Caribbean Curriculum
Vol. 24, 2016, 1–26.

STEM AND TVET IN THE CARIBBEAN

A Framework for Integration at the Primary, Secondary, and Tertiary Levels

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Technical and vocational education and training (TVET) by its nature offers an ideal platform for the integration of STEM. High-quality TVET or advanced technology programmes can provide a strong foundation for, and serve as a delivery system of, STEM competencies and skills for a broader range of students. But it can also be argued that integrative STEM is an ideal vehicle to facilitate TVET because of its focus on innovation and problem solving. Combining both paradigms in education and training seems to offer a breakthrough in how to prepare the workforce to be much more effective and productive in the present knowledge-based economy. So far, however, while there has been an increased focus on the importance of STEM in curricula and for a globally competitive workforce, the idea of teaching integrated STEM has been explored in a limited manner, particularly in the Caribbean. This paper examines the goals of integrated STEM education, and describes a framework for integration that is built on goal orientation, constructivism, systems thinking, and situated learning. Issues relating to STEM pedagogy and research are addressed to offer a pragmatic lens to the context, nature, and scope of integration that is attainable at the primary, secondary, and post-secondary levels.

Introduction

STEM Overview

The argument to refocus Science, Technology, Engineering, and Mathematics (STEM) to a more central role in the educational experience of students at all levels in the educational system has been gaining traction in many countries. The technological and work realities of our modern world have influenced many educators, employers, and policy makers to affirm that young people need to have some degree of scientific and technological literacy in order to lead productive lives as citizens, whether or not they ever work in a STEM-related field. In the USA, multiple reports issued by influential education, policy, and business groups have argued the case for expanding and improving STEM education (e.g., American Association for the Advancement of Science [AAAS], 1989, 1993; Carnegie Corporation of New York-Institute for Advanced Study

Commission on Mathematics and Science Education, 2009; Council on Competitiveness, 2005; National Research Council [NRC], 2012; President's Council of Advisors on Science and Technology, 2012). STEM education is widely believed to be essential to prepare a more modern workforce with the competencies to address the technological challenges of the 21st century, increase the competiveness of companies that increasingly have to function in a global economy, and also increase the number of engineers and scientists.

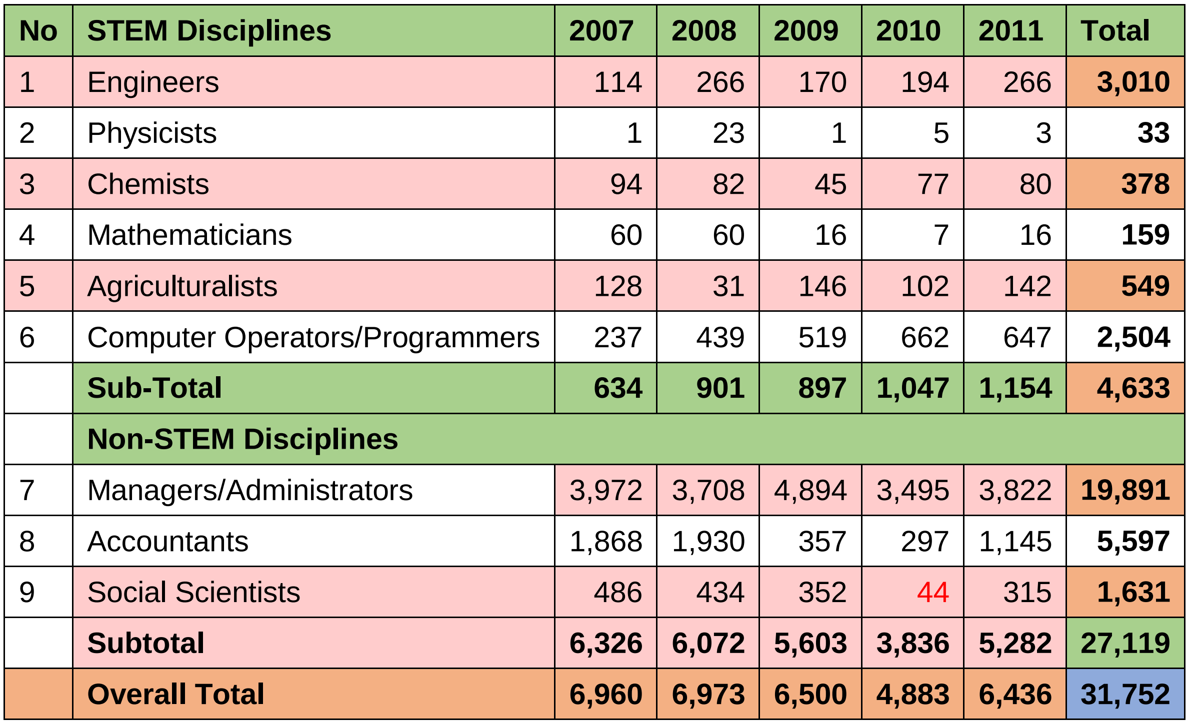
STEM education, however, is not new. Science and mathematics have always existed as individual or discrete tracts of study at various levels in the education system. Technology has been taught in secondary and higher education, and engineering primarily in higher education. Each discipline is comprised of a knowledge base and structure, specialized practices, and particular habits of mind. It was historically seen that to best deal with the complexities associated with learning in each discipline, a silo approach to teaching was more pragmatic (National Academy of Engineering [NAE] & NRC, 2014). Such a framework for delivery is still relevant. However, the complexities of problems faced in business and industry; the multidisciplinary nature of technology, science, and the related issues associated with them; and the requisite competencies for the 21st century workforce demand an interdisciplinary approach to instruction.

STEM Challenges in the Caribbean

The Caribbean is known for its tourist destination and strong hospitality industry. Warde and Sah (2014), however, indicated that the protracted weak rates of growth and high borrowing levels over many years have left the Caribbean the most heavily indebted region of the world. This indebtedness limits fiscal flexibility, discourages private investment, and pushes up borrowing costs, creating a vicious circle.

