FUTURE DIRECTIONS

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# STEM Education Research, Policy, and Practice in the Caribbean: Imperatives for the Next 5 Years

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## Abstract

The last 10 years have seen repeated calls of increasing urgency regarding the importance of STEM and STEM education in the Caribbean regional economy (iNews Guyana, 2018; Mitchell, 2018; Warde & Sah, 2014). In 2019, the *Journal of Education and Development in the Caribbean* published a special issue entitled "STEM Education in the Caribbean: Challenges, Goals, and Possibilities". In the Editorial to that special issue, we articulated four primary considerations regarding future regional efforts toward integrated STEM education policy and practice (Sweeney & George, 2019, pp. vii-x). The commentary below (i) offers our reflections on the quality and extent of progress toward this goal approximately 5 years after publication of that Editorial (2019–2024); (ii) highlights what we believe to be the key roles and responsibilities of STEM education scholars in the region; and (iii) provides recommendations for integrated STEM education research, policy, and practice in the Caribbean over the course of the next 5 years.

## Introduction

The quest to achieve consensus regarding a comprehensive and "universal" definition of science-technology-engineering-mathematics (STEM) education continues to preoccupy education researchers and practitioners globally (Akerson & Buck, 2023; National Taiwan Normal University & Ministry of Education, Taiwan, 2022; Moore et al., 2020; Nadelson & Seifert, 2017; English, 2016; Bybee, 2013). Current thinking in the field has been widely influenced by Kelley and Knowles (2016), who define *integrated* STEM education as "the approach to teaching the STEM content of two or more STEM domains, bound by STEM practices within an authentic context for the purpose of connecting these subjects to enhance student learning" (p. 3).

As a consequence of noting the multiple broad definitions of integrated STEM education that exist in published research and policy documents, Roehrig et al. (2021a) provide a detailed conceptual framework of integrated STEM education that includes seven key

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characteristics, i.e. a focus on contextualised real world problems; the centrality of engineering; context integration; explicit content integration; STEM practices; 21st century skills; and informing students about STEM careers (p. 3). Roehrig et al. (2021a) also suggest that the incorporation of 21st century skills (e.g. real-world problem solving; skilled communication; critical thinking; creativity) in such an integrated conceptual framework necessarily subsumes competencies in the arts and in research, respectively, and obviates the need to further distinguish STEAM or STREAM education (p. 12).

Given the complexity of clearly defining and achieving consensus on what actually is meant by integrated STEM education, it is not surprising that challenges continue to be faced in the conceptualisation and implementation of integrated STEM curricula (Roehrig et al., 2021b). In the Caribbean, such challenges are apparent. In Guyana for example, the Education Sector Plan 2021–2025 prominently declares the intent to "ensure [that] STEAM is embedded in the teaching-learning process" by emphasising "structured digital literacy programmes at primary and secondary schools through the use of robotics and other ICT tools" and "improving the quality of teaching mathematics […] for all teachers at the primary level" (Guyana Ministry of Education, 2021, p. 80). In Trinidad & Tobago, current education policy states that it is necessary to "clarify the role of Science, Technology, Engineering and Mathematics (STEM)" in curriculum development, and highlights the perceived importance of expanding curriculum and teaching "to link core areas such as literacy, numeracy, science, technology, research, engineering, the arts, and mathematics (STREAM) to real-life applications" (Government of the Republic of Trinidad & Tobago Ministry of Education, 2023, pp. 27, 29). In Barbados, attention is drawn to forthcoming efforts in curriculum reform that "will be underpinned by a project-based approach with an emphasis on Science, Technology, Engineering, Arts & Mathematics (STEAM)" (Barbados Ministry of Education, Technological & Vocational Training, 2023, pp. 17–18).

