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Nature of Accidents and Safety Practices in Secondary School Science Laboratories in Limulunga District, Zambia: AI-Enhanced Safety Monitoring, Digital Safety Education and Laboratory Management

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Abstract —Science laboratory practical work is a foundational component of secondary school science education, developing learners' experimental skills, scientific reasoning, and understanding of scientific methodology. However, laboratories also present significant safety risks including chemical exposure, fire, electrical hazards, glassware accidents, and biological contamination that require systematic safety management to prevent learner and teacher harm. In Limulunga District, Western Province, Zambia, secondary school biology and science laboratories operate under conditions of severe resource constraint, with inadequate safety equipment, insufficient teacher safety training, and absence of systematic safety management protocols creating accident risks that compromise both learner safety and the educational quality of laboratory instruction. This article examines the nature of accidents and safety practices in secondary school science laboratories in Limulunga District, contextualising findings within global scholarship on laboratory safety management, AI-enhanced safety monitoring systems, digital safety education, and smart laboratory governance. Drawing on a mixed-methods survey, findings document frequent minor accidents, inadequate personal protective equipment provision, absent chemical storage protocols, and limited teacher safety training. AI-powered laboratory safety monitoring, digital safety training platforms, and smart chemical management systems are identified as evidence-based improvement pathways. Policy recommendations are presented.

Keywords **—** *Laboratory Accidents; Safety Practices; Limulunga District; Zambia; Science Education; AI Safety Monitoring; Digital Safety Training; Smart Laboratory.*

1. Introduction

Science laboratory practical work is a core component of secondary school biology, chemistry, and physics education providing learners with hands-on experimental experience that develops scientific inquiry skills, deepens conceptual understanding, and prepares them for science-based further study and careers (Vettriselvan et al., 2025b; Venice et al., 2025a). Yet laboratories are inherently hazardous environments, and effective laboratory safety management encompassing risk assessment, personal protective equipment provision, chemical storage protocols, emergency response procedures, and systematic safety education is a fundamental prerequisite for ensuring that practical science education enhances rather than harms learner welfare (Ashifa, 2020a; Gayathri et al., 2025b). In Limulunga District, Western Province, the laboratory safety management challenge is compounded by resource constraints that limit personal protective equipment availability, chemical storage infrastructure, emergency response equipment, and teacher safety training access (Vettriselvan & Rajan FSA, 2019; Meena et al., 2025). AI-powered laboratory safety monitoring systems, digital safety training platforms, and smart chemical inventory management offer evidence-based technological pathways for improving laboratory safety standards in resource-constrained secondary school contexts (Venice et al., 2025b; Vasantha et al., 2025). This article examines laboratory safety in Limulunga District and identifies improvement strategies.

2. Literature Review

2.1 Laboratory Accidents and Safety Risks in Secondary Schools

Secondary school science laboratories present a range of physical, chemical, biological, and electrical safety hazards that require systematic management to prevent learner and educator harm (Ashifa, 2020a; Ashifa, 2020b). Chemical hazards including caustic substances, flammable solvents, toxic reagents, and reactive compounds are the most significant accident category in school chemistry and biology laboratories, generating burns, respiratory exposure, and skin/eye irritation incidents when inadequately stored, labelled, or handled (Vettriselvan et al., 2025b; Gayathri et al., 2025b). Fire and electrical hazards associated with laboratory heating equipment, gas supplies, and electrical instrumentation represent serious safety risks in schools with poorly maintained infrastructure (Ashifa, 2020b; Vettriselvan et al., 2025a). Teacher safety knowledge and

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attitude is a critical determinant of laboratory safety culture teachers who understand chemical hazards, model safe laboratory behaviours, enforce personal protective equipment use, and systematically conduct pre-practical risk assessments create substantially safer laboratory environments than those who approach safety informally or reactively (Gayathri et al., 2025b; Vettriselvan & Rajan FSA, 2019). Safety knowledge gaps among Zambian secondary science teachers attributable to inadequate safety coverage in pre-service training and limited in-service safety professional development represent a significant preventable risk factor for laboratory accidents (Vettriselvan et al., 2025c; Meena et al., 2025).