For example, in Jamaica, the inability to solve the dire economic problems constitutes the basic reason for proposing a STEM programme for the education system. The gradual reduction in manufacturing, and over-reliance on a mediocre service and banking sector, have not helped the economy of Jamaica. This reinforces that for there to be significant economic growth, Jamaica must urgently develop and tap into strong STEM-trained human capital. Over the years, however, universities have consistently turned out more graduates in non-STEM fields than in STEM fields, pointing to a lack of STEM identity among most students who are entering higher education. Figure 1, from the *Economic and Social Survey of Jamaica* by the Planning Institute of Jamaica

[PIOJ], illustrates that approximately 14% of the 34,256 students who were trained at the Mona Campus of The University of the West Indies (UWI) and the University of Technology, Jamaica between the years 2007 and 2011 were trained in STEM fields.



No	STEM Disciplines	2007	2008	2009	2010	2011	Total
1	Engineers	114	266	170	194	266	**3,010**
2	Physicists	1	23	1	5	3	**33**
3	Chemists	94	82	45	77	80	**378**
4	Mathematicians	60	60	16	7	16	**159**
5	Agriculturalists	128	31	146	102	142	**549**
6	Computer Operators/Programmers	237	439	519	662	647	**2,504**
	Sub-Total	**634**	**901**	**897**	**1,047**	**1,154**	**4,633**
	Non-STEM Disciplines						
7	Managers/Administrators	3,972	3,708	4,894	3,495	3,822	**19,891**
8	Accountants	1,868	1,930	357	297	1,145	**5,597**
9	Social Scientists	486	434	352	44	315	**1,631**
	Subtotal	**6,326**	**6,072**	**5,603**	**3,836**	**5,282**	**27,119**
	Overall Total	**6,960**	**6,973**	**6,500**	**4,883**	**6,436**	**31,752**

Figure 1. STEM and non-STEM discipline graduates from universities in Jamaica (PIOJ, 2011).

The quality of math and science teachers in the Caribbean is also of concern. According to the Caribbean Centre for Competiveness (2014), the World Bank indicated that the availability of adequately trained teachers in mathematics and key science subjects remains a concern in the region. This presents a major challenge as it is becoming increasingly evident that STEM education is necessary to support a 21st century workforce. Figure 2 shows each country's ranking in the quality of math and science education in the region:

> Barbados is the region's leader with a rank of 9th in this indicator, a two spot drop from its 2012 position. Guyana, Haiti, Jamaica and Suriname all saw improvements in their rankings from 2012 to 2013 with Guyana displaying the greatest improvement moving from 70th to 53rd. (Caribbean Centre for Competiveness, 2014, p. 3)

Figure 3 summarizes the number of passes in STEM areas in CSEC between the years 2002 to 2011.

In order for the region to break this cycle and become a significant player in the global market, Warde and Sah (2014) recommend a path for sustainable development through economic diversification. This must be built upon a new economic pillar based on services and products derived by harnessing STEM. According to Warde and Sah, this paradigm shift would require reform in STEM education and the integration of entrepreneurship in the curriculum as early as Grade 8. The recommendations they made for the multilevel modification of STEM education include the following:

- STEM learning that encompasses activities both inside and outside the classroom
- Syllabus updates and STEM teacher professional development
- Using indigenous everyday material as teaching resources
- Maximizing the use of the Web

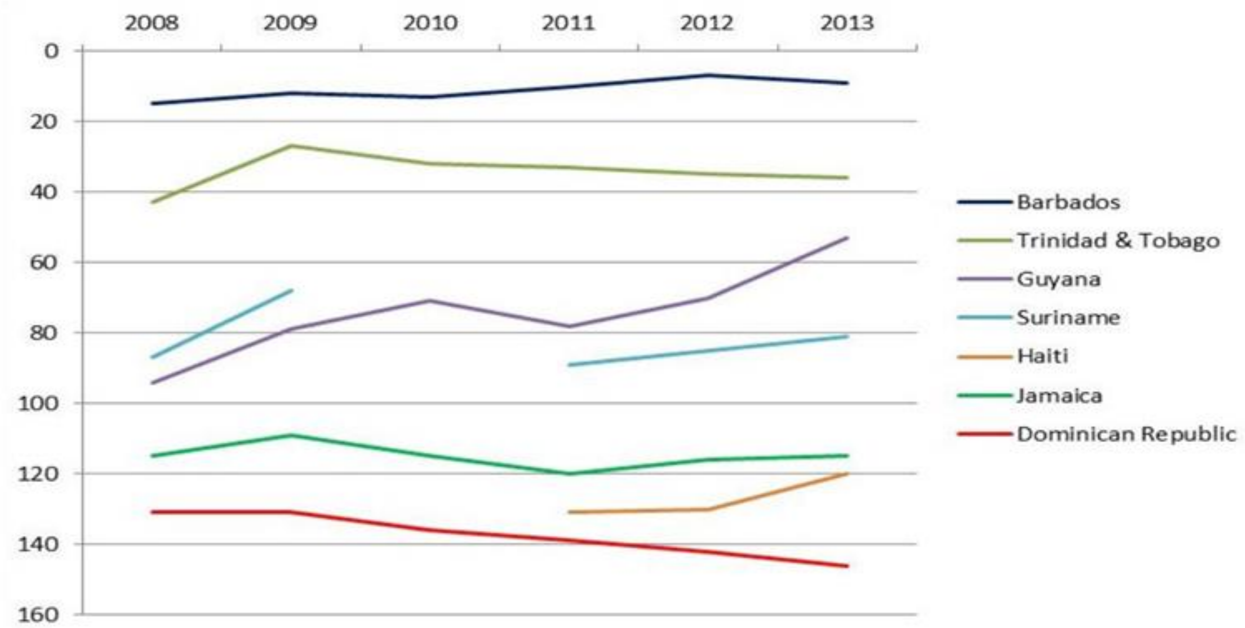


Figure 2. CARIFORUM countries rankings in the quality of math and science education indicators, 2008-2013 (Caribbean Centre for Competiveness, 2014).

