Creating a STEM-based Economic Pillar for the Caribbean: A Blueprint

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ABSTRACT

Caribbean countries need to work their way out of debt. Most Caribbean economies continue to rely on tourism. In a few countries, oil and natural gas underpin the economy. The financial services industry, which had helped to bolster some of these economies, has shrunk in recent years. Graduates with engineering degrees continue to have severe challenges in finding employment in their field within the Caribbean region. This human resource, for the most part, is wasted. The region needs to put this valuable talent to work by attracting and creating more technology-based companies whose products and services can be sold on global markets. A blueprint is proposed for building a STEM-based economic pillar that would rival tourism in its ability to bring in foreign exchange and create more technology-related employment opportunities. The concept includes models for: (a) attracting and home-growing more technology companies; (b) providing the technical support and infrastructure that such companies will need; (c) attracting more Caribbean scientists, engineers, and entrepreneurs from the diaspora, as well as more world-renowned technology academicians to the region; and (d) reforming STEM education to support the development of the proposed STEM-based economic pillar.

Keywords: STEM, education reform, economic development, Caribbean

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Introduction

The quality of life of most Caribbean people has stagnated or even regressed in the past ten years, and the current economic outlook for the region is not bright. The Caribbean region urgently needs to embrace STEM (Science, Technology, Engineering and Mathematics) education reform to: (a) promote more STEM awareness in teachers and in the general population, of the link between science and engineering, and the potential for regional economic development; and (b) encourage more youngsters to pursue careers in science and engineering. This is particularly important in light of the current regional challenges such as energy security, food security, and threats from climate change, which are all impediments to economic development. This paper is an outgrowth of an earlier report (Warde & Sah, 2016a) developed by the Caribbean Science Foundation (CSF) [http://caribbeanscience.org] for the Government of Barbados, outlining an action plan and implementation strategy for the promotion of STEM education, innovation, and employment for Barbados.

One of the many reasons Caribbean countries have not been able to commercialise science and technology for economic development is that there has not been a strong cultural focus on “engineering” in the region. Many in the region still refer to technicians as engineers. The concept of an “engineer” as a person who uses mathematics, chemistry, biology, physics, and computer science (often in combination) to design, research, and invent new technologies, and as one who patents technology, and starts technology companies that build globally competitive products is not widespread in the region. The reliance of engineering on a solid physics background is well understood, but it is not widely appreciated that the very basic mathematics curriculum for most engineers begins with single- and then multi-variable calculus; differential equations; linear algebra; vector calculus; probability theory; statistics; and functions of complex variables. Of course, we should add computer programming to the mix, as modern engineers and scientists use this tool daily to model and simulate problems they are trying to solve. For completeness, the essentials of cellular and molecular biology are a must, as this is the century where mind-boggling advances are being made in the biological sciences. Indeed, the engineering disciplines are being rapidly cross-fertilised by the principles of biological systems, leading to new innovations. For example, while genetic algorithms have long been a commonplace mathematical tool in science and engineering problem-solving, we are now witnessing a proliferation of artificial neural network hardware and software. Additionally, "hybrid fields" such as bioelectrical engineering, biomedical engineering, computational biology, and bioinformatics are rapidly growing disciplines. Thus, in this blueprint, when we use the word "engineer", we are referring to a person with most of these higher mathematics skills, along with specialised higher education in their subfield.

Unfortunately, for students who are mathematics–challenged, careers in engineering, computer science, and computer engineering are not options. However, jobs at the technician level are possible, since higher-level mathematics and engineering design and analytical skills are not necessary to carry out repairs and maintenance of modern complex devices and systems.

Regarding computer science, the region also tends to blur the distinction between computer programmers and computer scientists. Fortunately, programmers and software developers do take user-friendly software and use it to create profitable businesses and services. However, the region does not often recognise the computer scientists and engineers who have created the same user-friendly software the programmers are employing. The fact is that most computer scientists typically hold Master's or PhD degrees, and most programmers do not. As an example, a computer scientist/engineer would be concerned about the "magic" of how the software "talks" to the hardware, or would be employing sophisticated mathematical theorems and algorithms to enable simple and efficient solutions to what normally would be complex and lengthy computations.

Today, it is the computer scientists who are developing the new tools in areas such as machine learning, and using neural network approaches for problem-solving that are bringing us most of the breakthroughs in artificial intelligence. Programmers are also very important, as they use these tools to create and develop new products and services that increase our work efficiency, along with new forms of entertainment. More Caribbean youth need to embrace both disciplines.

The blurring of the distinctions between engineers and technicians, and between computer scientists and programmers, inadvertently sends the wrong message to some of our young students aspiring to careers in fields such as electrical, chemical and aerospace engineering, and computer science, since they do not often see role models (or glamour) in such jobs. So it is not surprising that careers in medicine and law, which are readily seen and understood, and which appear more culturally glamorous, are viewed as more attractive options. The fact remains, however, that engineers and scientists create many more jobs than doctors and lawyers, and it is the engineers and the scientists who are needed more now, in the 21st century, to help build the new economic pillar we are proposing for the Caribbean.

Not surprisingly, Caribbean engineers and scientists are not yet sufficiently involved in projects on the forefront of innovation, for example: (a) finding the optimum design of low-power circuits for the next generation of cell phones; (b) finding more clever ways to encode signals so that we can pack more voice or video content into an assigned bandwidth in the electromagnetic spectrum; (c) designing the next-generation internet; (d) designing new computer models and software systems for weather forecasting; (e) designing and testing new, light-weight, high-capacity batteries for electric cars; (f) designing and prototyping 3D displays for augmented virtual reality; (g) building robots for special-purpose applications; (h) applying artificial intelligence and machine learning techniques to fields such as healthcare, and to the processing of big data; and (i) designing drugs to slow the progression of Alzheimer's disease.

Cutting edge science and engineering can lead to new industries, but until the region makes the cultural shift and starts educating its people to think and act accordingly, the region will continue to be slow to build globally competitive technology companies (Warde & Sah, 2016a, 2016b; Warde & Sah, 2014a, 2014b; World Bank, 2016; Warde, 1998). Progress in STEM education reform will help to attract more youth to the science and engineering professions, but that alone is not enough. It is also imperative that the region: (a) engages in more science popularisation; (b) begins to build, stimulate, and nurture the industrial base and ecosystem, which includes more access to capital; and (c) provides more mentoring for its technology entrepreneurs. Recommendations for addressing some of these challenges are offered in this paper.

Proposed Technology Company Creation Model

The STEM disciplines have tremendous potential as a base upon which to build the proposed new economic pillar. Figure 1 illustrates the plan that has been recommended by the CSF to address the low number of technology jobs in the region, and to begin the process of building a STEM-based pillar (Warde & Sah, 2016a).

