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Learner Perceptions of Educational Robotics for Advanced-Level Science Teaching in Rwanda: A Five-School Descriptive Study and Conditions for Future Integration

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Abstract

Educational robotics has attracted growing interest as a means of supporting practical science learning, computational thinking, creativity, and problem-solving. This study presents a secondary descriptive analysis of existing research data from five selected secondary schools in Rwanda. The available documentation reports 250 learners and seven purposively selected key informants, including headteachers, Directors of Studies, and teachers. Summarized questionnaire responses were analyzed using frequencies and percentages, while key-informant information provided contextual insights. The available summary for the broad educational-benefit item recorded 244 positive responses out of 257 reported participants (94.9%), although the denominator requires verification because the questionnaire was described as learner-administered. For the challenge and strategy items, only 88 responses per item were documented, limiting interpretation of the findings. Among these recorded responses, participants expressed concerns about equipment costs, insufficient instructional materials, and potential employment displacement, while also supporting creativity, decision-making, and innovation. Based on the descriptive findings and relevant literature, the study proposes six conditions for future educational robotics integration: curriculum alignment, teacher capability, resource sufficiency, inclusive participation, authentic problem-solving, and evidence-based evaluation. The findings reflect perceived educational value rather than demonstrated improvements in learning outcomes. Further research using validated instruments, complete datasets, and direct learning assessments is recommended.

Keywords: Real-world calculus, business mathematics education, sustainability education, mathematical modelling, calculus pedagogy, sustainable business management

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Introduction

Educational robotics has been investigated as a tool for practical STEM learning, programming, problem solving, and technology literacy. It is under growing pressure to prepare learners for environments shaped by digital technologies, automation, artificial intelligence, embedded systems, and programmable devices. Educational robotics is distinctive because it links abstract knowledge to physical action: learners can program devices, connect sensors and actuators, test prototypes, diagnose faults, revise designs, and observe the consequences of their decisions. Such cycles of design, experimentation, feedback, and revision are consistent with integrated STEM approaches that connect disciplinary knowledge with authentic problem solving and transferable competencies (Yeung et al., 2026).

Recent evidence indicates that educational robotics can support learning, although effects vary by outcome and context (Shu et al., 2026a). (Lu & Geng, 2026a) reported a moderate positive overall effect on STEM learning, while Lu and Geng (2026) reported moderate to large overall effects across cognitive and affective outcomes. (Tsingidou & Sapounidis, 2026) found positive effects for robot supported computational thinking, and (Marín-Marín et al., 2024) documented the use of Arduino in secondary education for programming, physics, problem solving, and interdisciplinary learning. These findings support cautious interest in robotics rather than the assumption that technology automatically improves every learning outcome.

The pedagogical rationale is commonly associated with constructivist and constructionist learning. Learners actively build understanding through experience, while constructionism emphasizes learning through the creation of meaningful, shareable artefacts (Wouters et al., 2026) Robotics can operationalize these principles when learners formulate ideas, build or program systems, test outcomes, explain failures, and revise solutions.

In Rwanda, national policy has emphasized digital learning, infrastructure, teacher capacity, competencies, curriculum review and inclusion, and technology-enabled education (Alagbonsi et al., 2026). Government initiatives and guidance have also promoted smart classrooms and technology supported STEM learning (Iyamuremye et al., 2024). UNESCO supported STEM activities have exposed learners and educators to emerging technologies including robotics and artificial intelligence (Qi et al., 2026). World Bank analyses emphasize that technology investment must be accompanied by teacher capacity, effective classroom use, and broader digital-education support (Vu et al., 2026).

Despite this policy interest, school level evidence on learner perceptions of educational robotics in Rwandan upper secondary science remains limited. This study therefore examines possible educational benefits, anticipated barriers, and priorities for future robotics integration in advanced level secondary school settings.