STEM Subjects	Total No. of Passes	Performance
Biology	**45,006**	● There were **757,000** entrants for STEM subjects; there was an average of 65% passes ● The number of passes in STEM subjects increased by an average 57% ● **2-5** times less passes in Info. Tech., Chemistry, and Physics than Mathematics ● **7-14** times les entrants for these subjects than for Mathematics ● Passes in Social Studies were **66%** of the passes in Mathematics ● Physics has the lowest number of **passes and entrants** outside of Mech. Eng. Technology ● Even though there were **492,000** passes in STEM subjects over the period, there is no visible evidence of economic impact
Average % success	**68.08**	
Human & Social Biology	**49,489**	
Average % success	**57.2**	
Chemistry	**37,502**	
Average % success	**59.49**	
Physics	**33,898**	
Average % success	**61.33**	
Information Tech.	**78,657**	
Average % success	**68.7**	
Integrated Science	**54,800**	
Average % success	**71.07**	
Mathematics	**184,156**	
Average % success	**37.44**	
Mech. Eng. Technology	**8,951**	
Average % success	**57.01**	
Total Science & Math	**492,459**	
Social Studies	**122,222**	
Average % success	**73.7**	
Overall Total	**614,681**	

Figure 3. Summary of secondary school passes in STEM subjects at the CSEC level Grades 1-3 (PIOJ, 2011).

STEM Education for Workplace Preparation

STEM education is often defined as an interdisciplinary approach to learning, where rigorous academic concepts are coupled with real-world lessons as students apply science, technology, engineering, and mathematics in contexts that make connections between school, community, work, and the global enterprise—enabling the development of STEM literacy, and with it the ability to compete in the new economy (Tsupros, Kohler, & Hallinen, 2009). Sanders (2009) points to the difference between *STEM* and *STEM education*. He argued that most—including those in education—say *STEM* when they should be saying *STEM education*. This overlooks the fact that the acronym *STEM* without education is a reference to the fields in which scientists, engineers, and mathematicians labour. Therefore, according to Sanders, science, mathematics, and technology *teachers* are STEM *educators* working in STEM *education*. He also added that *Technology* in STEM is often viewed narrowly as meaning computing, thereby distorting the intended meaning of the STEM acronym. The STEM being addressed in this paper is not the traditional silo disciplines of study, but rather a pedagogical strategy—an integrated approach to the teaching of science, technology, engineering, and mathematics—referred to from henceforth as integrated STEM.

According to Gomez and Albrecht (2014), "STEM pedagogy is rooted in interdisciplinary application of knowledge. STEM Education is a philosophy designed around a cooperative effort to provide students with a comprehensive, meaningful, real-world learning experience." (p. 8). Sanders (2009) notes that "integrative STEM education includes approaches that explore teaching and learning between/among any two or more of the STEM subject areas, and/or between a STEM subject and one or more other school subjects" (p. 21).

The past two decades in the USA have seen an increased focus on educational standards to address the connection of content across the STEM domains, so that students can be exposed early in their education to the interdisciplinary orientation that is now required to solve complex problems in the workplace and the wider society. In technology and engineering, the emphasis has been on expanding attention to these disciplines at the pre-college level through the development of educational standards (International Technology Education Association, 2000), making the case that exposing students to the *T* and *E* of STEM has the potential to improve learning of science and mathematics (NAE & NRC, 2014). More recently, according to NAE and NRC (2014), the release of the *Common Core State Standards for Mathematics* and the *Next Generation Science Standards*—the latter uses a model that crosscuts science, mathematics, and engineering core concepts—have further focused the nation's attention on the teaching and learning of these subjects.

Advocates of more integrated approaches to K-12 STEM education argue that STEM subjects can become more relevant to students if they are taught in a more connected manner, using the context of real-world issues. This, in turn, can enhance motivation for learning and improve students' interest, achievement, and persistence. Ultimately, this will lead to better workplace and college readiness, as well as increase the number of students who consider careers in STEM-related fields (Dixon & Brown, 2012; NAE & NRC, 2014; Sanders, 2009; Sanders & Binderup, 2000).

The reality that exists in modern business, research, and manufacturing practices reinforces this rationale. For example, professional practices in many workplace and research settings have been transformed to emphasize multidisciplinary enterprises, such as biomedical engineering. Also, professional scientists and engineers in the vast, interconnected enterprise of companies, academic institutions, and government laboratories that conduct research and develop new products and services almost always work in ways that integrate the disciplines of STEM. The NAE and NRC (2014) report goes on to say:

> More generally, scientists use technological tools to conduct experiments and mathematics and statistics to interpret the data produced by those experiments; engineers draw on scientific knowledge and mathematical reasoning to develop and model potential design inventions and solutions; technologists who build and maintain the products and systems designed by engineers must understand the scientific and mathematical principles governing their operation. And these professionals interact with one another in increasingly diverse and multidisciplinary teams. (p. 20)

Integrated STEM education includes a range of different experiences that involve some degree of connection; not just a single, well-defined experience. The integrated activities may be accomplished in several ways, including:

- engagements in one or several class periods,
- engagements throughout a curriculum,
- delivery within a single course,
- curriculum organized for an entire school, and
- out-of-school activity.

Each variant of integrated STEM education suggests different planning approaches, resource needs, implementation challenges, and outcomes. While the approaches to integrated STEM education vary and are on the increase, the research grounding the activities lags behind. There isn’t enough research that explains best practices for integration; factors that make integration more likely to increase student learning, interest, retention, and achievement; and other valued outcomes from integration.

In regards to integrated STEM, there is lack of a common agreed-upon definition of what constitutes integration. Because of this, there is no consistency in describing pedagogy or comparing results across studies to form a clear picture of what approaches to integration support learning. In addition, there are few direct measures of integration as a construct of outcomes that show how well students are able to make connections across disciplines (NAE & NRC, 2014). The few studies that have been conducted show mixed results about the benefits of an integrated approach to the learning of STEM. The following section describes the results from efforts to use mathematics, science, and technical and vocational subjects as a platform to integrate the learning of STEM.

Integrating STEM and TVET to Improve Student Learning

Math and science are the most studied integrated STEM pedagogies (see Berlin & Lee, 2003; 2005; Czerniak, Weber, Sandmann, & Ahern, 1999; Hurley, 2001; Pang & Good, 2000). In a meta-analysis of 31 studies, Hurley (2001) found that the effect size for mathematics achievement was positive and large when using a sequenced integration model—that is, science and mathematics are planned and taught with one preceding the other—but much lower for all other models of integration, such as total integration and parallel instruction. Using either science or mathematics as the major discipline of instruction both enhanced instruction and total integration. Studies at the middle and high school levels indicate that it might be difficult to improve mathematics achievement by trying to integrate mathematics into another disciplinary context (Hartzler, 2000; NEA & NRC, 2014). Lehrer and Schauble (2006), however, found that scientific concepts known to be challenging to students were better understood when students used mathematics as a resource to represent and model natural systems. Other studies indicated that “the nature of the mathematical tools and systems of representation available to students determine the depth and breadth of learning about core ideas in science because mathematical forms correspond to forms of understanding natural systems” (NAE & NRC, 2014, p. 54).