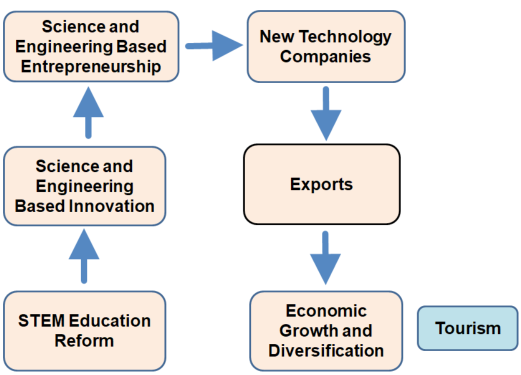

Figure 1. A Model for the Economic Diversification and Development of the Caribbean Region

The four main components of the plan addressed in this paper are models for: (a) attracting and home-growing more technology companies; (b) providing the technical support and infrastructure such companies will need; (c) attracting more Caribbean scientists, engineers, and entrepreneurs from the diaspora and more world-renowned academicians to the region; and (d) reforming STEM education to support the development of this proposed STEM-based economic pillar. Ultimately, it is the private sector that will be the main engine driving and developing the new STEM-based economic pillar, with government facilitation. Expansion of the private sector by building more STEM-based companies is key.

Attracting and Home-growing Technology-based Companies for Private Sector Expansion

While Caribbean countries should continue to encourage and support the development of cottage industries, and micro and small businesses (many of which focus on local markets), a new policy is needed, with primary focus on the creation and development of companies that would employ large numbers of Caribbean citizens; be globally competitive; and bring in significant foreign exchange.

It is unfortunate that at present, Caribbean nationals holding advanced degrees in the STEM disciplines (whether trained abroad or in the region) have great difficulty finding suitable employment in the Caribbean. The problem is that most of those who are trained abroad do not come back to the region because there are no jobs, and there are no jobs because they do not come back to create them.

Figure 2 is one model that breaks this cycle. The process begins with government programmes designed specifically to attract as many foreign technology firms as possible (and fewer financial services firms) to the region. The attracted foreign technology companies (A, B, C, etc.), are shown on the left side of Figure 2. As part of the attraction package, there must also be an ample supply of specialised technical talent that the companies need. That talent consists of local university STEM graduates; STEM graduates abroad who want to come back to the region; and technology entrepreneurs from the diaspora who have an interest in working or setting up companies in the region. By this means, Caribbean youth who are trained abroad will begin to return to the region (in small numbers, initially), to fill some of the new technology jobs created within these foreign firms.

At the same time, the government needs to make it attractive for some of these Caribbean STEM graduates, professionals, and technology entrepreneurs in the diaspora to also set up home-grown businesses or branches of their businesses (i.e. New Local Technology Company X, Y, Z, etc.), as shown on the right side of Figure 2.

The private sector expansion process continues, for example, when one or more of the locally or foreign-trained persons who are employed at Foreign Technology Companies A, B, C, etc. leave to start their own technology business (New Technology Company A1, A2, A3, etc., and New Technology Company B1, B2, B3, etc.), most likely in a related area. A similar process occurs at the home-grown local companies (X, Y, Z, etc.) and thus additional new child companies (New Technology Company X1, X2, X3, etc., and Y1, Y2, Y3, etc.) will be created, as shown in Figure 2. By this leave-and-start process, grandchild companies (A_{11}, A_{12}, A_{13}, etc., and A_{21}, A_{22}, A_{23}, etc., and A_{31}, A_{32}, A_{33}, etc.) of Foreign Technology Company A, for example, will be formed. Similarly, grandchildren of New Foreign Technology Companies B and C would be born. By this very same process, grandchild companies of Local Technology Companies X, Y, Z would proliferate. Not all these companies will be successful, but the goal is to have this exponential growth process repeat itself until a stable technology economic pillar is built and sustained.

Expansion of the number of private sector technology companies can be further enhanced by encouraging more regional university, community college, and TVET (Technical and Vocational Education and Training) students to start their own

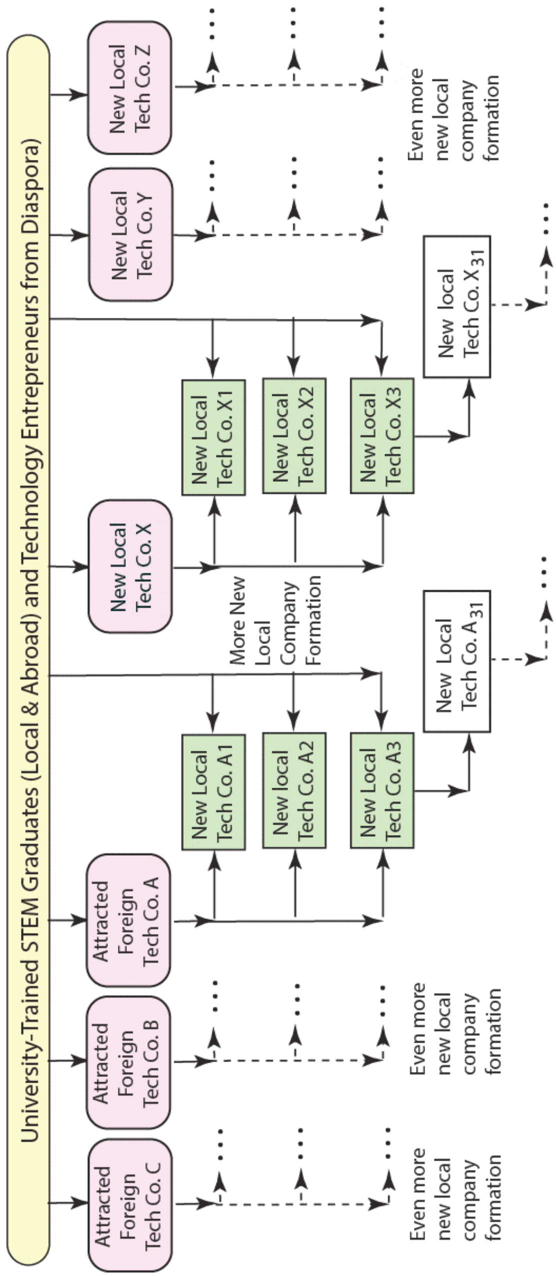

Figure 2. A Technology Employment Creation Model

technology-based businesses and create jobs, rather than ask for jobs. Additionally, non-scientists should be encouraged to focus their companies on products and services derived from the application of science and engineering in areas such as the arts, agriculture, fashion, and value-added products and services. It will be important to make sure that such persons get the help they may need with the relevant science and engineering principles. Helping them to identify projects that could lead to commercialisation in large regional and global markets will be essential.