Similar to other countries in the Caribbean region, it is clear that Jamaica considers an increased emphasis on STEM education to be indispensable in achieving its wider socioeconomic aspirations (Jamaica Ministry of Science, Energy and Technology, 2022). A report commissioned by the British Council (2022) comprehensively discussed the current status of STEAM education in Jamaica, with findings that are likely to be broadly applicable across the region. The report notes that STEAM methodologies ostensibly are being utilised to varying extents in the implementation of Jamaica's National Standards Curriculum from kindergarten to Grade 9. However, at Grades 10–13, instruction is focused on preparing students for external examinations administered by the Caribbean Examinations Council (CXC) "which do not allow for the forms of assessment recommended by the STEAM education methodology" (British Council, 2022, p. 9). The report also identified several "gaps" or areas of deficiency, i.e. teachers' lack of understanding of STEAM education; inadequate training in STEM education; lack of teachers adequately trained in STEM or STEAM education methodology; lack of investment in research and development; and challenges in assessing STEAM education (pp. 37–41). To its credit, Jamaica's Ministry of Education and Youth has continued to move forward in its STEM education efforts "to advance student learning and innovation throughout the country" (Henry, 2024; *Jamaica Observer*, 2023).

While the examples given here are not comprehensive, we believe that they offer a reasonable representation of what is occurring broadly across the region at this time. At the regional level, we note the recent Caribbean Community (CARICOM) Girls in ICT Partnership STEM/STEAM career webinar series which explicitly expressed its commitment to "fostering and promoting growth in the fields of Science, Technology, Engineering, Arts, and Mathematics (STEM/STEAM) with specific focus on women and girls" (CARICOM, 2023). Throughout the examples given, we also note the extensive use of variants in terminology such as "STEAM" and "STREAM". For our commentary below, we will use the more inclusive term *integrated STEM education* as described by Roehrig et al. (2021a).

Against this backdrop, we return to the four primary considerations articulated by Sweeney and George (2019) regarding future regional efforts toward integrated STEM education policy and practice.

## Four Primary Considerations

Conceptualising, developing, and implementing effective integrated STEM education approaches in the Caribbean are ambitious and daunting tasks. Multiple issues need to be considered, such as requisite social and physical infrastructure; time constraints; appropriate curricular and teaching materials; student interest; and workforce demands, to name but a few. These cannot be ignored. Nevertheless, while the four considerations that we again present for brief discussion are not exhaustive, each of them play particularly significant roles in the contemporary social; political; and economic contexts of the region (Sweeney & George, 2019, p. vii).

1. *The goal of understanding the specific terminology of specialised STEM content will need to be carefully balanced with how we promote literacy in integrated STEM teaching and learning, and associated integrated STEM curriculum development*.

Each of the individual disciplines comprising “STEM” has its own highly specialised vocabulary, and learners are required to comprehend and master this vocabulary. Such efforts are compounded by the fact that specific words, phrases, and concepts in one STEM discipline often have different meanings or nuances in another (Kwok et al., 2020; Yoho, 2020). In seeking to establish integrated STEM education in our region, this becomes even more challenging when taking into account the linguistic forms typically used in the Caribbean (e.g., creole; dialect; patois/patwa) which embody their own distinct, culturally influenced ways of thinking and communicating (Lodge, 2017, 2020; George, 2013; Hewitt-Bradshaw, 2013; Sweeney, 2003).

We note that none of the education plans mentioned above (i.e. Guyana; Trinidad & Tobago; and Barbados) make any reference to this issue regarding the development and implementation of STEM/STEAM education. Similarly, the British Council (2022) report describing the current status of STEAM education in Jamaica makes no mention of this important consideration. While we find substantial merit in the ten STEAM education policy objectives recommended in the report (p. 11), we suggest that policy objective #2 (to advance a cohesive national integrative STEAM education curriculum throughout the pre-tertiary phase of education) and policy objective #8 (to develop a national education campaign promoting the value of STEAM education to the development of the economy) will be difficult to fully achieve without taking into account the almost ubiquitous use of Jamaican Creole in this officially English-speaking country. Similar concerns will need to be addressed in other anglophone Caribbean countries, which, while officially English-speaking, typically have large proportions of their respective populations who preferentially communicate in their local creoles (Kozlova et al., 2022; Myrick et al., 2020).

2. *The process of integrated STEM teacher education will require the professional preparation of teachers who are competent not only in one area of specialisation (as currently is the case), but in at least two STEM areas, along with the necessary pedagogical content knowledge to guide integrated STEM teaching and learning*.