Problem Statement

Science education aims to develop learners' inquiry, experimentation, critical reasoning, problem solving, and practical application of knowledge. Educational robotics can support these competencies by engaging learners in the design, programming, and testing of physical systems. However, its

classroom integration depends on access to equipment, teacher preparedness, instructional time, maintenance, and curriculum alignment. Previous reviews have identified financial constraints, limited resources, inadequate teacher training, time limitations, and curriculum integration as major implementation challenges (Norma et al., 2026). Despite growing interest in technology enhanced science education, empirical evidence on how advanced-level science learners in Rwanda perceive educational robotics remains limited. Examining these perceptions can provide context specific insights to guide future implementation and evaluation, although learners' perceptions alone cannot demonstrate educational effectiveness.

Purpose, Objectives, and Research Questions

The purpose is to describe learners' perceptions of the potential educational value, perceived barriers, and possible conditions for future integration of educational robotics in advanced level science teaching. It is tied to the following objectives:

1. To identify the perceived benefits learners, associate with educational robotics in advanced level science teaching.

2. To examine major barriers learners, perceive as constraining robotics integration in Advanced level science teaching.

3. To identify learners supported strategies that may inform future sustainable robotics integration in science teaching.

The study was guided by the following research questions:

RQ1. What educational benefits do learners perceiving educational robotics offer in advanced level science teaching?

RQ2. What major barriers do learners perceive as constraining educational robotics in advanced-level science teaching?

RQ3. What strategies do learners consider useful for strengthening future robotics integration of educational robotics in advanced-level science teaching?

Literature Review

Educational robotics has emerged as a STEM learning environment in which programmable technologies can support interdisciplinary learning, practical experimentation, and the application of scientific concepts. Understanding its educational value requires attention to learning theories, potential benefits, implementation barriers, teacher capacity, inclusion, and the policy context, particularly in Rwandan advanced level science education.

Educational Robotics as a STEM Learning Environment

Educational robotics uses programmable robotic systems, construction kits, microcontrollers, sensors, actuators, and related software as learning resources. Robotics may be taught as content or used as a medium for learning other disciplines. (Zhang, 2025) reviewed robotics based STEM

education and found frequent use of project based learning and interdisciplinary approaches. Earlier reviews also show that educational value depends on how robotics is embedded in learning activities rather than on the hardware alone (Shu et al., 2026b).

Robotics literacy can include programming, systems understanding, computational thinking, engineering design, and responsible use. Research also indicates that age, instructional design, platform, task type, and assessment influence outcomes (Yin et al., 2027).

Constructivism, Constructionism, and Experiential Learning

Constructivism views learners as active builders of knowledge, while constructionism emphasizes learning through making public and meaningful artefacts (Parmaxi et al., 2016). In robotics, learners can externalize ideas through programmed or constructed systems, test assumptions, observe consequences, and revise explanations. Project and problem based approaches are therefore common because they provide a meaningful context for design and reflection (Khapre et al., 2026).

Evidence of Learning Benefits

Meta-analytic evidence supports positive but non-uniform effects. (Lu & Geng, 2026b) reported a moderate overall effect of educational robotics on STEM learning and positive effects on performance and attitudes. (Wang, 2026) found positive effects for robot-supported computational thinking, while (Xiao et al., 2026) reported positive cognitive and affective outcomes across a broader three-level meta-analysis. These findings should not be transferred directly to the present study because the present data measure perceptions rather than achievement.

At secondary level, Arduino and related programmable platforms have been used in technology, physics, programming and interdisciplinary STEAM projects, with reported opportunities for motivation and problem solving as well as challenges related to complexity and implementation demands (Omrany et al., 2026)

Higher Order Competencies and Inclusion

Robotics design tasks can create opportunities for creativity, problem solving, collaboration, and decision making when learners are required to generate alternatives, justify choices, test solutions, and reflect on failures (Sen et al., 2021). Inclusive participation is not automatic: limited equipment or unequal prior experience can allow some learners to dominate technical roles. Role rotation, structured participation, accessible entry tasks, and multiple forms of contribution are therefore important.

Social, Ethical, and Future of Work Dimensions

Robotics and automation also raise social and ethical questions concerning employment, human machine relationships, responsibility, and equitable participation. These issues can form part of technological literacy rather than being treated simply as positive or negative attitudes. Educational robotics should therefore be accompanied by discussion of ethics, safety, sustainability, and the changing nature of work (Callari et al., 2024).

