

Assessing the Efficacy of Tiered Robotics Integration in Resource-Constrained Educational Ecosystems of Belize

David Garcia¹
Lloyd Augustin Jr¹
Immanuel Garcia¹

Abstract

For developing countries, establishing advanced Science, Technology, Engineering, and Mathematics (STEM) curricula is commonly hindered by a shortage of specialised infrastructure and skilled personnel. Belize, as it moves towards an economy based on technology, needs a strong STEM foundation, but the pedagogical impact of robotics under severe resource constraints has not been thoroughly investigated. This research assesses the efficacy and longitudinal benefits of introducing robotics activities in primary, secondary, and tertiary education in Belize. More specifically, it looks at the relationship between resource scarcity and the development of adaptive computational thinking. The research employs a mixed-methods approach, analysing student metrics in algorithmic problem-solving and qualitative case studies of "frugal engineering" projects, in which students use open-source platforms and materials available in Belize to compensate for expensive or unavailable equipment. The research proposes that a vertically integrated robotics framework covering all levels of education will encourage the kind of innovative skills that are suited to Belize's specific situation, lessening the impact of a lack of resources by developing high-level cognitive flexibility and heuristic problem-solving skills. Initial results indicate that the "expert scarcity" in Belizean classrooms encourages students to utilise peer-to-peer mentorship and collaborative debugging. This appears to build a stronger, longer-lasting understanding of systems engineering than is typically found in resource-saturated classrooms.

Keywords: Robotics education, frugal innovation, Belize STEM, computational thinking, resource-constrained environments, information technology.

¹ University of Belize

Corresponding Author: David Garcia, Faculty of Science and Technology, University of Belize, Hummingbird Ave, Belmopan, Belize. email: dgarcia@ub.edu.bz.

Introduction

Statement of the Problem

The increasing global focus on science, technology, engineering, and mathematics (STEM) has made robotics a critical pedagogical tool, but introducing such curricula in developing countries, like Belize, is held back by a systemic "triple constraint" of limited government funds, slow infrastructural development, and a lack of experts in the field (Ministry of Education, Culture, Science and Technology [MoECST], 2021; Sa'adah et al., 2025). Typically, traditional teaching approaches depend on being able to get expensive, licensed robotics kits, and reliable, fast internet access; however, primary, secondary and tertiary institutions throughout Belize do not have these things in a consistent manner (MoECST, 2021; Sa'adah et al., 2025).

Therefore, it is unknown if using robotics when there are few resources makes it harder for students to get involved, or if it instead encourages "frugal innovation", which is a specific type of cognitive adaptability where students create valuable technology from very little (Bhatti et al., 2018). Unless we carefully assess how well this works, Belize may risk a widening digital divide and lose the opportunity to leverage robotics to improve the skills of its population.

Contextual Background

The possibility of incorporating robotics into Belize's schools must be considered alongside the overall economic situation of the country. Belize has had substantial economic difficulties, and these were made much worse by the global COVID-19 pandemic. The country had to move from nearly failing financially to a regime of prudent fiscal management (Government of Belize, 2022; UNICEF Belize, 2023). This economic state creates difficulties for the adoption of new technology. Although Belize's economy has improved after the pandemic - with a GDP increase of 6.1% by the end of 2025 and a fall in government debt from 103.3% to 64.7% of GDP - many people in Belize are still living in poverty (UNICEF Belize, 2025). In fact, 30.5% of those between 0 and 14 are in multidimensional poverty and in areas like Toledo, this rises to 70% (UNICEF Belize, 2025).

In 2023, around 23% of Belize's government spending went to education, which is more than in other countries in the region and the amount recommended in the Incheon Declaration (UNICEF Belize, 2023). However, more than 90% of the education budget is used for the salaries and operational expenses of the system. This leaves under 10% for investing in technological infrastructure and innovation (UNICEF Belize, 2023). This financial situation is the first part of the triple constraint: a large total amount of spending does not translate into the expensive infrastructure required for typical robotics programs.