A variant of a past model undertaken in Chile is one approach for attracting new startup companies to the region (Startup Chile, https://www.startupchile.org; Moed, 2018). In this model, government and private venture capital institutions would open up business plan competitions to any small business in the world, with the understanding that winners would be required to locate their business in the region and that the total Caribbean citizenship ownership exceeds 51% during the first five years. Further, the proposed Shared Regional Research Laboratory (SRRL) of the Caribbean (see pp. 251–254), once established, should help to make the region a very attractive location for an emerging technology company.

Areas of focus for company attraction and formation should be wide-ranging, and could include: (a) information and communications technology; (b) software development (especially animation and the processing of big data); (c) 3D display technology; (d) renewable energy; (e) nanotechnology; (f) electronics circuit design; (g) semiconductor chip design; (h) specialised manufacturing of electronics systems, and optical and biological components; (i) biotech contract laboratory services (followed later by biotech companies); (j) niche food and agricultural products that could be enhanced by the use of modern agricultural technology; and (k) technology-enhanced arts, crafts, and services. The strategy would be to avoid businesses that directly compete with the USA and China, unless the process, approach, or technology is truly disruptive.

Supporting and Sustaining New Private Sector Company Growth

This section discusses some of the programmes, policies, infrastructure, and cultural adjustments that would be needed to expedite the development of a STEM-based economic pillar for the Caribbean. The discussion is limited to five initiatives: (a) reform of government policies and legislation; (b) access to capital, mentors, and incubation support services; (c) development of a small business innovative research and development programme; (d) infrastructure development, in particular, the establishment of an SRRL; and (e) reform of STEM education at all levels.

Supportive Government STEM Leadership, Policies, and Legislation

Most Caribbean governments do not have a Ministry of Science and Technology, and when they do, science and technology is often an appendage to some other ministry, such as education. This gives the impression that science and technology is not a high priority for these governments. A better barometer of priority is the annual budget allocated to science and technology initiatives, which is much less than 1% of the Gross Domestic Product (GDP) in all Caribbean countries (UNESCO, 2018). Further, most government leaders do not have a science and engineering background, and are generally out of their comfort zone when tackling science and engineering initiatives.

Since long-term planning is needed to build the proposed new economic pillar, most politicians see little personal value in investing time and energy in a project that will likely not bear fruit during their time in office. Also, because of tight budget constraints, most Caribbean governments worry most about the near-term challenges of survival. The challenges are compounded because the governments of the region do not traditionally look to technology for solutions to their economic problems. However, we believe that in these difficult economic times, it is even more imperative that emphasis be placed on solutions informed by science and engineering, along with implementing STEM-based economic diversification.

Although it is the private sector that will drive the development of the STEM economic pillar, if the will of the governments of the region is lacking, the plan will go nowhere. Clear government leadership with the authority, the budget, and the will and passion to build the STEM economic pillar will therefore be needed to move the process forward. We wish very much that the CARICOM Single Market and Economy (CSME) [https://caricom.org/caricom-single-market-and-economy] will truly get off the ground soon, as the vision presented here can be implemented much more efficiently once the region can share the sacrifices needed to put the plan in place. Until then we recommend that in each country, the overall budget allocated for science and technology agencies and projects be increased annually until the internationally recommended target level of 1% of GDP (United Nations, 2016) is reached. A five-year goal to reach this target level is recommended. A bipartisan approach to obtaining commitment from all political parties to tie the science and technology research and development budget to a fixed percentage (or the 1% goal) of the GDP for the long term is strongly recommended, for the good of each country and the region.

To implement this model, the region should first put in place a collective and competent Science and Engineering Advisory Board (SEAB) with budget and authority to aggressively move the plan forward. The Chair of the SEAB could report to a council of regional prime ministers. The SEAB would be charged with providing critical input and perspective on all science and engineering matters in the region. The SEAB would assist the respective governments in creating more solid policies and in making more informed decisions related to STEM, especially in areas such as cybersecurity; telecommunications; energy; food security and agriculture; and biotechnology.

The existence of an SEAB would strengthen the interface between science, technology, innovation, and the decision-making powers of the Cabinets, since the Ministers will now have greater and easier access to science and technology experts. Engaging such experts on the SEAB will also allow government leaders to stay "ahead of the curve" on upcoming technology trends. The SEAB could be established with assistance from the CSF. SEAB members would include influential and highly experienced individuals from the wider Caribbean and the diaspora. Composition of the SEAB would include scientists, engineers, business technology leaders, finance experts, and venture capitalists. In particular, the agricultural sector would be represented.

We also recommend the appointment of a Director General for Science and Engineering (DGSE) within each country, who would have overall responsibility for implementing each government's science and engineering programmes and policy. Each Director General would receive guidance from the SEAB, and could carry out the local plan with the approval of their local government. Another very important action that the region must take to attract and retain new technology companies is to foster a more progressive and supportive small business environment. Here, the governments must enact legislation to remove unnecessary hurdles to starting and maintaining a business.

STEM Popularisation: Developing a Culture of Science and Engineering

For the Caribbean region to implement a significant cultural shift — such as the development of a culture of research and innovation in science and engineering aimed at implementing social and economic development — the people must be on board with the policy. Thus, governments must be prepared to sell the strategic plan to the people. To fully engage the general population and to get the necessary buy-in, the population should be made scientifically literate and "culturally savvy" about the benefits of the plan for them. That is, the science and engineering strategic plan must be communicated to the people in simple, clear, and concise terms, over and over again, until the general population understands the plan and can readily see how it will benefit their lives and national development, in that order.

Science popularisation is an effective way to engage the people in the strategic plan. At the very least, a basic STEM education up to the high school level for most of the population will make a big difference. Disseminating information on science and technology to all citizens will help to garner support and engender a greater understanding of the role of science and technology in economic development. The government should use all avenues of communication, such as radio, television, social media, websites, and print media, over several years, to raise awareness and create the cultural shift. The region could also establish an annual STEM week that includes STEM talks aimed at the youth and the general public, along with demonstrations of ongoing science and engineering projects in the region.

Young people in the region also need more exposure to role-model scientists and engineers to motivate and excite them about careers in science and engineering, and to make them aware of the diverse career opportunities available. It is recommended that more of this be done in the schools and at science fairs, and that role models be featured in all forms of social media (such as Twitter, Facebook, Instagram, Snapchat, etc.), television, YouTube videos, educational websites, and smartphone apps.

To complement the formal in-school curriculum, it is further recommended that each Caribbean country: (a) upgrade its science fairs; (b) start annual math olympiads, computer programming clubs, hackathons, and robotics competitions; (c) consider opening a science museum; and (d) weave some of the high-visibility, project-based exercises into their science fairs for cost-effectiveness and implementation efficiency. The region should, as standard practice, feature children who have won science fairs, research and innovation awards, math olympiads, hackathons, and robotics competitions on television, radio, social media, and print media.