Studies that looked at using engineering design to enhance the learning of mathematics and science have also showed mixed results. Some revealed the effectiveness of learning science in situations where concepts are introduced when students are engaged in design activity (Baumgartner & Reiser 1997; Fortus, Krajcik, Dershimer, Marx, & Mamlok-Naaman, 2004; Mehalik, Doppelt, & Schunn, 2008), or when design failure provokes conceptual change as students redesign an artifact to meet a goal (Lehrer, Schauble, & Lucas, 2008). The NAE and NRC (2014, p. 59) report points out that:

- Studies reveal that students may not spontaneously make connections between the devices being designed and the related scientific concepts. They tend to focus on aesthetic or ergonomic aspects of design
- Connections between the representations and notation systems used for design and for science need to be made explicit to students
- Material must be presented in such a way that students grasp they can invent and revise systems of representation to understand how a natural or designed system works

Learning STEM, particularly in the context of TVET (or Career and Technical Education [CTE] in the USA), and more specifically using technology to enhance mathematics, have shown promising results both at the middle school and the secondary level. At the middle school level, mathematics concepts and skills were introduced in the Engineering and Technology Education curriculum at critical points, through focused lessons to facilitate students' ability to make connections between the disciplines. Students in both the infusion and comparison classrooms completed an assessment of mathematics concepts that were relevant to the bedroom design unit, before and after instruction in the unit. Students in the infusion classes showed greater gains in scores from pre- to post-test than those in the control classes (Burghardt, Hecht, Russo, Lauckhardt, & Hacker, 2010; NAE & NRC, 2014).

In a study that examined mathematics-enhanced CTE courses in high schools that covered multiple occupational contexts such as business and marketing, auto technology, health and information technology, and agriculture (but *not* engineering), Stone, Alfeld, and Pearson (2008) found that students in the two courses—math-enhanced and regular technical education—performed at similar levels in terms of technical skills, but those in the math-enhanced courses did better on measures of general math ability compared to students in the regular technical education courses.

TVET Facilitating Interest in STEM

A review of studies and evaluation of school-based projects and curriculum units, afterschool programmes, and summer camps by the NAE and NRC committee revealed some evidence that integrated STEM programmes can support the development and maintenance of interest in Technology and Engineering. For example, Burghardt et al. (2010), after assessing students' interest in mathematics and their perceptions of the importance of mathematics for technology, found that students in the mathematics-infused curriculum reported that the subject was more important and interesting than did students in the comparison group (controlling for responses on the pre-survey).

In an evaluation study, participants who were involved in an enrichment programme for high school youths that integrated engineering with biology concepts in a health care context, using lecture and hands-on activities, reported increased interest and more positive attitudes toward science and engineering on post-programme surveys (Monterastelli, Bayles, & Ross, 2011). Self-reports from girls involved in an all-girl summer camp with a STEM focus indicated the likelihood of their pursuing a career in mathematics, science, or engineering. The average rose from 6.3 to 7.4 on a 10-point scale, respectively, before and after the summer camp (Plotowski, Sheline, Dill, & Noble, 2008).

The NAE and NRC report (2014, p. 68) goes on to show that an unpublished study of a school-based engineering project for 6th and 7th graders similarly showed positive effects on students' attitudes. Students participated in the designing of a prosthetic arm. A comparison group of students did not participate in the design project. Both groups were surveyed before and after the project. Students who participated in the design project reported increased interest in engineering as a potential career as well as increased confidence in mathematics and science. Girls, however, scored lower than boys in terms of their interest in engineering as a career and in their beliefs that they could become engineers (High, Thomas, & Redmond, 2010).

Emphasis on the importance of STEM education has also caused many to revisit the role of TVET is preparing future technicians, technologists, and engineers. While normally seen as a separate path of study for students who are not college bound, the perception of the role of TVET in preparing college-bound students is changing. In addition, TVET has always used applied sciences and mathematics in its framework for instruction, and many of the instructional paradigms that are being championed as part of STEM education have been used exemplarily in TVET for many decades.

Revisiting TVET's Importance in View of STEM

The World Bank and the European Finance Association (EFA) use the following definition for TVET:

> TVET is a comprehensive term referring to those aspects of the educational process involving, in addition to general education, the study of technologies and related sciences, and the acquisition of practical skills, attitudes, understanding, and knowledge relating to occupants in various sectors of economic and social life….Technical and vocational education is further understood to be:
>
> a) an integral part of general education
>
> b) a means of preparation for occupational fields and for effective participation in the world of work
>
> c) an aspect of lifelong learning and a preparation for responsible citizenship
>
> d) an instrument for promoting environmentally-sound sustainable development
>
> e) a method of facilitating poverty alleviation (UNESCO & ILO, 2002, p. 7)

The term *TVET* is still widely used in many European, Eurasian, African, Asian, and Caribbean countries. In many developing countries, the primary goal of TVET is to prepare youth for the workforce, making it a primary part of the educational agenda. This focus is consistent with the original aim of TVET. Recent trends in developed countries that use TVET have seen it becoming more integrated in the educational system. These educational initiatives constitute responses to the global technological revolution, which demands higher levels of education and technological skills for the 21st century (Fawcett, El Sawi, & Allison, 2014).

Types of TVET Systems and Models

According to Fawcett, El Sawi, and Allison (2014), TVET systems contain three main organizational components: (1) general education, (2) initial training systems, and (3) continuing training systems. General education provides the basic skills required as a foundation for courses specifically related to vocational skills. They also articulated that although;

> TVET traditionally follows general education (i.e. it depends on the general skills of basic education), recent reforms in Australia and the United Kingdom have turned this thinking around. In these countries, all competencies and skills can be gained in either general education or TVET. Under such reforms, general education offers a curriculum that includes vocational and workplace components, while TVET can lead to higher and more advanced education. (p. 3)

Initial vocational training begins as early as age 14 and is offered in the curriculum of upper secondary and tertiary education. New trends in some countries see the incorporating of vocational skills in general or academic courses, and expanding vocational education into tertiary education. Continuing training systems involve lifelong vocational training and support a wide range of skills learning and training, including on- and off-the job, and formal and informal training funded from multiple sources, such as state, labour unions, enterprises, social organizations, and so on (Keating, Medrich, Volkoff, & Perry, 2002).