Teacher Capacity, Resources, and Learner Readiness

With research from Godzicki, L. et al. (2013) successful integration of educational robotics depends on both teacher preparedness and learners' readiness to engage with technology supported learning. Teachers require technical knowledge, troubleshooting skills, curriculum awareness, classroom management strategies, and appropriate assessment practices. Reviews identify inadequate teacher knowledge, limited practical training, low self efficacy, equipment costs, time constraints, and difficulties integrating robotics into existing curricula as recurring challenges (Nikolic et al., 2026). Sustainable implementation also requires maintenance, replacement parts, storage facilities, instructional materials, and continuous professional development.

Beyond these institutional and instructional conditions, learners' perceptions, attitudes, and previous experiences with technology may influence their willingness to participate in robotics-based activities. Interest, confidence, perceived usefulness, and readiness to acquire new skills may shape how learners view robotics as a tool for understanding scientific concepts. However, limited access to digital devices, unequal prior exposure, and varying levels of technological confidence may affect participation (Van Deursen, A. J.et al. (2021). Examining learners' perspectives alongside teacher capacity and resource availability can therefore help identify the perceived benefits, practical barriers, and support strategies relevant to integrating educational robotics into advanced-level science teaching in Rwanda.

Robotics Integration in Advanced Level Science Education

Integrating robotics into advanced-level science education in Rwanda offers students opportunities to learn scientific concepts through hands-on activities that involves understanding of the real matter and concepts that were usually unexplainable or difficult to explain in a normal situation. According to Choudhary, P., & Potdar, P. (2023) The integration of robotics into STEM education has attracted growing interest among educators and researchers because of its potential to improve student learning and engagement. Educational robotics develops practical skills, creativity, and problem-solving abilities while making science lessons more engaging. As Hampden-Thompson, G., & Bennett, J. (2013) confirm.

Research Gap and Conceptual Framework

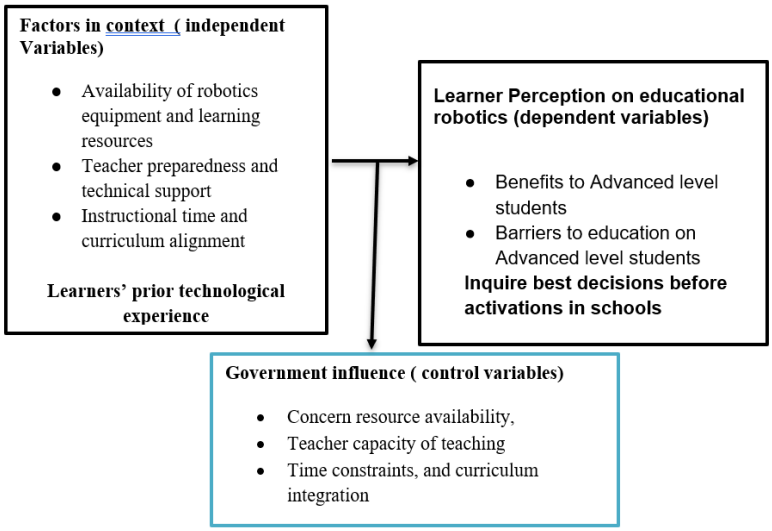
Research Gap

Although previous studies have documented the potential benefits of educational robotics in STEM learning, its implementation remains constrained by equipment costs, limited resources, inadequate teacher preparation, instructional time, and curriculum integration (Norma et al., 2026). However, empirical evidence on how advanced-level science learners in Rwanda perceive educational robotics remains limited, particularly regarding its potential learning benefits, perceived implementation barriers, and strategies for sustainable integration. This study addresses this gap by examining learner perceptions across five schools in Rwanda. The findings are intended to inform context-specific planning for educational robotics in advanced-level science teaching, while recognizing that learners' perceptions alone cannot establish its effectiveness in improving learning outcomes.

Conceptual Framework

Tamene, E. H. (2016) assumed that the conceptual framework presents major meanings from scholars. We are referring to educational robotics, learners' perceptions, and recommendations for future integration. The contextual factors include access to equipment and other resources, teacher preparedness, instructional time, curriculum alignment, and learners' previous technological experience. These factors provide the context for examining learners' views but are not assumed to have causal effects within this descriptive study.