The Ministry of Education, Culture, Science and Technology (MoECST) identified technology as a key part of its 2021-2025 sector plan, with the aim of creating a system which is inclusive and technologically driven (MoECST, 2021). This research looks at how a tiered robotics framework impacts the development of adaptive computational thinking and suggests that "expert scarcity" and hardware limitations, in fact, encourage and serve as unique catalysts for innovation (Adhav & Khairnar, 2024).

Literature Review

Frugal Innovation and Resource Bricolage

This research is based on the idea of frugal innovation, which means getting a higher level of benefit from using fewer resources (Bhatti et al., 2018). In contrast to conventional innovation which typically prioritises enhanced performance and complexity, frugal innovation instead stresses affordability, accessibility, simplicity, sustainability, quality and a defined purpose (Bhatti et al., 2018; Weyrauch & Herstatt, 2016). When applied to education, this is commonly referred to as "frugal pedagogical innovation," and it views limitations as a source and catalyst for creativity and ingenuity, not as an impediment (Thirkell, 2026). Often, in resource-scarce environments, this is coupled with "bricolage", or the ability to manage with what is available by using a combination of existing resources in new ways to solve issues (Baker & Nelson, 2005).

In Belize, bricolage is seen in the way students convert discarded electronics or metal scraps into working robots when they do not have access to official kits (Love FM, 2022). For instance, in order to continue to perform well in international competitions, teams have used gate openers as gearboxes and door hinges as robotic claws (Love FM, 2022). This type of "resource-scarce solution" strengthens students' ability to "make do" with available resources and also promotes sustainable development by getting the most from limited resources (Fu et al., 2024).

Cognitive Flexibility Theory (CFT)

Cognitive flexibility describes the mental capability to suitably alter how one thinks or acts as situations change (Spiro et al., 1988). Spiro et al. (1988) suggest that a truly thorough understanding of complex subjects in ill-structured domains, for example, robotics, necessitates students approaching the material from multiple perspectives and changing their thinking to deal with unanticipated problems. Circumstances where resources are limited, and hardware breakdowns and communication losses happen often, are "ill-structured" in that they require students to move beyond rigid, familiar approaches.

Studies indicate that improving cognitive flexibility can raise the efficiency of problem-solving in complicated situations by as much as 35% (Barrella et al., 2021). Moreover, students exposed to interdisciplinary, project-based learning (PBL) environments are 42% more likely to show better cognitive adaptability in comparison to those in traditional, single-discipline programs (Zimmermann et al., 2010). In Belize, troubleshooting malfunctioning hardware without standard instructions directly strengthens cognitive adaptability. Such unscripted problems force students to think on their feet, which in turn bolsters their sense of computational thinking and cognitive flexibility (Jeong & González-Gómez, 2026). One might expect an environment like this to breed frustration at first, but once they have come to terms with those structural obstacles, it prepares them for long-term problem-solving readiness (Jeong & González-Gómez, 2026).

Computational Thinking as a Critical Literacy

Integrating robotics into education facilitates the development of Computational Thinking (CT), which includes abstraction, decomposition, algorithmic thinking, and debugging (Wing, 2006). For students in the early years of learning, actual physical robots function as "cognitive manipulatives" offering instant feedback to actions and consequently bolstering both logical thought and the formulation and assessment of assumptions (Bers et al., 2019). Robotics, in contrast to coding on a computer screen, enables what is called "mechanical debugging"; students have to consider actual, physical factors such as friction, and surface resistance, leading to a more thorough comprehension and grasp of the principles of systems engineering (Costa Junior et al., 2024).

Methodology

This research employs a mixed-methods approach to assess the efficacy of tiered robotics integration across the primary, secondary, and tertiary tiers of the Belizean education system.