It is widely acknowledged across educational research literature that teachers’ quality and teaching methods are primary determinants of academic success (Patfield et al., 2022; Murray, 2021). Fortunately, there appears to be consensus across Caribbean territories that teacher education reform is essential to produce competent integrated STEM practitioners who can effectively implement integrated STEM education to attain the intended educational outcomes (Barbados Ministry of Education, Technological & Vocational Training, 2023; Government of the Republic of Trinidad & Tobago Ministry of Education, 2023; Jamaica Ministry of Science, Energy and Technology, 2022; Government of Belize Ministry of Education, Culture, Science and Technology, 2021; Guyana Ministry of Education, 2021; The Jamaica Education Transformation Commission, 2021).

To advance integrated STEM teacher education, opportunities must be considered to build teacher educators' capacity to prepare teachers using techniques that support the acquisition of interdisciplinary and transdisciplinary pedagogical and content knowledge (Darling-Hammond et al., 2024; Tairab & Belbase, 2023). Transitioning from single-discipline teaching methodologies to adopting interdisciplinary and transdisciplinary approaches embedded in real-world contexts will require teachers to have extensive first-hand experience with inquiry-based teaching and learning practices. Completing a single, standalone course that covers the techniques and best practices in STEM education will be insufficient to prepare proficient integrated STEM education practitioners (Byrd et al., 2022; Richmond et al., 2017). Therefore, it is imperative that teacher educators be engaged in thorough, ongoing professional development to ensure competency in the preparation of integrated STEM educators.

We identify several challenges that are likely to hinder the region's progress in developing and implementing a robust integrated STEM teacher education curriculum model. These challenges include, but are not limited to, the following:

- A common understanding of how integrated STEM education is conceptualised, defined, and operationalised is yet to be established for the Caribbean (Sweeney & George, 2019). Evidence of this dissonance is highlighted by the multiple variants of the STEM acronym (i.e. STEAM; STREAM) adopted by individual territories. The current lack of a unified vision on the way forward may pose a difficulty in appropriately restructuring teacher education, since a guiding philosophical framework has not yet been declared.
- Difficulty persists in designing appropriate assessments within teacher education and, by extension, within the primary and secondary school curricula. Developing a rigorous framework for authentic assessment in integrated STEM education will require collaboration across various public and private sector entities to ensure that there is no disconnect between educational goals and workforce expectations. The nature of this collaborative process is generally time-consuming and, in some instances, may be expensive to undertake (British Council, 2022).
- There is no guarantee that national/regional investment in integrated STEM teacher education will encourage prospective teachers' interest in pursuing this as a career. There is a notable decline in enrolment within teacher education institutions in Jamaica, especially for science and mathematics education, despite the government's introduction of full scholarships and other subsidies (Rowe, 2023; The Jamaica Education Transformation Commission, 2021, pp. 153–154). Additionally, as noted by Hylton (2022), most of the graduates from two of Jamaica's largest tertiary institutions pursued qualifications in business, humanities, or social sciences because of their perceptions regarding more attractive career opportunities.

These challenges are further exacerbated when we consider the problematic case of mathematics, which plays a central role in integrated STEM education (National Council of Supervisors of Mathematics and National Council of Teachers of Mathematics, 2018).

Using Jamaica as an example, teacher education institutions in this country are primarily responsible for preparing aspiring educators with the knowledge, skills, and competencies needed to effectively teach and support student learning at the primary and secondary educational levels (Wanliss, 2023). One of the main entry requirements to pursue a Bachelor of Education (BEd) degree in Mathematics Education includes attainment of Grade I or Grade II in the Caribbean Secondary Education Certificate (CSEC) mathematics examinations that students typically sit at age 16 following completion of high school. Using student population data made available by the Jamaica Ministry of Education and Youth (MoEY), George (2023) examined CSEC mathematics performance across 4 years for 2015, 2016, 2017, and 2018. Findings from this analysis indicated that on average, 23.4% and 33.1% of the test takers obtained Grades I and II, respectively. This small percentage of students constitutes a very small pool from which to draw potential pre-service mathematics teachers.

To pursue the same BEd degree, the regional tertiary level institution (The University of the West Indies), has a higher matriculation requirement, i.e. one Unit (Year 1) of Caribbean Advanced Proficiency Examination (CAPE) mathematics. At the CAPE level, over 5 years from 2013–2017, George (2020) found that, on average, approximately 20% of the candidates who pursued CAPE level studies in Jamaica opted to study a mathematics course. However, there was marked attrition after Year 1 of the 2-year course of study. The analysis of data was restricted to a 5-year period from 2013–2017 because these were the data made available by the MoEY. Since it would be expected that only a small fraction of the individuals obtaining a passing mathematics grade at the CAPE level will pursue a degree in mathematics education, the pool of prospective preservice mathematics teachers is worryingly small. Coupled with the high rate of STEM professionals migrating from Jamaica to developed countries (Adams & Aguilar-García, 2024; World Bank, 2021; Wilson-Harris, 2019), the portrait related to the recruitment and professional preparation of adequate numbers of mathematics teachers appears stark.