The central outcome of interest is learner perception of educational robotics, examined through three dimensions: perceived benefits, perceived barriers, and learner-recommended strategies for future integration. Perceived benefits include opportunities for practical science learning, problem-solving, creativity, and engagement. With reference to Chuene, D. M., & Teane, F. M. (2024) perceived barriers to education may include resource availability, teacher capacity, time constraints, and curriculum integration. Recommended strategies may include teacher training, adequate resource provision, appropriate curriculum integration, and sustainable implementation arrangements. Chari, W., Mutseekwa, C., & Dzavo, J. (2025).



Educational Robotics in the Rwandan Context

Rwanda's ICT in Education Policy emphasizes infrastructure, digital resources, teacher development, and active use of technology in learning (Jean Claude et al., 2025). The Education Sector Strategic Plan 2024 to 2029 continues to emphasize quality, competencies, learning materials, teacher capacity, infrastructure, inclusion, and relevance (Mutoni et al., 2026) Ministry initiatives concerning smart classrooms and technology-enabled STEM teaching demonstrate policy interest in practical digital learning (Nsabayezu et al., 2025). UNESCO (2022) has also reported STEM boot-camp activities in Rwanda involving emerging technologies. World Bank reports stress that digital infrastructure must be translated into effective classroom use through teacher capacity and system support (Abbasi & Yang, 2026a).

Methodology

Research Design and Data Provenance

Normally, a research design is a well determined pattern of results to be analyzed (Myers, J. L., et al. (2013). This study adopted a descriptive cross-sectional research design to examine learners' perceptions of educational robotics in advanced-level science teaching across five selected secondary schools in Rwanda, representing the four provinces and the City of Kigali. The study used an existing dataset from a supervised academic research project involving 250 students and key informants. It focused on perceived educational benefits, implementation barriers, and strategies for future robotics integration. A quantitative descriptive approach was employed, with questionnaire responses analyzed following Wickham, H. (2016) line. The frequencies and percentages, supplemented by contextual information from key informants in the IT domain and school leadership were therefore discussed.

Study Setting and Participants

According to Manohar, N. et al. (2018) we have to be systematic while selecting participants. The study examines learners' perceptions of educational robotics in advanced-level science education across five secondary schools in Rwanda: Christ Roi in Nyanza District (Southern Province), Kagitumba High School (Eastern Province), GS Apacope (Kigali City), TTC Rubengera (Western Province), and GS Musanze (Northern Province). The study was conducted in five selected secondary schools in Rwanda: Christ Roi in Nyanza District (Southern Province), Kagitumba High School (Eastern Province), GS Apacope (City of Kigali), TTC Rubengera (Western Province), and GS Musanze (Northern Province).

The study involved a total of 257 participants, comprising 250 learners and seven purposively selected key informants. Each school contributed 50 learners, including 15 from Senior Four (S4), 15 from Senior Five (S5), and 20 from Senior Six (S6). Consequently, the learner sample consisted of 75 S4 learners (30%), 75 S5 learners (30%), and 100 S6 learners (40%).

The seven key informants included headteachers, Directors of Studies, and teachers who provided contextual information relevant to educational robotics integration. Learners represented 97.3% of the total participants, while key informants represented 2.7%. This sampling structure supports descriptive comparisons across schools, grade levels, and gender. With findings analysis like Walker, J., & Almond, P. (2010), the interpreted in relation to the participating schools and should not be generalized to all advanced-level learners in Rwanda without appropriate consideration of the sampling procedure and study limitations.

Sampling

Sampling must be done following an interest as per Acharya, et al (2013). The study involved 257 participants, consisting of 250 learners from five selected secondary schools and seven purposively selected key informants. The learner sample was distributed equally across the five schools, with 50 learners from each school. Within each school, the reported distribution comprised 15 Senior Four learners, 15 Senior Five learners, and 20 Senior Six learners. The seven key informants were purposively selected based on their professional roles and potential to provide relevant contextual information about educational robotics in secondary education. They included headteachers, Directors of Studies, and teachers.