1. **Quantitative analysis** of student performance in algorithmic problem-solving and the success of teacher training. The figures for this are derived from the MoECST Annual Technical Reports from 2023 to 2025, specifically regarding how many students are enrolled, how many finish their programmes, and how much access to the internet is being expanded (MoECST, 2024a; Ministry of Education, Science and Technology [MoEST], 2025).
2. **Qualitative case studies** gather accounts of "frugal engineering" projects from Belize High School (BHS), Itz'at STEAM Academy and the University of Belize (UB). These projects focus on "adversity-driven innovation" and the use of open-source platforms like Arduino and micro:bit.
3. **A vertically integrated framework** looks at how skills are built at each of the three tiers:
 - a. **Primary (Foundational CT)** emphasises foundational computational thinking and focuses on "unplugged" activities - work involving activities that don't need a computer, coding micro:bit, the FIFA Foundation programme (FIFA Foundation, 2024), and the FIRST LEGO League World Championship (FIRST, 2023).
 - b. **Secondary (Project-Based Application)** where projects are the core of the work, includes examining how many students are involved in international events such as FIRST

Global (FIRST Global, 2026) and the Caribbean STEM Olympiads (Caribbean Science Foundation, 2026a).

- c. **Tertiary (Industry 4.0 Integration)** where the focus is on the principles of Industry 4.0, the specialised engineering, information technology courses and research at University of Belize (University of Belize, 2020) and Galen University (Barrow, 2025) will be evaluated.

The study suggests that a vertically integrated robotics framework that works from primary to higher education will help create innovation competencies suited to Belize's conditions, reducing the impact of a lack of resources by encouraging high-level cognitive flexibility and heuristic problem-solving skills.

Results

Understanding the pedagogical challenge requires looking at how many students are enrolled and how teachers are being trained at the primary and secondary tiers. Table 1 presents important figures for education from the 2023-2024 and 2024-2025 reporting periods, and these show the overall issues affecting the implementation of STEM at these tiers (MoECST, 2024a; MoEST, 2025). At the secondary tier, enrollment decreases to 67.8% and the number of qualified teachers falls to 68.5%, highlights the systemic triple constraint where economic hardship like multidimensional poverty and expert scarcity caused by a lack of skilled personnel, threatens the scalability of STEM initiatives. The ratio of 22 students to each teacher in primary school, and 18 to each teacher in secondary school, specifically indicates that students in technical subjects require, and would benefit from, a more individualised learning approach (MoEST, 2025).

Table 1. Enrollment and Teacher Preparation (2023-2025)

Metric	Pre-Primary	Primary	Secondary
Gross Enrollment Ratio (2023-24)	44.2%	95.8%	72.0%
Gross Enrollment Ratio (2024-25)	42.1%	91.7%	67.8%
% Trained Teachers (2024-25)	89.7%	95.4%	68.5%
Student-Teacher Ratio	N/A	22:1	18:1
Primary Completion Rate (2023-24)	N/A	97.0%	N/A
Transition Rate to Next Level	N/A	85.6%	N/A

To improve technological adoption, the MoEST has connected 283 schools (pre-primary to tertiary institutions) to the national grid—a 33% increase providing internet access to 87,000 students—and transitioned to a competency-based National Curriculum Framework that prioritises "innovative knowledge and skills" over rote memorisation (MoECST, 2022; MoEST, 2025). This systematic restructuring aligns with contemporary pedagogical frameworks, such as the Integrated Constructive Robotics in Education (ICRE) model, which posits that tech-enabled, experiential environments are vital to cultivating holistic student agency and deeper conceptual clarity in STEM tracks (Alam & Mohanty, 2024).

Primary Tier: Foundational Literacy and Local Innovation

At the primary tier, robotics is being used as a way to make STEM subjects more engaging and socially oriented, with a focus on fun interaction and relevance to the students' own surroundings. The FIFA Foundation Digital Education Programme has delivered computer science and robotics to forty Belizean primary schools, with more than 200 Belizean teachers receiving training to help around 10,000 children between eight and eleven years of age (FIFA Foundation, 2024; Greater Belize Media, 2024).