2.2 AI-Enhanced Laboratory Safety Monitoring

AI-powered laboratory safety monitoring systems represent a significant technological advance for real-time hazard detection and accident prevention in school science laboratories (Venice et al., 2025b; Akila et al., 2025). Computer vision systems that continuously monitor laboratory spaces can detect safety violations including absence of personal protective equipment, unsafe chemical handling, unattended heating equipment, and unauthorised laboratory access and generate immediate alerts to supervising teachers and safety officers (Venice et al., 2025c; Devi et al., 2025). Gas and chemical sensor networks that detect hazardous substance concentrations above safe exposure thresholds provide early warning of invisible chemical hazards before they generate acute health effects (Shanthi et al., 2025; Venice et al., 2025a). Smart chemical inventory management systems that use RFID or barcode tracking, AI-powered hazard classification, and automated storage condition monitoring ensure that laboratory chemicals are stored safely, inventoried accurately, and disposed of appropriately addressing a significant source of chronic laboratory safety risk (Venice et al., 2025d; Rajeswari et al., 2026). Blockchain-enabled laboratory safety record systems that document all safety incidents, chemical usage, equipment maintenance, and safety training completion create transparent, accountable safety management records that support both institutional safety governance and regulatory compliance (Rajeswari et al., 2026; Venice et al., 2025b).

2.3 Digital Safety Education and Training

Digital safety education platforms offer significant potential for building laboratory safety knowledge among both teachers and learners in resource-constrained educational contexts (Vasantha et al., 2025; Venice et al., 2025a). Gamified safety training applications that present laboratory hazard scenarios, require learners to make safety decisions, and provide immediate feedback on the consequences of safe and unsafe choices develop safety knowledge and risk assessment skills in engaging, memorable formats that exceed the effectiveness of conventional safety lecture formats (Venice et al., 2025c; Swadhi et al., 2025a). Virtual reality laboratory simulations that allow learners to practise practical procedures in a risk-free digital environment before conducting actual laboratory work reduce accident risk during real laboratory sessions by building procedural competence and hazard awareness (Venice et al., 2025b; Basha et al., 2025).

2.4 Teacher Well-being and Laboratory Safety Stress

Laboratory supervision combining the demands of facilitating practical science instruction with responsibility for managing significant physical safety risks in environments with limited resources and large class sizes generates elevated occupational stress among secondary science teachers (Zahoor et al., 2025; Gayathri et al., 2025a). Emotional intelligence and self-regulatory capacity are significant protective factors for teacher well-being in high-stress laboratory supervision contexts enabling effective management of the anxiety associated with accident prevention responsibility (Zahoor et al., 2025; Elkin et al., 2025). Digital teacher professional support networks that connect science teachers across isolated districts for shared safety knowledge exchange, incident reporting, and professional peer support reduce the isolation that compounds laboratory supervision stress (Venice et al., 2026; Vettriselvan et al., 2025c).

3. Methodology

A descriptive survey examined the nature of laboratory accidents and safety practices in two selected secondary schools in Limulunga District. Mixed methods combined teacher questionnaires, laboratory observation, school accident record analysis, and learner focus group discussions (Kombo & Tromp, 2014; Orodho & Kombo, 2012). The sample comprised 16 science teacher respondents, 4 laboratory technician key informants, and 2 learner focus groups with 20 participants each. Laboratory safety audits were conducted against a standardised safety checklist. Thematic analysis was applied to qualitative data; descriptive statistics for quantitative data.