Essentially, there are three types of TVET models in the world: (1) the liberal market economic model, (2) the state regulated bureaucratic model, and (3) the dual system model. The *liberal market economic model,* common in countries such as Australia, Great Britain, Canada, and New Zealand, uses a sector approach to TVET that supports rapid economic change (Sung, Raddon, & Ashton, 2006). The TVET system therefore reflects the demands of the private market led by industries and firms. Industry-sector skill councils decide on the types of occupational qualifications that industry and support firms need to train their workers. Private industries and firms are willing to sponsor worker training and apprentices (Sellin, 2002). The *state regulated bureaucratic model* is common in countries such as France, Italy, Sweden, Finland, and also countries in the Caribbean region. TVET is primarily provided and financed through the central ministry responsible for education. In addition, funding is also generated from international agencies such as the World Bank, ILO, and UNESCO. TVET is therefore an extension of the national educational system, and while public and private companies and labour unions may partner with the government, this is done mainly at a consultative level. According to Sellin, the national curriculum fixes the content of the courses. Finally, the *dual system model* used in countries such as Germany, Austria, Switzerland, Denmark, and Norway includes a wide range of public and private stakeholders, such as trade unions and state agencies and organizations in design, development, and implementation of TVET. This system, according to Sellin, is characterized by strong public-private collaboration, enterprise-financed apprenticeship training, and state agency-financed TVET schools.

Integrating TVET and STEM

Benefits of Integrating TVET and STEM

Many students may have difficulty grasping mathematical concepts and scientific theories if they are presented in an abstract manner devoid of clear application (Association for Career and Technical Education [ACTE], 2009). Because of the contextual, situated, concrete way in which TVET courses deliver STEM, many students are able to grasp STEM concepts much easier than how they would in academic courses. Advanced technology programmes in TVET, like their counterparts in CTE, draw upon "scientific method, cutting-edge technologies, mathematical thinking skills that contribute to innovation and problem solving, and the systems-thinking that undergirds engineering and design to create new services and solutions to meet customer demands" (ACTE, 2009, p. 4). STEM integration into TVET, therefore, can expose students to various opportunities to experience the learning of different concepts in a contextual manner—rather than bits and pieces, and then assimilating them at a later time (Tsupros et al., 2009). Even areas of TVET that are not regarded as STEM career areas often require a deep understanding of science, technology, engineering, or math principles. The fact is that rigorous TVET programmes can provide a strong foundation for, and serve as a delivery system of, STEM competencies and skills for a broader range of students (National Association of State Directors of Career Technical Education Consortium [NASDCTEc], 2013).

Features that are already built into the traditional delivery system of TVET, and which are now being touted as ways to deliver STEM, also point to why TVET is ideal for STEM. For example, the majority of TVET programmes engage students in the use of various types of technology to an advanced level in preparation for the workforce. Students are engaged in the solving of authentic problems that are customarily encountered in the real world or the world of work through project-based and problem-based approaches. Many TVET programmes have strong business/education partnerships that influence and enrich the students' experience through internship, apprenticeships, scholarships, and competitions.

Framework for Integrating STEM

The NAE and NRC report (2014) provides a descriptive framework of the subcomponents that need to be taken into consideration when integrated STEM is being implemented in schools. The framework consists of four features: (1) *goals* of integrated STEM education, (2) *outcomes* of integrated STEM education, (3) *the nature and scope* of integrated STEM education, and (4) *implementation* of integrated STEM education. Goals and outcomes should address both teachers and students. Goals for students should include STEM literacy, 21st century competencies, STEM working readiness, interest and engagement, and making connections. Goals for teachers should include increased STEM content knowledge and increased pedagogical content knowledge. Nature and scope of integration include considering the types of STEM connections; disciplinary emphasis; and duration, size, and complexity of the STEM initiative. Implementation must consider instructional design, educator supports, and adjustment to learning environments. Finally, outcomes for students will include 21st century competencies; STEM course taking, educational persistence, and graduation rates; STEM-related employment; STEM interest; development of STEM identity; and ability to make connections among STEM disciplines. Outcomes for educators will include changes in practice, and increased STEM content and pedagogical content knowledge.

Asunda (2014) explicated a conceptual framework for the integration of STEM in CTE that can also apply to TVET. The framework promotes a problem-based learning approach that is built upon the principles of systems thinking, situated learning, constructivism, and goal orientation—all guided from a developmental level by pragmatism. According to Asunda, systems thinking allows educators and students to study how each of the STEM disciplines interrelate and contribute to aspects of real-world learning. Understanding systems and the overall relationship, pattern, and functionality of subsystems and their components are important in the solving of complex real-world problems. Design, a problem-based iterative activity that demands a high level of cognitive processing and executive control (metacognition), draws upon students' creative energy and taps into their systemic thinking.

According to constructivists, students learn by fitting new information together with what they already know. All knowledge is therefore context bound and individuals make personal meaning of their own learning experiences (Knowles, Holton, & Swanson, 1998). Because knowing, learning, and cognition are viewed as social construction enabled through the action of people interacting within communities, according to Wilson and Myers (2000), without actions there is no cognition, no knowing. Situating teaching and learning in rich contexts is therefore very significant. Advocates of situated learning state that whatever is present during learning becomes a part of what is learned, including the context. Situating learning in contexts that are authentic will likely increase the chance of transfer in other situations because more of the cues that are needed for transfer are present during learning (Asunda, 2014; Wilson & Myers, 2000). Real-world examples that are derived from pragmatic decisions are important and offer students the opportunity to reflect and make connections (Asunda, 2014). According to Asunda, this “can be a motivating factor for students because they can see connection between what they are learning and their long-range goals, which enhances their sense of achievement” (p. 9).

Goal orientation is also a very important part of this framework. Asunda (2014) indicated that one most recent embodiment of the motives-as-goals tradition is the Achievement Goal Theory or Goal Orientation Theory. Goals are central to the understanding of motivated behaviour, and a conceptual framework for integrated STEM must be driven by an understanding of goals that are implicitly built into activities. This is coupled with the achievement goals of students, because this can differentially influence student accomplishment on a given task and also the level of cognitive self-regulation processes invested in an activity. In fact, Woolfolk (2013) points out that “in a supportive, learner centered classroom, even a student with a lower sense of self-efficacy might be encouraged to aim for higher mastery goals” (p. 441) constructed as a part of the triadic reciprocal interaction of person, environment, and behaviour.