- Considerable success with robotics in Belize's primary schools is illustrated by the following:

- Our Lady of Guadalupe Primary School in Belmopan, for example, won the National FIFA Coding and Robotics Expo in early 2026, and their success showed a very high level of skill in both problem solving and digital literacy (Love FM, 2026a).
- Girls 4 Tech, in collaboration with MasterCard and Belize Bank, has provided workshops on Artificial Intelligence and the Internet of Things (IoT) to Holy Redeemer, Grace Primary and Pancotto Primary School (Love FM, 2025).
- St. Joseph RC Primary School received forty robotics kits and associated materials from the FIFA Foundation in late 2024, giving their students the chance to engage in hands-on programming (Greater Belize Media, 2024).
- The pilot programme CODE Caribbean, starting in twenty-two primary schools in 2022 and then increasing to twenty-five in 2023, has been developing children's computational thinking abilities through micro:bit coding (MoECST, 2024b).
- The Island Academy (TIA)'s "Island Innovators" team, from San Pedro, competed for Belize at the FIRST LEGO League World Championship in Houston, Texas in 2020 after their victory in the inaugural National Elementary School Robotics Event (Ambergris Today, 2020; The San Pedro Sun, 2020).

Secondary Tier: Competitions and Frugal Engineering

The second tier of development is where students put their academic STEM knowledge to work on complicated issues from the actual world. Importantly, the Ministry of Sports in Belize has now officially classified robotics as a sport, and this has increased a feeling of national importance and enthusiasm (Love FM, 2023).

There are specific examples at this tier:

- Bridget Pineda, a student at Nazarene High School, won a gold medal for her "Cricket" device for fire safety in 2025, and received the only platinum award for her "OxyFlow" design, a medical ventilator in 2026, at the Caribbean STEM Olympiads. She created both devices entirely from scratch (Caribbean Science Foundation, 2026b; Flowers, 2025; Humes, 2026).
- Belize High School's robotics team (STEAMBel 9244) has been successful on an international level, winning gold at the 2022 FIRST Global Challenge in Geneva and receiving the FIRST Robotics Rookie Inspiration Award in Houston, Texas, in 2023 (Love FM, 2022; Love FM, 2023a). In December of 2025, Belize High School students worked with the Belize Robotics Federation to create VEX CTE Workcells and ClawBots, and their focus was on industrial automation (Government of Belize, 2025).
- Saint Catherine Academy, with Dr. Salome Tillett, who is a leading proponent of the flipped-classroom method, also worked with the Belize Robotics Federation in December 2025 on the construction of VEX CTE Workcells and ClawBots, and they too concentrated on industrial automation (Government of Belize, 2025).
- Ladyville Technical High School won the country's robotics competition and as a result represented Belize at the 2024 Samsung "Solve for Tomorrow" competition in Guatemala, gaining a silver award for "AODI" (Assistive Oral Device Interface), a device for people who have difficulty speaking (Love FM, 2024).
- Itz'at STEAM Academy employs a maker-centric curriculum focused on making things; for example, students have built prototypes of "multifunctional hats," including crowns with incorporated sunglasses and cardboard hats which transform into bags, in order to apply constructionist design principles. They also use a geodesic greenhouse as a way to link geometry with environmentally sound farming (MoECST, 2024a; Ouellette, 2024).
- At the 2024 Caribbean STEM Olympiads, Muffles College's "TechoTactic" team received a gold award and Giselle Garcia, a student, won a platinum medal for her "Protective Measures" application for hurricane preparedness (Love FM, 2024).
- Pallotti High School's all-female team, "PHS ROTECH", won the gold award in the 2023 Samsung Solve for Tomorrow final competition in Panama. Their "SMARTZ" blind stick, using sensors to notify visually impaired people about obstructions, was the winning invention (Love FM, 2023b).
- In the 2022 Web Development competition, hosted by the Public Utilities Commission (PUC), Stann Creek Ecumenical College (SCEC) was very successful. They overcame seven other schools

to create a website using web design coding, and won \$10,000 of computing devices for the school (7 News Belize, 2022).