Instrument and Administration

With reference to Marshall, G. (2005) we can use questionnaire as data collection tool. Therefore, data were collected using a structured learner questionnaire administered through Microsoft Forms (MS Forms). The questionnaire covered three domains: perceived educational benefits of robotics, implementation challenges, and strategies for future integration into advanced-level science teaching. Responses were organized and analyzed using the Statistical Package for the Social Sciences (SPSS), as mentioned by Mustafy, T., & Rahman, M. T. U. (2024). with descriptive statistics, including frequencies and percentages, used to summarize learners' perceptions. Items addressing multiple concepts were interpreted as broad perception measures rather than validated multi-construct scales.

Reliability, Validity, and Analytical Constraints

According to Mohajan (2017), research reliability and validity are essential for ensuring the credibility and trustworthiness of research findings. The project documentation indicated that the questionnaire was piloted and developed based on a review of relevant literature. However, detailed records of the pilot study were un The available dataset comprised summarized questionnaire responses from 250 learners across five selected secondary schools in Rwanda and contextual information from seven purposively selected key informants, including headteachers, Directors of Studies, and teachers. Individual respondent-level records were unavailable for reanalysis for this secondary analysis, limiting the assessment of the instrument's reliability and validity.

Ethical Considerations

According to Comstock (2013), research ethics emphasize respect for participants' moral rights, including voluntary participation, confidentiality, and the right to withdraw. This study used secondary data collected voluntarily and confidentially, with respondents' identities protected. However, ethical approval details, consent procedures, and data storage arrangements were not documented in the available manuscript.

Results and discussions

Participant Profile

Table 1. Participant profile

Characteristic	Category	Frequency (n)	Percentage (%)
Participant type	Learners	250	97.3
	Key informants (Headteachers, Directors of Studies, and Teachers)	7	2.7
Sub Total		257	100.0
School distribution	School 1 in North	50	20.0
	School 2 in South	50	20.0
	School 3 in East	50	20.0
	School 4 in West	50	20.0
	School 5 in Kigali City	50	20.0
Total learners		250	100.0

Learners' grade level in 5 schools	Senior Four (S4) with 15 students each	75	30.0
	Senior Five (S5) with 15 students each	75	30.0
	Senior Six (S6) with 20 students each	100	40.0
Total learners		250	100.0
Sampling method	Census of the defined learner group	250	97.3
	Purposive sampling (key informants)	7	2.7
Grand Total		257	100.0

The study involved 257 participants, comprising 250 learners (97.3%) and seven purposively selected key informants (2.7%). The learners were distributed equally across five selected secondary schools, with 50 learners from each school. The learner sample comprised 75 Senior Four learners (30%), 75 Senior Five learners (30%), and 100 Senior Six learners (40%). The seven key informants provided contextual information and were analyzed separately from the learner questionnaire responses.

General Learner Acceptability of Robotics

Table 2. Responses to the broad educational-benefit item

Response category	Frequency (n)	Percentage (%)
Strongly agree	230	89.5
Agree	14	5.4
Disagree	2	0.8
Unaccounted for	11	4.3
Total	257	100.0

The findings indicate a highly positive perception of educational robotics among respondents. Of the 257 participants, 230 (89.5%) strongly agreed, 14 (5.4%) agreed, and 2 (0.8%) disagreed that robotics could enhance productivity, steadfastness, fittingness, and performance. Overall, 94.9% expressed positive perceptions, while 4.3% of responses remained unaccounted for. These findings suggest strong perceived usefulness and acceptance of robotics in education. However, because the questionnaire item combines several broad concepts, the results reflect general perceptions rather than independently measured improvements in specific learning outcomes. Furthermore, the findings do not establish actual improvements in academic performance.