Integrated STEM at the Primary Level

There is increasing consensus in many countries that STEM education should be integrated at all levels in the educational system. Sir Michael Tomlinson, former Chief Inspector of Schools for the UK Office for Standards in Education, Children’s Services and Skills (Ofsted), stated that STEM development in early years at primary school would help to challenge the current belief among school children that these subjects were difficult and only led down a specific career path such as being a scientist, when actually STEM subjects open up a variety of career options (Gurney-Read, 2014). In the Caribbean, the consensus is similar (Warde & Sah, 2014), but we are faced with an even more pragmatic question: What is the best way to go about integrating STEM in all levels of the educational system?

In order for the Caribbean as a region to become competitive in a global market, the region must move beyond viewing general education as being defined only by language arts, mathematics, and the sciences. Literacy must also encompass an understanding of the nature of technology, and every student from primary to secondary levels must be exposed to systematic, age-appropriate curricula that allow this to be achieved (Dixon, 2013). Standards for STEM literacy must be developed for the region to govern the quality of STEM teaching and the movement of human capital within the region. At the national or country level, standards for technology should be developed for both primary and secondary levels of the school system, and these standards should be cross-mapped to the relevant mathematics and science standards or concepts. As the descriptive framework by NAE and NRC (2014) illustrates, attention must be given to concepts that are required for 21st century competencies and STEM literacy. In addition, pragmatism would dictate that concepts related to major occupational areas (clusters) for the country (e.g., energy, agriculture, hospitality) must also be given special consideration. The aim is to provide core concepts in science, technology, and mathematics that initiate students at the primary level in STEM literacy or thinking, stir their interest in the STEM fields, and develop their STEM competencies in preparation for global citizenship. This can be achieved through a thematic curriculum that is driven, but not limited, by themes from major occupational areas and which engage students through discovery-based and problem-based learning (see Figure 4).

The technology concepts (and procedures) that students will be exposed to will deliver foundational technical knowledge, which students will need later in their secondary and post-secondary school years as they pursue courses in TVET or in the individual STEM fields. The subject areas used as a platform to teach integrated STEM at the primary level may vary among countries in the region; nonetheless, there is clear evidence that the teacher training colleges in the region will have to prepare teachers in this new disciplinary focus—integrated STEM education—with the necessary content and pedagogy content knowledge. Teachers will need to learn, through professional development and in training, how to apply constructivist approaches to scientific inquiry, technological design, and applied mathematics. They will need to be competent in making explicit connection to STEM concepts, building on students' previous knowledge and diverse interest, engaging students in age-appropriate discovery learning and collaborative problem solving, and using real-world contexts for situational learning.

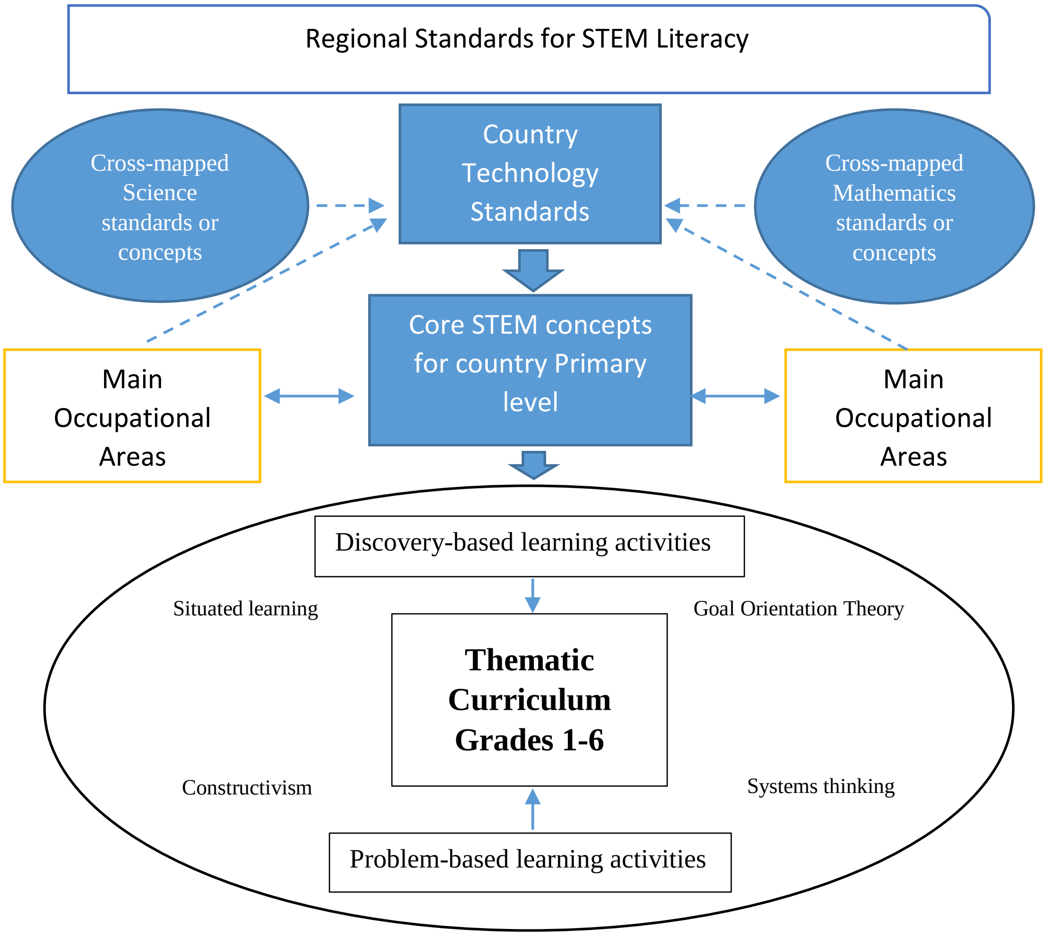


Figure 4. Integrating STEM at the primary level.

Through technological design, students will be introduced to basic engineering design concepts from primary schools. They will also be able to relate science and mathematics to technological products, and understand basic biological and technological systems. Students should be engaged in problem-solving activities that require them to use math, science, and technology concepts. They should be taught how to communicate their solutions through reports and other communication tools. This emphasizes the importance of the arts and the development of skills that are important for entrepreneurship.