A VEX Robotics (VEX Robotics, n.d.) technical workshop was conducted at the Fort George Digital Connect Centre on December 6, 2025, for students at Belize High School and Saint Catherine Academy, and was run by the Ministry of E-Governance and the Belize Robotics Federation (Government of Belize, 2025). This activity supports the goals of Belize's Country Strategy 2026-2030 by developing digital access and improving national skills through practical STEAM learning (Inter-American Development Bank Group, 2026). A significant Memorandum of Understanding between the Ministry of E-Governance, the Belize Robotics Federation and VEX Robotics was signed in March 2026 to help close the gap in digital skills, and Belize High School is being used as a model for the introduction of VEX robotics systems and appropriate competition programs throughout the country (Iglesias, 2026; Love FM, 2026b).

Tertiary Tier: Advanced Training and the University of Belize

There is a distinct structural gap in the broader framework of tiered robotics integration in Belize, particularly at the independent junior colleges of the Association of Tertiary Level Institutions in Belize (ATLIB) network. While an associate track run by a university is woven into the fabric of their campus initiatives, these standalone two-year institutions follow a more conventional transfer model geared toward general competencies (Aird, 2024). As a result, their technical curriculum is limited to web design, conceptual logic and software problem-solving. In doing so, it leaves an intermediate stage in the curriculum that is entirely disconnected from any national robotics effort.

The University of Belize (UB) is the principal provider of advanced training in engineering and information technology at the higher education level, and this is in accordance with the country's National Science, Technology, and Innovation Strategy (2024-2034) which is intended to position Belize for the Fourth Industrial Revolution (Government of Belize, 2024).

Within UB, the Mathematics, Physics, and Information Technology (MPIT) Department delivers the Bachelor of Science in Information Technology (BINT), a degree that gives students a thorough understanding of software engineering, networking, database management and cybersecurity (University of Belize, 2025). Robotics has been included in central technical courses, such as "Programming Languages", "Algorithms", "Digital Logic & Design", and "Practical Electronics", since 2018, giving BINT students practical experience of how fundamental ideas are used in actual systems (Garcia, 2024).

A central element in encouraging student innovation at the Belmopan Campus is the JaguarTech Studio. This studio, created from a previously underused area, represents a strategic investment to enhance STEM capacity at the University (Garcia, 2025). The MPIT Department oversees the studio which is the main hub for the UB Robotics Challenge, and collaborative cross-disciplinary projects in the areas of robotics and Artificial Intelligence (Garcia, 2025; UB Association of Computing Machinery Student Chapter, 2026).

The use of robotics in tertiary education has moved from simply considering the theoretical concepts to applied design. Early in 2026, the University reached a pivotal point, transitioning from ad hoc robotics projects to a systematic, institution-wide program with the creation of the UB Council on Robotics Education (CORE). CORE is the official university-sanctioned governing body responsible for providing direction and managing all robotics-related academic work, research, outreach initiatives, and public engagement (Garcia, 2026a). An initial key priority for CORE is the management of the institution's pivot to the VEX Robotics ecosystem in August 2026. This change is to ensure that secondary level outreach and tertiary level curricula and competitions are vertically aligned (Garcia, 2026b). This plan encompasses the introduction of specialised elective courses, such as "CMPS4221: Robotics Systems," which combines theoretical logic with the practical use of hardware (Garcia, 2026b). CORE also functions as the University's official point of contact with organisations like the Belize Robotics Federation and the Ministry of E-Governance (Garcia, 2026a).

Additionally, robotics is being used in professional contexts as a result of partnerships with the University. As an example, the Coastal Zone Management Authority & Institute (CZMAI) used "C-WORKER", a robotic, unmanned boat, to carry out oceanographic and bathymetric surveys to evaluate the condition of coral reefs (Coastal Zone Management Authority & Institute, 2018). In addition, Galen University's Office of STEM, Robotics and AI and its Computer Science program have AI and robotics in their curriculum, with an emphasis on learning by doing, through practical software projects (Barrow, 2025).

