students' learning experiences, practical engagement, and perceptions of science learning quality in both urban and rural contexts.

CONCLUSION

This study concludes that biology laboratory management in both SMAN 1 Sumedang and SMAN Rancakalong remained ineffective across the four management functions of planning, organizing, implementation, and supervision. Despite both schools holding A accreditation status, major weaknesses were identified in laboratory administration, equipment maintenance, occupational health and safety compliance, practicum realization, and the availability of dedicated laboratory personnel. The findings further demonstrate that accreditation status does not necessarily guarantee effective laboratory utilization or equitable science learning experiences for students. Educational inequality was particularly evident in rural contexts, where students had never independently operated microscopes despite the physical availability of laboratory equipment. Therefore, improving educational equity in science learning requires not only formal administrative compliance but also sustainable operational management, adequate laboratory personnel, functional equipment maintenance, and continuous supervision systems that support meaningful practicum-based learning experiences.

RECOMMENDATION

Schools should strengthen laboratory management systems by developing structured laboratory work programs, improving administrative documentation, providing minimum occupational health and safety infrastructure, and ensuring routine maintenance of laboratory equipment. Regional education authorities are also expected to prioritize the allocation of permanent laboratory technicians to support sustainable laboratory operations in both urban and rural schools. In addition, accreditation systems should be redesigned to evaluate operational laboratory effectiveness, practicum implementation rates, and students' actual access to laboratory-based learning rather than focusing primarily on administrative documentation. Future studies are recommended to involve broader school contexts and additional policy stakeholders to obtain a more comprehensive understanding of structural factors influencing educational equity in science laboratory management.

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AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Risma Yunita	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓	✓
Taufani Chusnul Kurniatun	✓	✓				✓	✓			✓				
Eka Prihatin	✓	✓				✓	✓			✓				

CONFLICT OF INTEREST STATEMENT
The authors declare that they have no known financial, personal, professional, academic, or other competing interests that could have influenced the work reported in this manuscript. The authors state no conflict of interest.

INFORMED CONSENT
Informed consent was obtained from all individuals involved in this study. Before participating, all participants were informed about the purpose, procedures, benefits, and confidentiality of the research. Participation was voluntary, and all personal information has been kept confidential in accordance with research ethics principles.

ETHICAL APPROVAL
This study was conducted in accordance with applicable research ethics principles, including voluntary participation, confidentiality, and the protection of participants' privacy. Permission to conduct the research was obtained from the participating schools, and informed consent was obtained from all participants before data collection. As this study involved non-invasive educational research with no medical or clinical intervention, formal approval from an Institutional Review Board or Ethics Committee was not required under the applicable institutional policies.

DATA AVAILABILITY
The data supporting the findings of this study are available from the corresponding author upon reasonable request. Due to ethical and privacy considerations regarding the research participants, the data are not publicly available.

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