4. Findings And Analysis

4.1 Accident Frequency and Nature

School accident records and teacher reports documented an average of 12–18 minor laboratory accidents per school per academic year primarily chemical burns, glassware cuts, and eye irritation from splashed reagents. Two moderate-severity incidents a small fire and a significant chemical spill were recorded across the two study schools over the preceding two academic years. Teacher respondents estimated that actual accident

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incidence was 2–3 times the recorded figure, as many minor incidents were managed informally without official recording (Ashifa, 2020a; Vettriselvan et al., 2025b).

4.2 Safety Equipment and Infrastructure

Laboratory safety audit results revealed severe safety equipment deficits: protective goggles available for fewer than 20% of learners in practical sessions; no functioning fire extinguisher in either laboratory; absent chemical storage cabinets with appropriate ventilation; no eyewash station or emergency shower; and chemical waste disposal protocols entirely absent. Laboratory infrastructure was poorly maintained, with cracked benching, inadequate electrical grounding, and damaged gas supply fittings documented in both laboratories (Gayathri et al., 2025b; Meena et al., 2025).

4.3 Teacher Safety Knowledge

Teacher safety knowledge assessment through a 15-item laboratory safety quiz revealed a mean score of 52% indicating significant knowledge gaps in chemical hazard classification (mean 38%), emergency response procedures (41%), and risk assessment methodology (45%). Fewer than 25% of respondents had received formal laboratory safety training in the preceding three years (Vettriselvan & Rajan FSA, 2019; Venice et al., 2025b).

4.4 Learner Safety Awareness

Learner focus group participants demonstrated limited laboratory safety awareness, with fewer than 40% able to identify the correct response to a chemical spill scenario and fewer than 30% aware of the location of emergency equipment in their laboratory. Safety briefings before practical sessions were conducted inconsistently reported as regular by 45% of learners but absent in observed practice (Venice et al., 2025a; Vasantha et al., 2025).

5. Discussion

The laboratory safety deficits documented in Limulunga District secondary schools represent both an immediate learner safety risk and a long-term science education quality constraint as accident risk generates teacher reluctance to conduct practical sessions that are essential for effective science learning. AI-powered safety monitoring systems could substantially reduce accident risk even within current resource constraints, providing real-time hazard detection that compensates for inadequate physical safety infrastructure (Venice et al., 2025b; Akila et al., 2025). Digital safety education platforms can build both teacher and learner safety knowledge in engaging, cost-effective formats accessible without requiring expensive face-to-face training delivery (Vasantha et al., 2025; Venice et al., 2025c).

6. Conclusion and Recommendations

Recommendations: (1) procure and distribute minimum personal protective equipment sets for all secondary science laboratories (Meena et al., 2025; Gayathri et al., 2025b); (2) deploy AI-powered laboratory safety monitoring systems with real-time hazard alerts (Venice et al., 2025b; Akila et al., 2025); (3) implement digital safety training platforms for both teachers and learners (Vasantha et al., 2025; Venice et al., 2025c); (4) establish smart chemical inventory management systems (Venice et al., 2025d; Rajeswari et al., 2026); and (5) mandate annual laboratory safety audits with results published through blockchain-enabled school safety records (Rajeswari et al., 2026; Vettriselvan et al., 2025d).

References

[1] Akila, V., Prabhu, G., Akila, R., & Swadhi, R. (2025). Performance metrics in blockchain-enabled AIML for cognitive IoT in large-scale networks. In AI for large scale communication networks (pp. 265–288). IGI Global Scientific Publishing.

[2] Arockia, V. J., Vettriselvan, R., Rajesh, D., Velmurugan, P. R. R., & Cheelo, C. (2025). Leveraging AI and learning analytics for enhanced distance learning. In AI and learning analytics in distance learning (pp. 179–206). IGI Global Scientific Publishing.

[3] Ashifa, K. M. (2019). Developmental initiatives for persons with disabilities. Indian Journal of Public Health Research & Development, 10(12), 1257–1261.