Discussion

The Social Architecture of Expert Scarcity

The case of Belize demonstrates that expert scarcity, or a lack of specialist teachers does not automatically mean the standard of learning will be lowered. Instead, it changes how the classroom works socially, encouraging peer-to-peer mentorship with students supporting one another, guiding each other as they solve problems through collaborative debugging, and as a result achieving a stronger, more resilient grasp of systems engineering than would be typical in resource-saturated classrooms (Nasir et al., 2021). When teachers don't have every answer, the typical teacher-centric model where the teacher is the main focus is superseded by a learner-centric, collaborative way of learning where students are at the centre (Nasir et al., 2021; Medina & Garcia, 2025). This shift empowers students to be in charge of their learning, developing independent research skills, and a feeling of being mutually accountable for success through collective responsibility.

Peer-to-Peer Mentorship Models

Belizean robotics mentorship manifests in a number of ways, each of which supports the building of different capabilities (Nasir et al., 2021; Garcia, 2026b):

- **One-on-one mentorship** involves a more experienced student or professional being linked with a beginner to offer advice specifically for their needs (Felten & Lambert, 2020).
- **Group mentorship** involves a single mentor working with a team, encouraging members to work together and to consider many points of view (Martins et al., 2018).
- **Peer mentorship** involves students who have more experience helping those at the same level, offering guidance they can easily identify with, and importantly, reinforcing the mentor's own understanding by requiring them to explain things to another (Alegre et al., 2019; Topping & Ehly, 1998)
- **Reverse mentorship** has the younger or less experienced member of the pair share current expertise – for example, new coding methods or artificial intelligence software - with the more senior mentor (Sarioğlu et al., 2026).

This relationship between mentor and mentee is critical for closing the distance between knowing something in principle and being able to do it (Baltov et al., 2023). In robotics, where a machine actually working is the ultimate test, working with each other helps students learn to provide and accept constructive criticism, to deal with disagreements and to enjoy triumphs as a team (Nasir et al., 2021).

Collaborative Debugging and Soft Skill Development

Arguably, the most important benefit of using robotics when resources are limited is collaborative debugging, how people work together to find and fix problems. Students clustered around a robot that isn't working are using "multi-perspective team-based estimation", and research demonstrates this method leads to more precise assessments and resolutions of issues than an individual expert could achieve (Nasir et al., 2021). When students cooperate on the physical wiring of sensors and the programming of robotic motions, students strengthen valuable interpersonal abilities, including patience, understanding of others' points of view, and good communication, all of which are equally important to the technical skills they are learning (Alegre et al., 2019; Nasir et al., 2021).

Moreover, because broken equipment can't be immediately substituted with new parts, students are required to cultivate heuristic problem-solving skills that include resourceful, rule-of-thumb approaches to solving problems. In contrast to resource-saturated environments where a lot of equipment is available and hardware errors are commonly fixed by simply swapping out the broken part, the situation in Belize forces students to fundamentally rethink how they solve issues (Spiro et al., 1988). This "adversity-driven innovation" is a better preparation for the changing nature of the world's digital economy compared to just memorising information (Ouellette, 2024).

Comparative Regional Analysis: Belize in the Caribbean Context

The progress Belize has made in robotics education is representative of a broader regional trend for growth based on STEM in the Caribbean. Nevertheless, Belize has its own particular challenges and has built distinct strengths when compared with other countries in the region (Alexander et al., 2023). Jamaica and Trinidad and Tobago, for instance, can generally utilise their more substantial economies to pay for expensive, specialised systems. Belize, on the other hand, is defined by its lack of government funds, slow progress with infrastructure, and both of these things happening at the same time. As a result of this, Belize has become particularly good at frugal innovation, where resource scarcity acts as a catalyst for students to develop high-level cognitive flexibility and resilient competencies in engineering.