Some may wonder about the cost to set up labs for STEM. However, the indigenous materials available in the Caribbean, as well as the plethora of computer-assisted educational software that allow students to explore math, science, and technology, are resources that can be used to enrich the learning of STEM at the primary level. In addition, off-the-shelf, low-cost, and low-maintenance equipment and apparatus are available, which provide educational engagements through scientific inquiry, mathematics, and technological problem solving (Dixon, 2013).

Integrated STEM at the Secondary Level

Every student should be exposed to the intellectual domain of technology in both their primary and secondary education along with science, mathematics, and the arts. Technology standards for secondary level must include a progression in the development of engineering outcomes relating to engineering principles, engineering design, and engineering/material science (Dixon, 2013). At the early secondary level, particularly at Grades 7-9, students will necessarily complete individual curricula in mathematics, science, and technology in order to achieve the required depth and breadth in the respective knowledge domain. There must however be culminating experiences, whether through problem-based or project-based activities, which require students to collaborate in the solving of authentic problems relating to the occupational areas, and which require the application of STEM concepts. Standards in technology that are cross-mapped with standards in science and mathematics should encourage more collaboration between teachers across the STEM disciplines to achieve this outcome.

From Grades 9-11, the academic curriculum should be integrated with the TVET curriculum to ensure that students are not only prepared for college but are also prepared with the necessary competency for entry into various occupations. Through this integrated curriculum, students will acquire specific job competencies at the appropriate proficiency while they are still in secondary school, and also develop interest in STEM-related careers that they can pursue at college. Both standards—technology standards that are cross-mapped with science, mathematics standards, and occupational standards—used in synergy will produce a STEM literate and technically competent populace (see Figure 5).

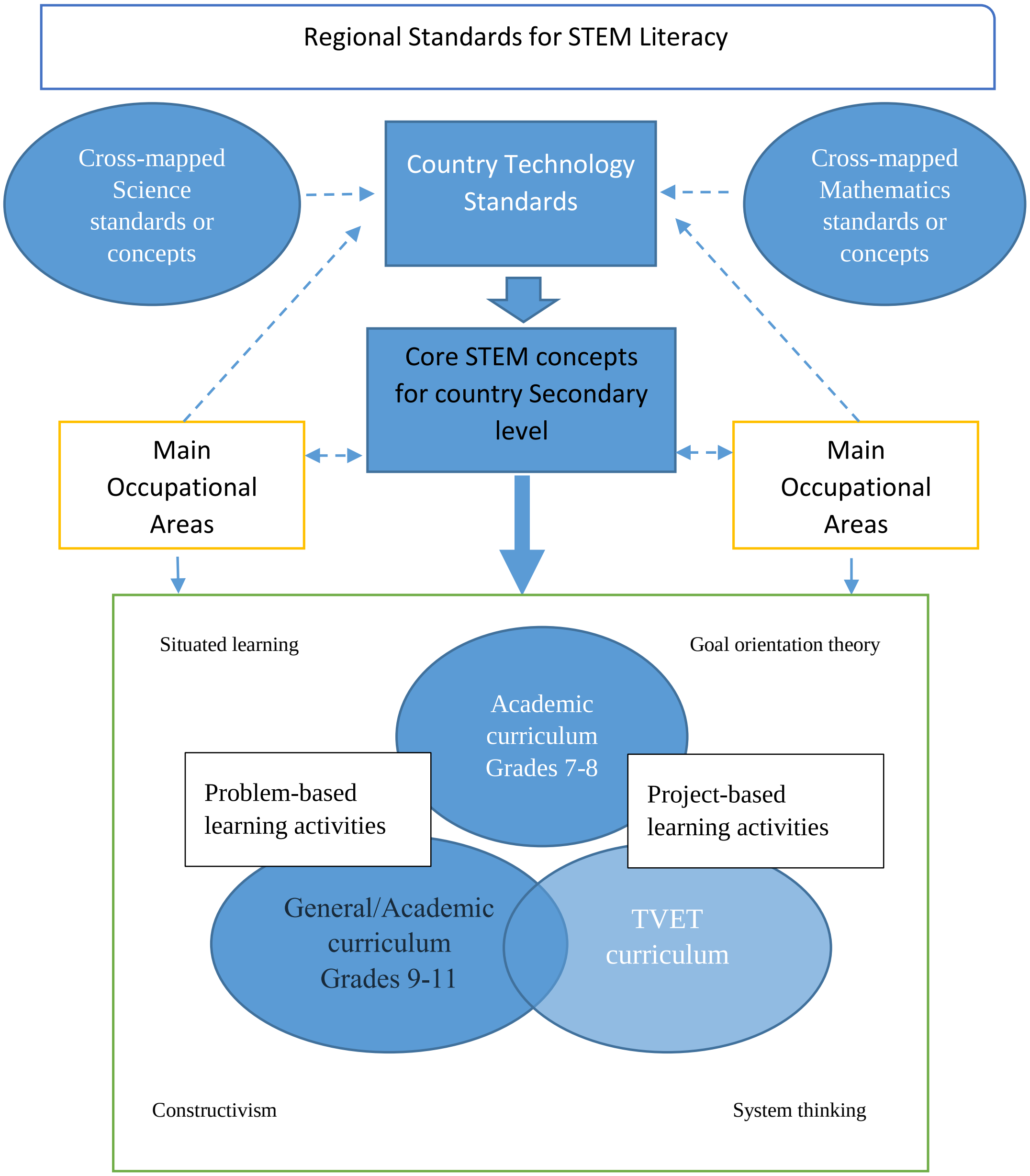


Figure 5. Integrating STEM at the secondary level.

Schools in each country can partner with national training agencies to integrate the early levels of key TVET programmes into high school curricula. Through this collaboration, schools can expose students to STEM professions, business and entrepreneurship, internships, and problem-based and project-based activities that require the application of STEM concepts and procedures learnt throughout their high school years. Much can be learned from Newly Industrialized Countries such as China and Korea, which share a new vision of the role of TVET, seeing it as equally important to equip students with the life skills of the 21st century. In these countries, increasing numbers of secondary school students are enrolled in TVET programmes that have a strong academic focus. In some schools, academic and vocational students share 75% of a common curriculum. Also, developed countries that deliver TVET programmes are increasingly integrating it with general education ("Focus: Vocational education," 2005; Lewis, 2008).