An important benefit from science popularisation (e.g. raising awareness about STEM, and the benefits of a basic STEM education for all), is that more people (including many non-scientists) will become involved in the development of companies based on the application of science and technology to the arts and agriculture (see pp. 247–250). Science popularisation is a low-cost, high-return initiative and its programmes should be implemented immediately. In addition, as part of this initiative, all countries in the region should establish special national science innovation awards to recognise technology innovators and companies whose products reach global markets at several different revenue milestones, and feature such champions in the media.

Access to Capital, Mentors and Incubation Support Services

Since there are very few "angel investors" to provide venture capital in the region, it is recommended that the promotion of an entrepreneurial culture include more access to multiple sources of capital as well as in-kind capital, by engaging the diaspora for assistance (World Bank, 2016). Investments tend to follow good projects with sound business plans, oftentimes irrespective of location. This can be achieved via partnerships between the angel investor networks and the few venture capital sources in the region, and similar entities in the diaspora.

To further promote the growth of the new home-grown companies, incubation harmonisation and mentorship strengthening will be needed to assist the entrepreneurs. For the purpose of conducting feasibility studies, it will be critical to support existing or new incubators that provide infrastructure, business guidance and administrative assistance to novice entrepreneurs with innovative concepts. Support from the incubators would include assistance with: evaluating the technological and economic potential of the inventor's concepts and proposals; preparing patents; constructing prototypes; preparing business plans; establishing contact with appropriate industry representatives; and attracting investors. Thus, each country in the region should re-engineer its science and technology incubator policy so that only companies with viable business plans and plausible time-limited incubator exit strategies are admitted and nurtured within the incubators.

Once established, the SRRL (see pp. 251–254) would provide the technology infrastructure for these novice entrepreneurs and very early-stage companies to test their ideas at minimal cost. The idea is that supporting such early-stage studies could lead to later non-government support (such as angel funding or venture capital) for the establishment and development of new companies, thereby preventing commercially viable technology ideas from going to waste.

Small Business Innovative Research & Development Programme

In addition to governments helping to set up stronger and more robust angel and venture capital networks, we recommend that each country in the region consolidate all of its government-sponsored science and engineering research funds into one bucket, irrespective of how small those funds may be. The major funding vehicle in each country should be some kind of Small Business Innovative Research and Development (SBIRD) programme. Such a model was initially proposed to Caribbean governments over 20 years ago (Warde, 1998), but received no traction at that time. Consolidating funds to get the SBIRD off the ground will allow governments to better control costs and minimise outlays to initiate this important programme. Ideally, it would be nice to have a single regional fund but, at the moment, lack of cooperation between the governments of the region is the reality.

The SBIRD programme could be modelled after the US Small Business Innovative Research (SBIR) programme (https://www.sbir.gov/) which has been highly effective in increasing the number of successful small technology businesses in that country. In year 2 and beyond, the budget allocated to the SBIRD programmes could grow slowly until a desirable funding goal is reached.

The proposed SBIRD programmes should be a three-phase initiative. Phase I would make grants to small companies (e.g., less than 100 employees) on a competitive basis to establish the feasibility of development of high tech, biotech and software commercial products and services. Preferred projects should have wide-ranging applications in diverse industries, and would be similar to those listed on p. 242. To start, Phase I grants could be approximately US$30,000, with a six-month period of performance, and Phase II grants could be approximately US$200,000, with a two-year period of performance. The numbers suggested are flexible; it is more important to fund fewer companies with good proposals at an adequate level, than to fund many companies where the funding levels are below critical mass.

Successful Phase I winners would be immediately eligible to use the services and the facilities of the SRRL (see pp. 251–254) to perform research activities, test samples, and build prototypes. Those Phase I awardees who successfully meet the technical feasibility milestones would be invited to submit new proposals for possible Phase II funding to develop pre-manufacturing prototypes of almost market-ready products and services.

Many of the successful Phase II winners would be expected to form alliances with larger companies (in the Caribbean or the diaspora), and in some cases, these larger companies could be expected to cost share or add to the level of the Phase II award from the government. Phase III would be the full commercialisation phase, where the funding would come from angel and institutional investors, facilitated by the regional governments if necessary.

The Phase I and II proposal evaluations would be carried out by a committee of experts, including members from the diaspora, perhaps assisted by the CSF. In particular, the Phase II proposals would be evaluated based on the overall ranking of the venture's probability of success, including: (a) technical merit; (b) competence and experience of the management and technical teams; (c) the go-to-market strategy with a feasible plan and timeline; (d) realism of the proposed market share and commercial potential (including global competitiveness); (e) potential for scaling to significant annual revenues (e.g., about US$20M–US$50M within 5–10 years); and (f) relevance to the needs of the region.

Companies that start outside the region and are ready to either relocate within the region or to set up branches or spin-offs within the region should also be considered for funding under the SBIRD. In fact, the programme could be open to applicants from anywhere in the world, as long as the foreign entrepreneurs agree to locate their business in the region, and the resulting companies have at least 51% ownership by Caribbean citizens for the first five years. Some of these would be the same companies started by the diaspora technology entrepreneurs, described in Figure 2.

The SBIRD programme would differ from the US programme in that the Caribbean country's government would take an equity stake in the company if it accepts Phase II SBIRD funding. If these companies go on to be highly successful, then the government should eventually sell its equity back to the founders or other interested investors, and reinvest the proceeds realised into the basic pool of SBIRD funds. In this way, the pool of funds could actively grow after about 10 years. Thus, in a well-managed programme, taxpayers could be repaid their initial investment into the programme, for a truly self-sustaining SBIRD.

By providing seed funding to existing small businesses, the governments will be sending a positive signal that can mobilise and attract private-sector funds for the growth of new and existing companies. We recommend that the SBIRD programme be part of the national entrepreneurship culture and dialogue. The people and the politicians must always be talking about the programme, which must continually be refined as the economy evolves so that it remains efficient and effective. The programme would need to be very heavily advertised to make sure that potential applicants are aware of the availability of the funds, and that the government is soliciting proposals for the development of new products and services, or the upgrade of the quality or performance of existing products and services.

Infrastructure Enhancement: SRRL

To ignite much more technology–based innovation and entrepreneurship in early–stage and well–established companies within the private sector, we propose the establishment of an SRRL. Because of the high cost of carrying out advanced scientific research, the existence of such an entity would make accessible certain key, expensive technical services and facilities that the region will need if it is going to rapidly accelerate the development of the proposed economic pillar.

The services of the SRRL would be available to scientists and engineers throughout the region on a fee-for-service access plan. The SRRL would house state-of-the-art equipment, machines, and tools that are too expensive to be purchased, maintained, or operated by any one institution in the region, but which are critical to modern scientific research.