STEM Olympiads and Regional Competitions

In the 2026 Caribbean STEM Olympiads, Jamaica won the most medals, and was followed by Trinidad and Tobago, with Belize ranking third (Humes, 2026). Even though Belize didn't get as many medals in total as the larger economies, their amazing platinum performance in the highest level of the competition, Level III Robotics category indicates that Belizean students are performing at the top of the regional standard in complex engineering tasks (Humes, 2026). This suggests that the Belizean model of frugal innovation is highly effective at producing elite performance despite lower overall resource availability.

Collaborative Initiatives and International Partnerships

Belize, as Jamaica has done, is building its robotics capacity by working with organisations in other countries. In Jamaica, students from Penn Engineering worked with Jamaican universities to create the "BioScout" drone and intelligent buoys for tracking the environment (Taylor & Johnson, 2025). The collaboration between MIT and Belize's Ministry of Education to start the Itz'at STEAM Academy is doing much the same thing in Belize (Ouellette, 2024). These international collaborations are vital for bringing sophisticated technologies, such as artificial intelligence and advanced sensors, into the country; they are effectively a "resource bridge", lessening the issues of the national triple constraint of limited time, money and skills (Ouellette, 2024).

Barriers to Scalability: Infrastructural Latency and Sustainability

Examples of very successful robotics programs are positive, however, the unequal access to technology - the digital divide - continues to be a significant barrier when considering implementing robotics education throughout Belize. The Ministry of Education has stated that improving the educational system, and changing how both teachers teach and students learn are key goals, yet a number of persistent obstacles must be resolved (MoECST, 2024a).

Infrastructural Gaps and the Cost of Access

Declining numbers of children in preschool, primary and secondary school are partly because 60% of those under fourteen in Belize are living in poverty (UNICEF Belize, 2023). Many families struggle with the expense of school uniforms, materials and, increasingly, schools are needing parents to cover the bill for internet access and equipment repairs. Consequently, robotics risks becoming an "elite" field of study available only to students in urban, better-resourced schools, such as Belize High School, with those in rural areas being excluded (MoECST, 2023).

To reduce this financial burden, the government is looking at "public-private partnerships" (PPPs) to fund things like providing internet service. In order to be fair and include all students, the National Digital Agenda for 2022 to 2025 has been implemented and, through the Giga initiative, schools are being connected (MoEST, 2025; UNICEF Belize, 2025). It is also essential to encourage "unplugged" computational thinking activities, and affordable, open-source platforms such as micro:bit, to make certain rural learners are not disadvantaged (African Union High-Level Panel on Emerging Technologies, 2024). In Toledo, the most remote district of Belize, and similar areas where infrastructure lag results in poor internet access, robotics education must be framed not as a cloud-dependent digital exercise, but as the study of autonomous logic and mechanical systems. In this context, robotics is defined by 'low-bandwidth'

learning, where logic is tested by using physical controls and software that is already in the system, rather than real-time internet connectivity.

The Teacher Training Imperative

Students demonstrate a great deal of inventiveness, however, a shortage of expert teachers continues to be a significant obstacle. Many teachers in the Caribbean are prepared to teach only one subject in a traditional manner, and do not have much experience with STEM learning that combines multiple subjects (Caribbean Educational Research Information Service [CERIS], 2024). For teachers to be trained effectively, the training needs to be more than just standalone courses; it should allow teachers to learn by doing, experiencing what it's like to be a student in a situation with limitations. The Ministry of Education, Culture, Youth and Sport's Teacher Learning Institute (TLI) is vital for developing this long-term capacity in teachers (MoECST, n.d.; MoECST, 2020a).

Moving from a focus on single subjects to an approach of "integrated STEM" will require a total transformation of how teachers are educated. Robotics education for teachers needs to:

- Develop pedagogical knowledge that is both interdisciplinary and transdisciplinary (CERIS, 2024)
- Provide ongoing professional development instead of standalone courses (CERIS, 2024)
- Incorporate inquiry-based teaching and learning practices, where the teachers themselves are learners in a robotics context (CERIS, 2024).