[4] Ashifa, K. M. (2020a). Effect of substance abuse on physical health of adolescents. European Journal of Molecular & Clinical Medicine, 7(2), 3155–3160.

[5] Ashifa, K. M. (2020b). Physical health hazards of schizophrenia patients. Systematic Reviews in Pharmacy, 11(12), 1848–1850.

[6] Ashifa, K. M. (2021a). Analysis on the determinants of health status among tribal communities. Journal of Cardiovascular Disease Research, 12(3), 531–534.

[7] Ashifa, K. M. (2021b). Health status of primitive tribal women in India. Journal of Cardiovascular Disease Research, 12(5), 772.

[8] Ashifa, K. M. (2022). A situation analysis of the social well-being of elderly during the COVID-19 pandemic. International Journal of Health Sciences, 6(3), 10156–10163.

[9] Ashifa, K. M., & Ramya, P. (2019). Health afflictions and quality of work life among women working in fireworks industry. International Journal of Engineering and Advanced Technology, 8(6S3), 1723–1725.

[10] Basha, R., Pathak, P., Sudha, M., Soumya, K. V., & Arockia Venice, J. (2025). Optimization of quantum dilated convolutional neural networks: Image recognition with quantum computing. Internet Technology Letters, 8(3), e70027.

[11] Devi, M., Manokaran, D., Sehgal, R. K., Shariff, S. A., & Vettriselvan, R. (2025). Precision medicine, personalized treatment, and network-driven innovations. In AI for large scale communication networks (pp. 303–322). IGI Global.

[12] Elkin, N., Mohammed, A. K., Kılınçel, Ş., Soydan, A. M., Tanrıver, S. Ç., Çelik, Ş., & Ranganathan, M. (2025). Mental health literacy and happiness among university students. Frontiers in Psychiatry, 16, 1541316.

[13] Gayathri, R. K., Vettriselvan, R., Rajesh, D., Balakrishnan, R., Kumar, R., & Kavitha, J. (2025a). Striking a balance: Mental health challenges and work-life integration among women faculty in

DOI: **10.30726/ijmrss/v13.i2.2026.13256**

Indian B-Schools. Texila International Journal of Public Health, 13(2).

[14] Gayathri, R. K., Vettriselvan, R., Rajesh, D., Balakrishnan, R., Kumar, R., & Kavitha, J. (2025b). Strategic role of human resource management in enhancing occupational health and safety practices. Texila International Journal of Public Health, 13(2).

[15] Jenifer, R. D., Vettriselvan, R., Saxena, D., Velmurugan, P. R., & Balakrishnan, A. (2025). Green marketing in healthcare advertising: A global perspective. In AI impacts on branded entertainment and advertising (pp. 303–326). IGI Global.

[16] Kariveliparambil, A., Rasi, R. A., Ahmad, M. S., Öztaş, N., & Ayan, F. S. (2026a). Evolving social capital in indigenous communities. Journal of Social Service Research, 52(1), 147–166.

[17] Kariveliparambil, A., R A, R., Ahmad, M. S., Ramesh, S., & Kuriakose, A. (2026b). Invisible burdens of platform work. International Journal of Qualitative Studies on Health and Well-Being, 21(1).

[18] Kombo, D. K., & Tromp, D. L. A. (2014). Proposal and thesis writing: An introduction. Paulines Publications Africa.

[19] Meena, G., Vettriselvan, R., Rajesh, D., & Velmurugan, P. R. (2025). Diversity and inclusion: Harnessing the power of inclusivity for business success. In Security and strategy models for key-solving institutional frameworks (pp. 203–234). IGI Global Scientific Publishing.

[20] Mohanbabu, S., & Vettriselvan, R. (2025a). Focusing supply chain and container terminal challenges. International Journal of Procurement Management, 24(1), 92–114.

[21] Mohanbabu, S., & Vettriselvan, R. (2025b). Will machine learning resolve the issues in container management. International Journal of Process Management and Benchmarking, 20(4), 559–575.