3. *There will be a need to develop relevant education policies (as individual nation-states and as a region), that address both the retention and "managed migration" of STEM/STEM education professionals and associated social and economic factors of regional importance*.

A recent international report warns that a global shortage of teachers currently threatens attempts to meet the goal of "ensuring inclusive and equitable quality education for all by 2030" (UNESCO & International Task Force on Teachers for Education 2030, 2024, p. 18). While the reasons for such a global shortage are complex and dependent on many factors, "in countries across all income levels, unattractive salaries, hard working conditions, and heavy workloads are discouraging many candidates from joining or staying in the profession" (p. 20). Within the Caribbean, an insufficient number of professionally prepared teachers who are needed to implement the public education goals of the region is often due to emigration for economic reasons. Brissett (2019) notes that emigration for economic reasons has been a constant feature of the region. George et al. (2021) provide further support for this observation in their analysis regarding the financial incentive for Caribbean teachers to migrate and "the extent of the income disparity between countries in the Caribbean and popular destination countries" (p. 29).

The situation in Jamaica is particularly pertinent. In a trenchant analysis of multiple issues leading to Jamaican teacher migration, Gentles (2020) notes that

> [o]ver the last 30 years, Jamaica has been grappling with the loss of large numbers of its teachers through recruitment to overseas jobs. This has created a shortage of teachers across all of Jamaica's 833 schools, particularly in subject areas such as mathematics, science and foreign languages (p. 197).

This is further corroborated by the Jamaica Teachers' Association, which estimates "that close to 50,000 teachers have left the school system over the past 20 years, with many of them being STEM teachers" (The Jamaica Education Transformation Commission, 2021, p. 153). From a pointedly economic perspective, the World Bank (2021) advised that "Jamaica does not fully benefit from its investments in teacher training" since "qualified teachers often emigrate, causing teacher shortages in core subjects such as Math and Science in the local education system" (p. 46). Several recent commentaries have continued to highlight this troubling state of affairs (Malabver, 2023; Romero, 2023; Campbell, 2022).

The Jamaica Education Transformation Commission (2021) suggests a number of strategies to attract, incentivise, and retain teachers (pp. 150–155). In addition to salary increases and other pecuniary rewards, promotion-based incentives for teachers who actively engage in education research might be especially applicable to integrated STEM education teachers (also see UNESCO & International Task Force on Teachers for Education 2030, 2024, p. 58).

While seemingly counterintuitive, it appears that serious consideration is being given in Jamaica to "training teachers for export" as an approach that could generate considerable economic returns for the country (*Caribbean Times*, 2022). The President of one of the country's leading teacher education institutions recently proposed the following:

> The Government could say to the colleges "increase your numbers". Each college could train an additional [number] because we know that England wants a certain number of maths and science teachers and we train more than we need so that there is no shortage (Francis, 2022).

Although this proposal now is receiving heightened attention, it is by no means "new", and Jamaica's current Minister of Industry, Investment and Commerce has been an unwavering proponent of this idea for at least the past 20 years (Ellington, 2022; Myers, 2014; Hill, 2012, 2013; Sives et al., 2006).

We agree that multiple options should be explored to address these issues. Referring specifically to measures that might be taken to retain integrated STEM education teachers in the Caribbean, we find merit in the argument advanced by Lewis (2011) that "solutions should be directed at increasing circulation of professionals within the region as an alternative to their migration outside of the region, increasing the opportunities for training, both in terms of the expansion of numbers as well as areas of specialization" (pp. 98–99). As a form of managed migration (perhaps in carefully calibrated concert with "training teachers for international export"), we suggest that this might best be undertaken as a regional effort, within the context of more fully achieving economic integration and human and social development in the CARICOM Single Market and Economy [CSME] (CARICOM, 2024, 2018).