By operating the SRRL as a shared facility, it will be easier to garner financial assistance for its establishment and operations from the international community. Operating as a shared facility also permits the overhead and maintenance costs to be spread out over a larger user base that includes all Caribbean countries (French, Dutch, and Spanish-speaking included) and Central America.

The SRRL could be set up as an independent, non-profit, regional organisation. It should be administered by a competent director with experience in running large research laboratories. Ideally, it should be located in close proximity to a campus of The University of West Indies (The UWI), and should operate in close collaboration with all the tertiary institutions in the region. The daily research operations of the SRRL would be run by research professionals with specialised skills, who are experts in the use of the machinery and equipment. Some of these operators will hold Master's and PhD degrees, and some could ideally have dual appointments with The UWI. These operators should be encouraged to carry out their own grant-funded projects using the specialised equipment in the SRRL.

Maintenance and repairs of the machinery and equipment (including building maintenance) are major challenges that must be properly managed. The estimate of the ongoing maintenance budget should include the costs of the service contracts (which will be substantial) and expenses for normal wear and tear on the building and equipment not covered by service contracts, taking into consideration the equipment's age and frequency of use. Each month, a fraction of the fees recovered from the use of the facilities should go into a maintenance account that is managed by the director of the laboratory. The governments of the region, collectively, should also make an annual contribution to the maintenance budget, as allowing such expensive and key equipment to go out of operation, year after year, would lead to the demise of the SRRL. The governments' component could come from the proposed 1% of GDP that should be set aside for science and engineering. If properly operated and maintained, the SRRL should break even as far as operating and maintenance expenses are concerned.

The SRRL will make the region significantly more attractive to Caribbean students and young professionals with advanced degrees in engineering, physics, chemistry, computer science, and the biological sciences who wish to return to the region to make contributions to scientific research, or to start technology–based companies, as described on pp. 160–164.

It is well known that world-class scientists and engineers want and need access to state-of-the-art equipment, tools, and resources. Thus, the SRRL would also attract many more experienced researchers and professors from high-ranking universities in Europe, Canada, the USA, and Latin America to the region. Having such top scientists and engineers at The UWI science and engineering faculty will attract the brightest students from around the world to come to the region to study with them. Some researchers may even want to spend their sabbatical at the SRRL. One advantage is that many academics and researchers on sabbatical have their salaries paid by their home institutions.

Additionally, such high-profile scientists and engineers can sometimes contribute significant additional pieces of equipment and tools purchased through their research grants and contracts. Another intangible benefit will be that the international ranking of the region's leading tertiary educational institutions will begin to rise sharply within 10–15 years, as a result of the added new research activity.

For most distinguished scientists and engineers, it is not necessarily the highest salary that binds them to an institution, but often it is the ease of conducting research and working with the brightest students and post-doctoral scientists and engineers. Thus, SRRL salaries would need only to be competitive, to attract top–notch scientists and engineers to the region.

Yet another primary benefit of having all of this science and engineering brain power concentrated in the region, will be the enhanced entrepreneurial activity that will take place in the region. The spin-off technologies and firms, and the startups that were established with the assistance of the SRRL can be expected to stimulate tremendous growth in the economies of the Caribbean region.

Clearly the SRRL would be a high-risk, high-return investment initiative, but if carefully planned and operated, it would be a significant game changer in the region. If all the funds to build the infrastructure were in place at inception, it would most likely be a five-year project (Warde & Sah, 2016a). However, the incremental approach which would permit its early use, while spreading its full development over a 10-year period, is more likely and should be seriously considered.

The question must also be asked, however, "if we could establish it tomorrow, would anyone use it?" That is, the adage of "build it and they will come," should not be assumed. We would like to think that The UWI would be a heavy user, but we should not take that for granted. An assessment of the user base and its needs should be done as a first-step to SRRL establishment.

The SRRL was first proposed in 2016, but to date no government in the region has shown serious interest. This is understandable, as the scale and complexity of the project, coupled with its operational risk, may seem too challenging to typical politicians, most of whom do not have a background in science and engineering, and whose tenures come in 5–year terms. So if the SRRL is to become a reality, it will probably have to be private-sector driven and developed. The CSF is willing to carry out the study of the user base and its needs, along with the potential impact of the SRRL on the region.

STEM Education Reform Initiatives

This topic is broad and controversial, so we will selectively focus our discussion on a few high-end initiatives that are most relevant to the theme of this paper: (a) STEM curriculum reform at the primary and secondary levels; (b) STEM teacher training; and (c) STEM curriculum reform at the tertiary level.

STEM Curriculum Reform at the Primary and Secondary Levels

To attract and retain foreign science and engineering companies to the region (see pp. 239–242), an adequate level of know-how in science and engineering must reside in the local workforce. To enable the desired technology–based, private sector expansion, the region must keep the pipeline full of STEM talent. At the same time, it is imperative that the education system produces well-rounded citizens. Therein lies the need for education reform in the STEM and communications disciplines.

Engineering and engineering principles are among the weaknesses in the Caribbean educational system. Robotics is an interdisciplinary subject, so adding robotics and coding will allow all students in the region to be exposed to engineering concepts at an early age. In addition, Information and Communications Technology (ICT) training is important because it can serve as a catalyst for the development of innovative businesses, products, and services, while providing enhanced productivity and a competitive advantage for companies in many sectors, including the government (Warde & Sah, 2016a). For secondary schools, the CSF recommends Python, as today Python is the entry-level coding language of choice for secondary and tertiary students in the developed world. Other modern languages would also suffice. The hope is that the Caribbean Examinations Council will replace Pascal with Python, or another modern language, as its computer programming subject within the next two years.

Such coding baseline knowledge, coupled with good communication skills, will become expected of all knowledge workers in the near future, just as spreadsheet and word-processing skills are expected today of many entry–level workers. Development of communication skills (listening, written, and oral) and competency in one foreign language must also be part of the basic curriculum required for well-roundedness.

Modification of the primary and secondary school curriculum at all levels to include the fundamentals of entrepreneurship is also a worthy goal, as a cultural shift is needed in the region in the way entrepreneurship is viewed and practised. A basic entrepreneurial education would complement the STEM and communications education, and should cover the fundamentals of finance; how to start a business; the various types of capital; intellectual property concepts; how to write proposals and business plans; marketplace competitiveness; ethics; and negotiation skills. Adding computer programming, robotics, science and engineering principles, and the elements of entrepreneurship to primary and secondary school curricula can begin as early as age 8 (Warde & Sah, 2016a; 2016b).