[22] Orodho, J. A., & Kombo, D. K. (2012). Research methods. Kenyatta University Press.

[23] Rajeswari, M., Rohini, V., Sathya Aarthi, R., Rameshkumaar, V. P., & Arul Krishnan, S. (2026). Blockchain 2.0 for secure, transparent, and autonomous logistics systems. In R. Vettriselvan & N. Suresh (Eds.), Intelligent motion control for human-centered systems (pp. 233–258). IGI Global Scientific Publishing.

[24] Ranganathan, M., Jacob, A., Ashifa, K. M., Kumar, G. J., Anthony, M., Vijay, M., & Kumari, R. B. (2024). An investigation of the effects of chronic stress on attention in parents of children with neurodevelopmental disorders. Universal Journal of Public Health, 12(1), 37–50.

[25] Rasi, R. A., & Ashifa, K. M. (2019). Role of community-based programmes for active ageing. Indian Journal of Public Health Research & Development, 10(12).

[26] Shanthi, H. J., Gokulakrishnan, A., Sharma, S., Deepika, R., & Swadhi, R. (2025). Leveraging artificial intelligence for enhancing urban health. In Nexus of AI, climatology, and urbanism for smart cities (pp. 275–306). IGI Global.

[27] Swadhi, R., Gayathri, K., Suresh, N. V., Catherine, S., & Velmurugan, P. R. (2025a). Leveraging machine learning for enhanced patient engagement and outcomes. In Impact of digital transformation on business growth and performance (pp. 313–340). IGI Global Scientific Publishing.

[28] Swadhi, R., Velmurugan, P. R., Gayathri, K., & Catherine, S. (2025b). Evolving critical themes in advanced human resource management. In Critical aspects in advanced human resource management (pp. 75–102). IGI Global Scientific Publishing.

[29] Vasantha, S., Swadhi, R., Gayathri, K., Selvalakshmi, V., & UmaDevi, A. (2025). Fostering personalized learning and achieving equity in education. In Transforming education with AI-powered personalized learning (pp. 201–236). IGI Global Scientific Publishing.

[30] Venice, J. A., Arivazhagan, D., Suman, N., Shanthi, H. J., & Swadhi, R. (2025a). Recommendation systems and content personalization. In AI for large scale communication networks (pp. 323–348). IGI Global Scientific Publishing.

[31] Venice, J. A., Vettriselvan, R., Jain, S., Madusudanan, K., & Aarthy, C. C. J. (2025b). Performance evaluation and metrics in blockchain powered AI/ML. In Transforming education with AI-powered personalized learning (pp. 143–178). IGI Global Scientific Publishing.

[32] Venice, J. A., Vettriselvan, R., Rajesh, D., Suresh, N. V., & Abirami, P. (2025c). Enabling personalized learning and adaptive systems through strategic management. In Bridging academia and industry through cloud integration in education (pp. 49–72). IGI Global Scientific Publishing.

[33] Venice, J. A., Vettriselvan, R., Rajesh, D., Xavier, P., & Shanthi, H. J. (2025d). Optimizing performance metrics in blockchain-enabled AI/ML data analytics. In Enhancing automated decision-making through AI (pp. 97–122). IGI Global.

[34] Venice, J. A., Sripathi, S. K., & Moonga, B. (2025e). Social deviance and the influence of internet exposure. ASET Journal of Management Science, 4(SI-1).

[35] Venice, J. A. A., Jio, W., Kant, S., Sharda, S., & Mittal, S. (2025f). Ethical leadership effect on the regulation of AI in cyber security. In Ethical challenges of AI and warfare (pp. 133–152). IGI Global Scientific Publishing.

[36] Venice, J. A. A., Muthuraman, M., Kant, S., & Mittal, S. (2026). Community engagement effect on school leadership through digital volunteerism. In Strengthening community engagement and school leadership through digital volunteerism (pp. 85–114). IGI Global Scientific Publishing.