4. *Those involved in STEM research and integrated STEM education in the Caribbean will need to consider the extent to which the region productively engages with a variety of 21st century STEM issues, topics, and concepts.*

Klaus Schwab (2016) is widely credited with popularising the concept of the Fourth Industrial Revolution, and observed that life in the 21st century is characterised by a

> staggering confluence of emerging technology breakthroughs, covering wide-ranging fields such as artificial intelligence (AI), robotics, the internet of things (IoT), autonomous vehicles, 3D printing, nanotechnology, biotechnology, materials science, energy storage and quantum computing, to name a few (p. 7).

Such advances "merge the physical, digital and biological worlds in ways that create both huge promise and potential peril" (World Economic Forum, 2024), and potentially influence every conceivable aspect of human interaction and experience (e.g. education; business and commerce; healthcare; politics; environmental sustainability; etc.). These all represent what we have referred to as "21st century STEM issues, topics, and concepts" (Sweeney & George, 2019, p. ix). The continued growth of integrated STEM education in the Caribbean (including curricular development and the professional preparation of integrated STEM education teachers) will be influenced considerably by such 21st century STEM issues, topics, and concepts. Two of these areas are of particular relevance at this time.

## Agricultural Biotechnology

Twenty years ago, Mitchell and Ahmad (2003) pointed to the considerable potential that existed across the Caribbean for research and development in medicinal plant biotechnology, and agricultural biotechnology more broadly. Twenty years later, it has been noted that "modern agricultural biotechnology has yet to take root in the Caribbean" (United States Department of Agriculture, 2023). While other parts of the world are moving ahead in research that explores the viability of genetically engineered crops for globally sustainable food production

(Aziz et al., 2022), research institutions in the Caribbean continue to focus on more traditional tissue culture techniques, rather than on genetic engineering (United States Department of Agriculture, 2023). Nevertheless, regional organisations such as the Caribbean Agricultural Research and Development Institute (2024) and the Inter-American Institute for Cooperation on Agriculture (2024) appear to be engaging more comprehensively with modern agricultural technologies, including genetic engineering. Within the Caribbean region, predominant social, cultural, and religious beliefs generate attitudes of suspicion regarding the safety and ethical acceptability of genetically modified organisms (Sweeney, 2022; Russell, 2019). It remains to be seen if efforts to further STEM research and associated integrated STEM education in the region will address this important issue.

### Artificial Intelligence

The increasingly ubiquitous availability and use of ChatGPT and other large language models holds tremendous implications for all aspects of education in all disciplines (Clusmann et al., 2023). Across the Caribbean, focused attention is being given to large language models and other types of artificial intelligence (AI) regarding the immediate and long-term implications for business and commerce; workforce preparation; and social and physical infrastructure (Government of the Republic of Trinidad & Tobago Ministry of Planning and Development, 2023; Mont et al., 2020), in addition to associated ethical issues (UNESCO, 2023). More recently, The University of the West Indies (2024) has established a regional initiative on "generative AI for good research […] dedicated to harnessing the transformative power of generative artificial intelligence".

"Digital twinning" is a pertinent example of how AI may be applied to address social and infrastructural problems. A digital twin is a virtual representation of a natural, engineered, or social system, which may be updated with real-time data from its physical "twin"; this provides the ability to predict future scenarios and to inform decision-making regarding the physical "twin" (Kreuzer, et al., 2024; National Academies of Sciences, Engineering, and Medicine, 2024). As a response to climate change concerns, Grenada (in 2021) became the first country in the world to make a digital twin of itself. Using the digital twin, landslide susceptibility maps, for example, may now be generated to predict how physical infrastructure in the country is likely to be affected (Chadha, 2022; Peters, 2022). The myriad possibilities here for socially and contextually relevant integrated STEM education are clear.

Muschett and Opp (2024), in their discussion of the response of Latin America and the Caribbean to the "AI revolution", pointedly note that during the process of preparing its workforce, the region *must* continue to invest in STEM education in schools. Pioneering work is now being undertaken regarding the use of AI in integrated STEM education teaching, learning, and assessment (Zhai & Krajcik, 2024; Zhai et al., 2023). Similar efforts will need to occur in the Caribbean, which, of course should take into account the particular social, cultural, and political contexts of the region.