Discouraging rote learning, and the value of the design experience in STEM education. The imagination of each and every student must be exercised in and out of the classroom. Rote learning needs to be discouraged. Instead, the focus must first be placed on understanding the concepts and fundamental principles in each discipline and to gain mastery, so that students are able to apply the fundamentals to solve new problems not previously encountered. The goal is to train students to think critically and to develop logical and analytical problem–solving approaches in all disciplines. In addition, a balance needs to be struck between theoretical and hands-on learning, as both are important. To achieve these goals, the region must place the student at the centre of the learning experience, not only in its primary level institutions, but in all its schools and universities.

One of the obvious flaws in the education system is that not enough attention is paid to the design component of learning in the region's educational system (primary through to tertiary). The design component draws on the creativity of the student. Thus, having students also engage in project–based learning is critical. Here, the student gains the experience of designing and carrying out their own experiments. These processes are effective for stimulating imagination and creativity, and can help students to become critical, logical, and independent thinkers as they pursue evidence–based conclusions.

STEM Teacher Training

Many persons in the region believe that the education system is not serving them well. They complain that creativity is too often stifled in the classroom at an early age, and that teachers who have outmoded classroom practices are teaching as they were taught, and are not giving students enough freedom or space to express their ideas and their thinking. Teacher training is a key area that needs addressing in order to: (a) increase the level of students' interest in the sciences; (b) encourage more youngsters to pursue careers in science and engineering; and (c) promote more awareness in the teachers themselves, and in the general population, of the link between science and engineering, and regional economic development.

Indeed, too many of the region's primary school teachers who are called upon to teach science do not fully comprehend the material, or have never taken a science course themselves. All teachers at all levels should be engaged in continuous training and continuous education, even if for a one- or two-day supplemental workshop annually. While an ineffective teacher can turn off an entire class of students, a good teacher can arouse passion and excitement, and create the will to learn in that same classroom.

In particular, teachers need to be trained in how to teach STEM subjects using active learning techniques such as Problem-based Learning (PBL), and engage in Inquiry-based Science Education (IBSE) methods. These methods emphasise observation; experimentation to gather data; having students question and interpret data; forming evidence-based conclusions with teacher guidance; and drawing on students' own background knowledge and ideas. Figure 3 illustrates the concepts as they could be applied in a classroom setting.

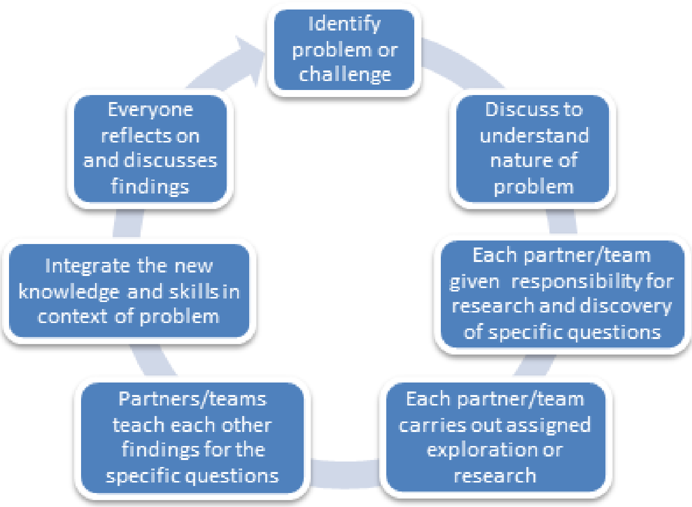

Figure 3. PBL/IBSE Learning Cycle

These teaching methods are also consistent with good research and scientific practices which often begin with a hypothesis; the design of one or more experiments; conduct of the experiments; and an analysis of the observations to test the hypothesis. The hypothesis usually gets refined after the first cycle, and the process starts over again until some definite conclusion is reached. The hope is that this early training in good research practices will manifest itself later in the design of new innovative products and services by a well trained and creative technology workforce.

It is anticipated that these approaches will promote more primary and secondary school students' interest and excitement in science and engineering prior to their entering the tertiary level. Ultimately, this should lead to higher numbers of students pursuing advanced degrees and careers in science and engineering. Substantial investments at the teacher training colleges will be needed to implement this expanded role, but the investment will ultimately pay dividends in preparing the region's technology workforce of the future.

STEM Curriculum Reform and Research at the Tertiary Level

We have already discussed the research role of the tertiary institutions in reference to the SRRL (see pp. 251–254). In addition, the tertiary education institutions in the region need to re-engineer themselves to play a more critical role in stimulating technology-based innovation and entrepreneurship. The region must demand that students in its tertiary institutions be trained today to create and fill the jobs of tomorrow, even though many of those jobs do not yet exist. Caribbean students are as intelligent as students in other parts of the world, so why are Caribbean students not more actively involved in creating the jobs of tomorrow? What is missing is the research and innovation culture — the teaching and continuous exposure to creative and innovate STEM research environments in the physical, biological, chemical, computational, and engineering disciplines. Unfortunately, the tertiary institutions often lack the human capital and adequate laboratory infrastructure to effectively carry out their desired mission. Significant investments in both areas over the next 10 years are recommended to broaden the scope of the mandate of the universities and community colleges from primarily teaching institutions to more balanced research and teaching organisations.

Roughly 80% of university research should be driven by the short- and long-term economic needs of the region. This is not to say that the university should abandon all theoretical research. In fact, theoretical research that can be shown to have a clear link to potential future product or service development should be encouraged. Technology transfer from university to industry, and vice versa, should also be more strongly encouraged and rewarded. Ideally, the university must help businesses sustain their competitive advantage through joint research projects.

Sometimes, it is one or two individuals within the university or a research laboratory (not necessarily the big companies) who come up with the next big, disruptive innovation such as Facebook (invented by Mark Zuckerberg, his roommates, and colleagues while at Harvard University) and Google (started by Larry Page and Sergey Brin while both were students at Stanford University). Ironically, the first evidence of a search engine is credited to Alan Emtage of Barbados, while he was a student at McGill University (https://www.internethalloffame.org/inductees/alan-emtage; https://history-computer.com/Internet/Conquering/Archie.html); however, he never benefitted significantly from his invention. The point is that such inventions can also be hatched within the tertiary education systems in the region, if effective research ecosystems could be put in place. The Emtage story points to the fact that students, professors, and university technology transfer officers must be savvy enough to recognise the potential value of disruptive inventions, and act swiftly to seek appropriate intellectual property protection. The region needs experienced technology transfer individuals who can provide business, intellectual property, and commercialisation advice and guidance. Such persons would have the skills to identify potentially interested companies and negotiate deals that would move university research into the private sector. The diaspora can help with finding leaders with such experience.