Perceived Challenges

Table 3. Perceived challenges to robotics integration

Challenge item	Strongly agree n (%)	Agree n (%)	Disagree n (%)	Unaccounted for n (%)	Total
Robotics are financially expensive	78 (30.4%)	7 (2.7%)	3 (1.2%)	169 (65.8%)	257
Robotics lacks human and emotional qualities	75 (29.2%)	0 (0.0%)	13 (5.1%)	169 (65.8%)	257
Insufficient didactic materials constrain inclusive implementation	81 (31.5%)	5 (1.9%)	2 (0.8%)	169 (65.8%)	257
Robotics may contribute to employment displacement	84 (32.7%)	4 (1.6%)	0 (0.0%)	169 (65.8%)	257

The findings indicate generally positive perceptions of educational robotics among the reported participants. Of the 257 participants, 230 (89.5%) strongly agreed, 14 (5.4%) agreed, and 2 (0.8%) disagreed with the broad educational benefit statement. Overall, 244 participants (94.9%) expressed positive perceptions, while 11 responses (4.3%) remained unaccounted for. These findings suggest general acceptability and perceived usefulness of educational robotics. However, because the questionnaire item combines several educational concepts, the findings do not establish improvements in academic performance or specific learning outcomes.

Learner-Supported Strategies and the Materials Consistency Check

Table 4. Learner-supported strategies

Strategy item	Strongly agree n (%)	Agree n (%)	Disagree n (%)	Unaccounted for n (%)	Total
Link robotics to income-generating innovation	67 (26.1%)	14 (5.4%)	7 (2.7%)	169 (65.8%)	257
Cultivate sound decision-making	78 (30.4%)	8 (3.1%)	2 (0.8%)	169 (65.8%)	257
Current integration provides sufficient inclusive didactic materials	9 (3.5%)	0 (0.0%)	79 (30.7%)	169 (65.8%)	257
Emphasize innovative and creative work	86 (33.5%)	0 (0.0%)	2 (0.8%)	169 (65.8%)	257

The findings reveal consistent concerns regarding the availability of instructional materials for robotics integration. In Table 3, 86 respondents (33.5%) agreed or strongly agreed that insufficient materials constrain inclusive implementation, while in Table 4, 79 respondents (30.7%) disagreed that existing materials were sufficient. These oppositely framed items suggest a consistent perception of inadequate instructional resources among recorded respondents. However, each item contains only 88 documented responses out of 257 participants, limiting conclusions about the full population. Furthermore, acquiescence and social-desirability bias remain possible limitations, particularly because the questionnaire's midpoint response options were not documented.

Contextual Key-Informant Input

The seven purposively selected key informants, comprising headteachers, Directors of Studies, and teachers, provided contextual insights that broadly supported the questionnaire findings. Their observations highlighted the potential contribution of educational robotics to practical learning, teamwork, responsibility, decision-making, and inclusive classroom participation. However, because the available secondary data lacked complete qualitative coding records, verbatim quotations, member-checking documentation, and researcher positionality information, these observations were used solely to complement and contextualize the quantitative findings rather than being presented as independently validated qualitative themes.

Evidence from discussion

Table 5. Proposed Six-Condition Framework for Future Testing

No.	Proposed condition	Evidence from the present study	Supporting literature/policy	Proposed validation approach
1	Curriculum alignment	Not directly assessed; literature-derived condition.	Kelley & Knowles (2016); Darmawansah et al. (2023); MINEDUC (2016, 2025).	Compare learning outcomes from curriculum-aligned robotics lessons with those from non-aligned lessons.
2	Teacher capability	Not directly measured; literature-derived condition.	Possaghi & Papavlasopoulou (2026); Rehman et al. (2025); World Bank (2024, 2025).	Assess teachers' robotics competencies before and after professional development and examine implementation quality.
3	Resource sufficiency	86 recorded respondents identified inadequate materials as a barrier, while 79 disagreed that existing resources were sufficient.	Alimisis (2021); Marín-Marín et al. (2024).	Examine how equipment availability, kit-to-student ratios, and instructional resources influence participation and learning outcomes.
4	Inclusive participation	Concerns about instructional-material accessibility, supported by contextual observations from key informants.	Alimisis (2021).	Evaluate equitable access, group participation, practical engagement, and learning opportunities across learner groups.
5	Authentic problem-solving	86 strongly supported creativity, 78 supported decision-making, and 67 supported income-generating innovation.	Arafat et al. (2024); Darmawansah et al. (2023).	Assess creativity, design quality, critical reasoning, and problem-solving skills using validated assessment rubrics.
6	Evidence-based evaluation and continuous improvement	Not directly assessed; literature-derived condition.	Ouyang & Xu (2024); Lu & Geng (2026).	Conduct repeated implementation and evaluation cycles using learning outcomes, participation, costs, and teacher-feedback indicators.