## Roles and Responsibilities of Caribbean Integrated STEM Education Scholars: Five Recommendations

In light of our preceding commentary, we briefly present five recommendations to be considered as imperatives over the course of the next 5 years:

1. Ministries of Education and other education stakeholders throughout the region are still seeking to conceptualise; define; and implement integrated STEM education. Varied use of the terms "STEM education", "STEAM education", and "STREAM education" continues to be evident. **Researchers and practitioners will need to determine if it is desirable in our regional context to seek unanimity in clearly defining what we mean by integrated STEM education**.

2. **Scholars in the region will need to both advocate for and undertake high-quality research that serves to drive integrated STEM education policy and implementation** (Monash University, 2024). How, for example, might STEM schools in Jamaica (Henry, 2024; Linton, 2023; McLeod, 2023) or a STEAM laboratory school in Belize (Government of Belize Ministry of Education, Culture, Science and Technology, 2021) provide avenues to further integrate research; policy; and educational practice?
3. **In order to build a strong base for integrated STEM teaching and learning at later educational levels, particular attention should be given to implementing developmentally appropriate integrated STEM education approaches at the early childhood and primary school levels** (Hapgood et al., 2020; Ison et al., 2019). A current example of such an effort is the *Written Numbers in Everyday Life* project undertaken as a collaborative effort between researchers at the University of Southampton and The University of the West Indies, Mona, respectively, which aims to "develop young children's understanding of the multiple meanings and social uses of written numbers in everyday life" (Mathematics and Science Education Research Centre/ University of Southampton, 2024; UWI MonaMedia, 2024).
4. **Scholars in the region should utilise relevant, contemporary socioscientific issues as contexts for the development of public STEM literacy.** As pertinent examples, rising rates of noncommunicable diseases (NCDs); global warming and climate change; and food security all constitute areas of heightened concern in the Caribbean (Miller, 2023; World Health Organization, 2023a, 2023b; Springer & Elliott, 2020). Each of these issues should be more fully incorporated into public STEM literacy efforts (Owens & Sadler, 2020) and into integrated STEM education curricula at all levels.
5. **Researchers, practitioners, and policymakers will need to carefully develop integrated STEM teacher education programmes at all levels**. The development of such programmes will need to satisfactorily address the following questions: Will longer periods of teacher education be needed if there is a focus on integrating multiple subject areas? What are the implications of integrating multiple subject areas within the same duration of currently offered teacher education programmes? Might a typical 3-year undergraduate (BEd) teacher education programme extend to 4 or possibly 5 years? Should STEM education degrees be offered only at the Master's level after obtaining an appropriate undergraduate degree? (see, for example, Shortwood Teachers' College, 2023).

Considering the region's collective goal to use innovations derived from a STEM-literate and competent workforce to drive economic growth and development, the careful development of STEM teacher education programmes at the primary, secondary, and postsecondary levels is of critical importance. The decisions in formulating these curricula should be informed by data from integrated STEM education research conducted across the Caribbean community. STEM education scholars in the region are encouraged to undertake empirical studies exploring various aspects of integrated STEM education, including Caribbean learners' indigenous, social, cultural, linguistic, and experiential learning contexts. Obtaining primary data within the Caribbean context is crucial to guide policymakers' decisions as they work to revolutionise integrated STEM education across the region. A pertinent example is an ongoing research project at The University of the West Indies, Mona, i.e., "Exploring Pre-service Science and Mathematics Teachers' Perceptions of Integrated STEM Education in Jamaica: Towards a STEM Teacher Education Framework" (Williams, 2024). The study aims to explore pre-service science and mathematics teachers' perceptions of integrated STEM education in Jamaica and subsequently use the perceptions to inform and guide the development of an integrated STEM teacher education framework. Upon completion of the study, the findings are anticipated to serve as a key reference in advancing integrated STEM education in Jamaica and beyond.

## Concluding Comments

Although by no means comprehensive nor strictly prescriptive, we are hopeful that our comments in this forum will serve as a useful and timely guide in the ongoing conceptualisation; development; and inplementation of a carefully considered framework for integrated STEM education research, policy, and practice in the Caribbean. We anticipate that scholarly work published in the *Caribbean Journal of Education and Development* (CJED) will assist in guiding the region toward realisation of this goal. We look forward to witnessing the continued growth of *CJED* and its influence in shaping the educational and developmental aspirations of the region.

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