Unless we change how we improve teachers' skills, the expert scarcity which is currently met by peer mentorship with teachers advising each other, will eventually restrict how complex students' projects can become.

Future Outlook: Robotics and the Sustainable Development of Belize

Robotics offers a considerable opportunity to revolutionise Belize's economy. Introducing robotics into the national educational program would empower young people and promote economic development in agriculture, healthcare, environmental sustainability and other areas (African Union High-Level Panel on Emerging Technologies, 2024). The inclination towards a frugal innovation mindset that students will develop is directly transferable to the workforce, where "wise problem solvers" with a "business mind and social heart" are needed to solve the nation's "wicked problems" (Bhatti et al., 2018).

Aligning with Sustainable Development Goals (SDGs)

Belize's robotics education programs support a number of the United Nations Sustainable Development Goals. These include:

- **Goal 4 (Quality Education)** is delivered by offering STEM education that is inclusive and equitable (Weyrauch & Herstatt, 2016).
- **Goal 5 (Gender Equality)** by prioritising gender-inclusive STEM initiatives that encourage female participation and innovation. (UNESCO, 2024).
- **Goal 8 (Decent Work and Economic Growth)** is being supported by getting people ready to work in the digital age (African Union High-Level Panel on Emerging Technologies, 2024).
- **Goal 9 (Industry, Innovation, and Infrastructure)** is being advanced by utilising inexpensive, artificial intelligence-driven solutions to fill infrastructural deficiencies (Weyrauch & Herstatt, 2016).
- **Goal 13 (Climate Action)** is supported through the design of robotic tools for environmental monitoring and sustainable agriculture (Taylor & Johnson, 2025).

The Ministry of Education's BESPlan 2021-2025 clearly indicates that resources for science and technology will be widely available and effectively used in ways that help and enhance the standard of teaching (MoECST, 2021). The plan's success, however, relies on incorporating the resilience to expert-scarcity and frugal engineering, both of which are presently characteristics of the country's strongest robotics teams.

Conclusion

Belize's adoption of robotics is a good example of managing the triple constraint of budget, resources, and timelines. The country's budget limitations and lack of infrastructure, instead of being obstacles, have driven a need for resourceful and frugal innovation, and in turn, have generated a high degree of cognitive flexibility and collaborative resilience among students. The expert scarcity has, furthermore, spurred a strong system of peer-mentorship of students helping students, which builds important, flexible soft skills valued in the twenty-first century. Robotics in the classroom is no exception; it has been shown to be a catalyst for motivation, cooperation, and creativity, taking learning well past the point of simply technical skill acquisition.

For Belize to leverage robotics as a vehicle for national development, the following strategic actions are required (UNICEF Belize, 2023):

- **Institutionalise frugal engineering** that standardises in the national curriculum the use of open-source and low-cost platforms to make it easier for rural schools to participate.
- **Expand teacher training** by progressing from isolated workshops to long-term, multidisciplinary professional advancement for teachers, and delivered by the Teacher Learning Institute (CERIS, 2024; MoECST, 2024).
- **Leverage public-private partnerships** to formalise agreements with businesses to finance the costs of technology, including internet access and hardware labs, to ensure that the 'triple constraint' is not reinforced but mitigated through sustainable budgets.
- **Maintain vertical integration** by ensuring that computational thinking skills learned in primary school must be developed in a logical progression by way of secondary school competitions and advanced engineering work and research at university (Dewa et al., 2026; MoECST, 2021).

By embracing the "advantages of adversity," Belize can ensure that its students are not merely consumers of technology, but instead are capable of creating long-lasting, relevant innovations for their own circumstances that will determine the country's future in the global digital economy. Ultimately, Belize's tiered robotics integration is a compelling model for other developing countries, proving that impactful engineering solutions are generated not by having plenty of resources, but by creative, resourceful and resilient mindsets in the face of difficulties, which is characteristic of global frugal innovation frameworks (Bhatti et al., 2018).

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