The six conditions are interconnected and complementary: curriculum alignment establishes educational objectives, teacher capability supports effective instruction, resource availability facilitates practical learning, inclusive participation promotes equitable access, authentic problem-solving enhances meaningful learning, and continuous evaluation supports improvement and sustainability. Although the framework provides a conceptual foundation for integrating educational robotics into science education, further empirical research is required to validate the relationships among these conditions and assess their effectiveness in Rwandan secondary schools.

Conclusion

The study revealed generally positive perceptions of educational robotics among learners from five selected secondary schools in Rwanda, highlighting its perceived potential to enhance creativity, decision-making, practical learning, and innovation. However, financial constraints, inadequate instructional materials, and concerns about employment displacement emerged as important challenges to its integration. These findings reflect respondents' perceptions rather than demonstrated improvements in learning outcomes or academic performance. Based on the study findings and supporting literature, a six-condition framework is proposed, emphasizing curriculum alignment, teacher capability, resource sufficiency, inclusive participation, authentic problem-solving, and evidence-based continuous improvement. The framework provides a conceptual foundation for the effective and sustainable integration of robotics into science education. Nevertheless, further empirical research involving multiple schools, direct assessments of learning outcomes, and rigorous methodological procedures is recommended to validate the proposed framework and establish the educational effectiveness and scalability of robotics integration in Rwandan secondary schools.

Recommendations for Policy, Practice, and Research for future researchers

I. Evaluate Learning Outcomes Through Intervention Studies

Future studies should assess whether educational robotics improves science learning through pretest–posttest designs, comparison groups, and standardized achievement measures. Learner acceptability should be considered an indicator of perceived value, not evidence of causal learning improvement, as robotics outcomes vary across contexts and assessment measures (Wang et al., 2026).

II. Strengthen Resource Availability and Equitable Access

Schools and education stakeholders should prioritize affordable robotics equipment, adequate instructional materials, replacement parts, storage, electricity, maintenance, and technical support. Low-cost platforms, such as Arduino-compatible boards and micro devices, may improve accessibility when supported by appropriate teaching resources and implementation plans. Resource allocation should also promote equitable participation among learners.

III. Invest in Teacher Preparation and Curriculum Integration

Education authorities and school leaders should provide sustained, practice-oriented professional development to strengthen teachers' technical skills, troubleshooting abilities, and capacity to integrate robotics into science lessons. Implementation should align with curriculum objectives, available instructional time, and assessment requirements. These measures are supported by the literature, although teacher capacity and curriculum alignment were not directly measured in the present study (Hyldahl & Gamlem, 2026).

IV. Integrate Creativity, Decision-Making, and Ethical Reflection

Robotics activities should include structured tasks that encourage creativity, problem-solving, collaboration, and evidence-based decision-making. These competencies should be assessed through observable learner performance and clear assessment rubrics rather than inferred from positive

perceptions alone. Lessons should also address the ethical, social, and economic implications of robotics and automation, including learners' concerns about future employment.

V. Align Implementation with Rwanda's Education Priorities

Future robotics initiatives should complement Rwanda's priorities in technology-enabled learning, competency development, teacher capacity, infrastructure, and access to learning materials (Ineza et al., 2025). Education stakeholders should begin with context-appropriate pilot programmes, monitor implementation and learning outcomes, and use the evidence to guide decisions about expansion. Consistent with broader digital education recommendations, investments should be accompanied by effective classroom implementation and ongoing evaluation (Abbasi & Yang, 2026b). Future research should build upon the findings of the present five-school descriptive study by incorporating direct assessments of learning outcomes, validated research instruments, and well-documented qualitative procedures. Longitudinal and quasi-experimental research designs involving a larger and more representative sample of secondary schools in Rwanda are recommended to evaluate the educational effectiveness, sustainability, and scalability of robotics integration in advanced-level science teaching.

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