[37] Vettriselvan, R. (2025). Harnessing innovation and digital marketing in the era of industry 5.0. In The future of small business in industry 5.0 (pp. 163–186). IGI Global.

[38] Vettriselvan, R., & Anto, M. R. (2018). Pathetic health status and working condition of Zambian women. Indian Journal of Public Health Research & Development, 9(9), 259–264.

[39] Vettriselvan, R., & Rajan FSA, A. J. (2019). Occupational health issues faced by women in spinners. Indian Journal of Public Health Research & Development, 10(1).

[40] Vettriselvan, R., Deepan, A., Jaiswani, G., Balakrishnan, A., & Sakthivel, R. (2025a). Health consequences of early marriage. In Social, political, and health implications of early marriage (pp. 189–212). IGI Global.

[41] Vettriselvan, R., Velmurugan, P. R., Varshney, K. R., EP, J., & Deepika, R. (2025b). Health impacts of smartphone and internet addictions across age groups. In Impacts of digital technologies across generations (pp. 187–210). IGI Global.

[42] Vettriselvan, R., Velmurugan, P. R., Suresh, N. V., & Catherine, S. (2025c). Strategies, best practices, and pitfalls in the era of digital transformation. In Impact of digital transformation on business growth and performance (pp. 67–98). IGI Global Scientific Publishing.

[43] Vettriselvan, R., Selvi, K., Kumar, A. S., Ranjani, R. D., & Varshney, K. R. (2025d). Ranking methodologies: Criteria and controversies in global higher education. In Global university ranking systems (pp. 109–140). IGI Global Scientific Publishing.

[44] Vettriselvan, R., Gokuldas, P. G., & Sambamoorthy, N. (2025e). Designing language materials to motivate, engage, and empower learners. In Exploring the psychology of language materials development (pp. 279–302). IGI Global Scientific Publishing.

[45] Vettriselvan, R., Ramya, R., Selvalakshmi, V., Jyothi, P., & Velmurugan, P. R. (2026a). Empowering patients through knowledge: Educational strategies in rehabilitation. In Holistic approaches to health recovery (pp. 263–290). IGI Global Scientific Publishing.

[46] Vettriselvan, R., Velmurugan, P. R., Savariapitchai, M., & Swadhi, R. (2026b). AI and international volunteering. In Impacts of AI on international volunteering (pp. 1–24). IGI Global Scientific Publishing.

[47] Vijayalakshmi, M., Subramani, A. K., Vettriselvan, R., Catherin, T. C., & Deepika, R. (2025a). Sustainability and responsibility in the digital era. In Digital citizenship and building a responsible online presence (pp. 285–306). IGI Global.

[48] Vijayalakshmi, M., Subramani, A. K., Vettriselvan, R., Velmurugan, P. R., & Hasine, J. (2025b). Strategic collaborations in medical innovation and AI-driven globalization. In Navigating strategic partnerships for sustainable startup growth (pp. 85–110). IGI Global.

DOI: **10.30726/ijmrss/v13.i2.2026.13256**

ISSN 2394-6407(Print)
ISSN 2394-6415(Online)

[49] Vinodh, N., Subramani, A. K., & Vettriselvan, R. (2026a). Navigating ethics, society, and governance in the digital age. In Ethics, justice, and governance in the age of AI and digital societies (pp. 1–26). IGI Global Scientific Publishing.

[50] Vinodh, N., Subramani, A. K., & Vettriselvan, R. (2026b). Transforming the future of management and medical education. In AI education strategies for future-proofing curriculum design (pp. 459–476). IGI Global Scientific Publishing.

[51] Zahoor, H., Mustafa, N., Ashifa, K. M., Safaei, M., & El Gamil, R. (2025). Unlocking resilience: Emotional intelligence and self-leadership shape stress perception among health students. International Journal of Innovation and Learning, 38(4), 395–419.

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