Within the tertiary institutions, key research areas (based on the needs of the region and on the identification of technologies with low financial barriers to market entry) should be prioritised through careful consideration of the probability of commercialisation success. These technologies, products, and services should be developed within new or existing research and development centres of excellence in the tertiary educational system and in the SRRL (see pp. 251–254). It is important to note that *both* the "R" and the "D" (Research and Development) *must* be present. The most competitive niche products and services emerging from these centres should be targeted for growth and development, and should be nurtured in well-run incubators, either within the tertiary institution or outside (see pp. 246–247).

Some of the funds for the development of more and better research capabilities in the tertiary institutions should come from the proposed 1% of GDP set aside annually by the respective Caribbean governments for research and development in science and engineering, as described in Section 3.1. The remainder would have to come from the international community, the diaspora, and the local private sector.

Tertiary Education Scientific Advisory Committee. The task of re-engineering the tertiary institutions to assist with economic development may appear daunting, so the SEAB (see pp. 243–246) should work with the leadership of these institutions to put in place a shared Tertiary Education Scientific Advisory Committee (TESAC). The TESAC would comprise science and engineering academic leaders and business visionaries from the diaspora and the region who would assist with strategic planning and implementation of university science and engineering research and teaching programmes. The TESAC should keep the regional weaknesses in engineering and engineering education in its cross hairs, and it should devise a plan to strengthen these weaknesses on all the campuses. It should be pointed out that new faculties of engineering are not necessary to teach and engage in engineering research. Costs can be managed with good curriculum planning, and wisely choosing the engineering disciplines in which excellence is desired. At least one member of the SEAB should sit on the TESAC, so that SEAB input and reporting back to the SEAB can take place.

The TESAC should also bridge the communications gap between the respective governments and the tertiary institutions, so that the tertiary institutions can better address the economic development needs of the region. The TESAC could help to ensure that there is more collaboration between the tertiary institutions, thereby providing for better sharing of scarce resources. With its international connections, the TESAC should also help to build linkages and collaborations with universities and industries in the region and the diaspora, thereby avoiding a reinvention of the wheel, and bringing much needed expertise to the region.

The Caribbean Science Foundation: A Catalyst for Change in the Region

Realising the need to assist the region with STEM education reform and STEM–based entrepreneurship, the Caribbean Diaspora for Science, Technology and Innovation (CADSTI) [http://caribbeanscience.org/cadsti/] launched the CSF (http://caribbeanscience.org) in 2010. Cariscience (https://www.cariscience.com/) hosted the launch in Port of Spain, Trinidad and Tobago. Today, the CSF is an independent, private, non-profit, non-governmental organisation with its headquarters on the Cave Hill Campus of The UWI. Its mission is to assist with the diversification of the economies of the Caribbean region by harnessing science and technology for economic development, in order to help raise the standard of living. Specifically, the CSF is helping to:

1. Accelerate education reform that supports technology-based entrepreneurship by promoting and funding programmes that focus on the STEM disciplines; business and entrepreneurship education; foreign languages; and communication skills.

2. Stimulate technology-based entrepreneurship by identifying and funding science and technology projects in new and existing enterprises that are relevant to regional needs.

3. Provide scientific and engineering advisory services to Caribbean governments by working with CADSTI to leverage the expertise in the diaspora.

Indeed, the CSF's motto is, "Grooming the Next Generation of Caribbean Science and Engineering Leaders". The recommended economic development strategy proposed herein presupposes that the STEM students of today will become the technology and business leaders of tomorrow, to help turn around the slowly spiralling downward economic trajectory of the region.

To demonstrate to the governments and the people of the region what is possible, the CSF has launched five catalytic STEM academic programmes since its creation in 2010. These are: the Student Programme for Innovation in Science and Engineering (SPISE); the Barbados Junior Robotics Camps (http://caribbeanscience.org/barbados-junior-robotics-camp/); the Computer Coding Workshops; the STEM Teacher Training Workshops; and the Sagicor Visionaries Challenge. The first four of these programmes are further described below.

Student Programme for Innovation in Science and Engineering

The Student Programme for Innovation in Science and Engineering (SPISE) is an intensive, 4-week, residential summer enrichment programme offered for exceptional Caribbean high school students who are interested in studying and exploring careers in the STEM-related disciplines (http://caribbeanscience.org/spise/). SPISE is modeled after the well-known MITES (Minority Introduction to Engineering and Science) programme at MIT (http://oeop.mit.edu/programs/mites). SPISE nurtures and supports the STEM talent in the youth, encourages them to stay in the STEM disciplines beyond university, and to consider technology-based entrepreneurship as a career option. The goal is to ensure that opportunities for future creation of technology-based jobs in the region are not lost. The CSF firmly believes that the next Google can be started in the region by a team of Caribbean students. One such company would supply high-paying jobs to a large percentage of the population in any of the countries in the region.

SPISE provides a special risk-free learning environment in which students are trained to think critically and to develop analytical and logical problem-solving approaches in several disciplines. Rote learning is discouraged, and instead, the focus is on teaching students to understand and apply the fundamentals so as to achieve mastery. SPISE students are immersed in rigorous university-level courses in calculus, physics, biochemistry, computer programming, Caribbean unity and entrepreneurship, as well as hands-on projects in underwater robotics, renewable energy, and electronics. SPISE students attend career seminars offered by luminaries in their fields, which expose them to the broad range of careers possible with a STEM degree. The students are also guided and mentored by role models from the diaspora on career paths and choices.

SPISE has served 131 students to date. Graduates from the 2012-2017 classes have attended or are attending some of the world's top science and engineering universities, including: The UWI; Massachusetts Institute of Technology; Stanford University; Harvard University; Yale University; Princeton University; Columbia University; Dartmouth College; University of Pennsylvania; Georgia Tech; Howard University; University of Rochester; University College London; University of Edinburgh, University of Toronto; and McMaster University. Most have received generous financial aid packages. All SPISE students have made a non-binding pledge to give back to the Caribbean region at some point in their lives.

The plan is that some of the students who have stayed in the region can take up employment opportunities at the newly created technology companies described in Figure 2, so that the region can take advantage of this talent base. Similarly, the hope is that several of those who left the region for university studies will return to work in these same newly created technology companies. Ultimately, we want to see a fraction of both cohorts go on to create their own technology companies. Assuming that this model can be implemented even partially, the resulting new economic pillar (based on science and engineering) could gain significant momentum within 15–20 years.

Barbados Junior Robotics Camps

The CSF has observed that the region is lagging behind the developed world in robotics education, and decided to help by launching the Barbados Junior Robotics Camps (http://caribbeanscience.org/barbados-junior-robotics-camp/) in 2015 as a pilot, Level I camp. Today, there are four levels of the camp. The regional lack of focus on robotics could be, in part, because so little engineering is practised in the region. About 55 to 60 students, ages 10–18, participate in the CSF robotics camps each summer. The camps are open to students of any nationality who can prove that they have attended a Caribbean school for the past four consecutive years. Students from low-income households and girls are encouraged to apply. The aim is also a balanced class with 50% girls and 50% boys. Students apply directly to the CSF for admission, but a recommendation from their science or mathematics teacher or school principal is required.