Integrating STEM and TVET at the University Level

The structure of faculties and programmes at university campuses traditionally are formed to promote the epistemology, practices, habits of the mind, and mode of inquiry of a particular discipline. This is quite pragmatic if real experts in a particular discipline are to emerge from the educational system, who are capable of adding new knowledge to that discipline. The ontology of some disciplines is such that they integrate two or more of the STEM knowledge areas, for example, engineering and biotechnology. The pursuit of integrated STEM curriculum at the university level can be done through interdisciplinary studies arising from collaborative initiatives between different programmes on campus. Interdisciplinarity is the "active integration of two or more disciplinary perspectives in the pursuit of a shared problem or topic" (Harris, 2010, p. 23).

In 2004, the National Academy of Sciences (NAS) identified nanotechnology, genomics and proteomics, bioinformatics, neuroscience, conflict, global climate change, and terrorism as pressing issues and interdisciplinary fields of study that require the attention of academics (Committee on Facilitating Interdisciplinary Research, Committee on Science, Engineering, and Public Policy, National Academy of Sciences, National Academy of Engineering, & Institute of Medicine [NAS], 2005). The fact is, while most disciplines on university campuses are siloed into colleges, schools, departments, and units, this compartmentalization is not a natural (artificial) integration of systems and processes, and often does not reflect the interdisciplinary approaches that are necessary to solve complex problems in the real world. It is that, as Katz and Martin (1997) explained, "no single individual will possess all the knowledge, skills, and techniques required" (p. 140), given the complexity of the type of challenges we face. Interdisciplinary collaboration in STEM and TVET can lead to new areas of research, products, services, and businesses. The struggling economies in the Caribbean need these types of collaboration to promote robust entrepreneurship in the region. To that end, a sequence of interdisciplinary curricula should be developed on campuses. For example, the social sciences can partner with TVET programmes to address pressing societal issues. Engineering can partner with biosciences, sport programmes, arts and entertainment in the pursuit of new products and services. Capstone projects on campus should reflect interdisciplinary collaboration. Here again, students from different disciplines can collaborate in project–based activities. Centres for innovation and interdisciplinary studies can be established, and should not be exclusive, but inclusive of all disciplines and ideas (see Figure 6).

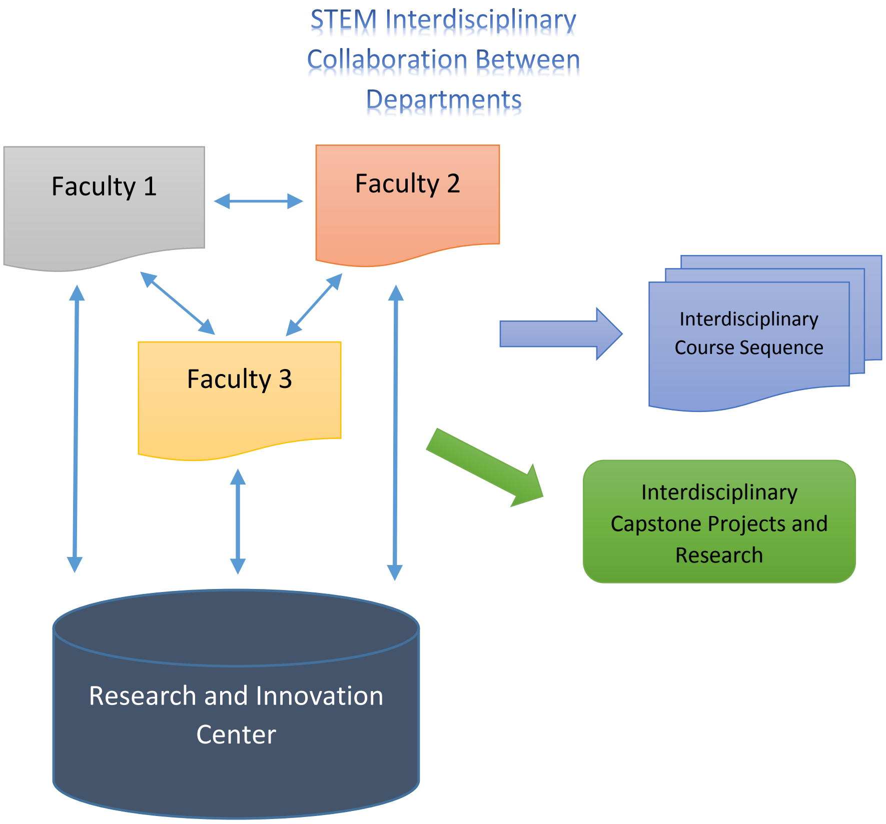


Figure 6. Integrating STEM at the university level.

Next Steps

In order for the Caribbean region to strategically produce a globally competitive workforce, full attention needs to be given to how students are prepared at the primary and secondary levels in STEM and TVET competencies. The participation of several Caribbean countries, and also international countries, at the May 2015 Second International Conference on TVET in the Caribbean held in Montego Bay, Jamaica, indicates the commitment of the leaders, educators, and other key stakeholders to address this important focus in education. Pragmatism, however, would demand that attention be given not only to the preparation of citizens that are literate in math, science, and the arts, but also citizens who are technologically literate. In addition, it demands that a realization must exist that general education at the primary and high school levels is not necessarily synonymous with educating students for the workforce. An integrated curriculum must be espoused that prepares students both for college and work. This does not demand a dismantling of the present educational system, but rather a reorientation of how teaching and learning is administered. Thematic curricula at the primary level, which draw from themes from the main occupational areas in a country, and which incorporate discovery-based activities and problem-based activities to solve STEM problems, can spark students' interest in STEM careers and also develop foundational STEM competencies that are required for learning at the secondary level.

At the secondary level, TVET programmes should be integrated with general education. TVET by its nature combines science and mathematics concepts, and through collaboration with teachers from the traditional education disciplines, authentic and engaging activities through project-based and problem-based learning can be organized for students. Teaching at all levels to emphasize connections across domains, and for students to understand underlying STEM principles within the context of TVET learning and problem solving, will prepare students with skills needed for the 21st century and, in the long run, provide human capital that has the competencies to transform the economies in the Caribbean region.

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