The camps are targeted at children who are passionately interested in science, technology, engineering, and mathematics (STEM); curious about science in their surroundings; who perform consistently well at school in science and mathematics subjects; and who enjoy hands-on work. At the camps, students participate in team-based projects under the supervision of several coaches. The interdisciplinary characteristics of robotics offer the CSF an opportunity to introduce computer programming and principles of physics (such as mechanics, sensors, optics, and engineering design) in a fun environment.

A CSF-modified VEX Robotics curriculum is employed for Level I–III camps. It comprises a mix of classroom teaching, computer programming, and hands-on building through the use of VEX Robotics Kits (http://www.vexrobotics.com/). Through this curriculum, the students learn about the basic components of robots, and see examples of how science and mathematics are applied to engineering. In the Level IV Camp, students build their own robots. Teamwork is an essential skill that is emphasised in all the camps, and its value is highlighted. A tour to a company which uses robots is sometimes planned, so that the campers can observe real robots in action. At the end of the month-long camp, the students demonstrate the operation of their robots to a public audience, and certificates of camp completion are awarded. The plan is to replicate the robotics camps in other Caribbean countries. The camps are held in partnership with The UWI, Cave Hill Campus, and the Caribbean Examinations Council (CXC).

CSF Computer Coding Workshops

It is believed that in the very near future, computer coding will be as essential a skill to have for many entry level positions as word processing and spreadsheet facility are today: The knowledge-based workforce of the future will be heavily dependent on computer coding skills. More and more developing countries are training their students in computer programming (coding), and much of that focus begins with html (for website development) and cell phone apps. Even at this level, the Caribbean is being left behind, as not sufficiently developing computer programming skills in its population, the region is unable to take full advantage of its potential to build a modern-day workforce and diversify its economies.

In order to help the Caribbean catch up with developed countries, beginning in January 2018, the CSF partnered with Scotiabank, the US Embassy in Barbados, and the Organization of Eastern Caribbean States (OECS) to launch a Level I pilot of the

CSF Computer Coding Workshops (http://caribbeanscience.org/coding-workshop/) which now run twice per year (January–March and September–December) on Saturday mornings. The workshops have most recently been replicated in St. Lucia (in January–March, 2019) with the hope that others in St. Lucia will later take ownership of their workshops. The plan is to further replicate the workshop in other Caribbean countries.

The goals of the CSF Computer Coding Workshops are to help: (1) address the challenge of increasing the low numbers of skilled Information and Commmunication Technology (ICT) workers in the region; (2) stimulate more interest in science and engineering careers; (3) train the technology workforce of the future; (4) stimulate more technology-based entrepreneurship by encouraging the formation of more globally competitive ICT companies; (5) get more students interested in going beyond programming into the field of computer science; and (6) prepare students for university study in the STEM disciplines.

CSF/CAS STEM Teacher Training Workshops

It is generally agreed that: (1) greater attention must be paid to the teaching of mathematics at the elementary school level; and (2) scientific principles need to be communicated clearly and effectively so that students can understand and apply the concepts. It is with this observation in mind that from 2015 to the present, the CSF teamed with the Caribbean Academy of Sciences (CAS) to offer a set of joint STEM Teacher Training Workshops (http://caribbeanscience.org/stem-teacher-training-workshops/). At time of writing, a total of nine workshops have been held in Antigua, Barbados, Dominica, Jamaica, St. Kitts & Nevis, and St. Vincent & the Grenadines; with four offered in Jamaica and one in each of the other territories listed. The workshops were sponsored jointly by the US Embassy in Barbados, the OECS, and the US Embassy in Jamaica.

The workshops are two- or three-day training events, with the goal of training teachers in the use of Problem-based Learning

(PBL) and Inquiry-based Science Education (IBSE) as teaching tools (see pp. 256–258). The teachers are selected by their respective Ministries of Education, and are persons who are genuinely and passionately interested in exposing their students to elements of STEM. The intent is that these teachers will become future trainers of other teachers. The workshops promoted themes such renewable energy, robotics, and food production as key components in hands-on science education and in the curriculum. They also helped teachers to identify several local issues that secondary school teachers face in teaching science and technology. Further, teachers leave with a plan for implementing PBL and ISBE as teaching tools, including a plan for assessing/monitoring the programme's effectiveness.

The current concern is that the methods taught in the workshops are not being effectively implemented in the schools when the teachers return to the classroom with new knowledge and teaching techniques. It is also not clear that there is always buy-in from the school principals. An impact assessment for the four Jamaican workshops is currently being carried out by a team from CAS, which, it is hoped, will shed some light on this question.

Conclusion

Clearly, we have taken an optimistic view in this blueprint. However, we do not underestimate the challenges involved. Building an economic pillar based on STEM in the Caribbean will not be a simple or straightforward task. While the vision has been provided here by the CSF, the political will must be present on the part of the respective Caribbean governments to move the region forward in the manner we have described. Ultimately, the governments of the region must take more responsibility for developing the proposed STEM-based economic pillar. Private sector expansion into STEM-based business is key for success in this endeavour, as it is the private sector that will have to do the "heavy lifting", in collaboration with the regional governments.

To sustain the proposed economic development movement, education reform from primary through tertiary levels is needed, so that the pipeline can be kept full of talent at all times. It is anticipated that the above-proposed PBL and IBSE teaching approaches will promote more student interest and excitement in science and engineering at all levels. Ultimately, this should lead to higher numbers of students pursuing advanced degrees and careers in science and engineering, and help the region to more readily develop the next generation of science and engineering leaders, and its future technology workforce.

The most challenging of the recommendations in this blueprint is the establishment of the SRRL. To move this project beyond the current “wishful thinking” stage, the CSF is currently assembling a team of experts from the region and the diaspora to brainstorm and develop a business plan for its establishment, operation and sustainability. We believe that this complex and large price tag recommendation will be easier to implement if the region can truly get the CSME (https://caricom.org/caricom-single-market-and-economy) initiative established. Ideally, all countries should share the challenges and the benefits from the SRRL. Assistance from the international community, which will be needed, is generally more forthcoming for large regional projects such as the SRRL, than for large national projects.

Finally, one should not expect different results if the region continues with the same traditions and policies it has followed to date. A forward looking paradigm shift is needed, or the region will continue to lose ground. Poverty and lack of jobs could increase, thereby leaving for the next generation a region that is in economically worse shape than it is today. Creating a STEM–based economic pillar for the Caribbean is the much needed paradigm shift.

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