Science, Technology, Engineering, and Mathematics (STEM) Education in the US and Its Translational Approaches to Thailand

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Executive Summary

To maintain its competitive edge as the top innovating nation, the United States (US), particularly during the two terms of the Obama administration, has placed special emphasis on Science, Technology, Engineering, and Mathematics (STEM) education. Numerous studies have shown that shortage of skilled STEM workers in the US and the weakening of US's leadership in innovation will be imminent, if nothing is done. Although Thailand's needs and aspirations are not exactly the same as the US, restructuring STEM education to build a strong tomorrow's workforce as well as a solid foundation for an innovation-driven economy still stands as one of Thailand's imperative missions, if strengthening its position in the region is an ultimate vision. This is precisely what Thailand is undertaking. A 5-year master plan for STEM education in Thailand has been developed by the Institute for the Promotion of Teaching Science and Technology (IPST). Despite the differences between the US's and Thailand's situations, there are still many valuable lessons that can be learned from the US's experiences. This can in turn be tailored to fit Thailand's needs.

The Royal Thai Embassy has important roles to play in Thailand's efforts to strengthen STEM education, particularly by identifying STEM educational resources in the US for Thailand to tap into and by fostering collaborations between the two countries. As a first step, the Embassy has requested the Association of Thai Professionals in America and Canada (ATPAC) to provide comments and suggestions on the IPST STEM master plan as well as to identify key resources and potential partners in the US. This report is prepared by ATPAC in response to the request.

After defining what STEM is and what its vital roles are in the opening section, the following section takes a candid look at the IPST plan and offers suggestions for improvement. In essence, the IPST plan sets the targets that by the end of the 5-year planning period, 50% (1) of high school and vocational schools graduates, (2) of teachers produced and (3) of skilled workforce created will be STEM-enabled. This, in turn, is projected to create 3.25 million workers to be well-equipped with 21st century skills by 2019. The main strategy proposed to achieve the desired targets is the reliance on the public-private partnership (PPP-STEM21) and on allowing each member of PPP-STEM21 to execute their individual programs or activities autonomously. The IPST plan proposes 7 specific STEM programs ranging from launching public relations campaign in STEM, creating STEM centers, finding or developing STEM experts, rebuilding STEM curricula, establishing STEM digital resources, instituting STEM competency measures and guidelines, and creating STEM workforce. The total estimated budget is 21,214 million Bahts, 77% of which goes to the STEM experts program, 0.3% to STEM curricula, and 0.6%-2.3% to the remaining 5 programs. In our view, we believe that the IPST plan focuses too heavily on the supply side as well as on quantity rather quality. As a result, budgets have to be loosely estimated resulting in huge numbers that are difficult to justify. It also hard to determine whether the disproportionate allocations of budget to the 7 programs are appropriate. To ensure prudent use of resources without sacrificing effectiveness in complex undertakings such as revamping STEM education, it is more sensible to begin by identify explicit goals (from global down to more concrete focus areas) and set their relative priorities. Appropriate programs/activities can then be designed to fit the goals and their priorities, and justifiable budgets can then be allocated accordingly. A goal-driven planning would produce a more coherent plan with linkages among goals, priorities, programs and budgets being easier to demonstrate. More specific recommendations to improve the IPST plan are listed in the next section of the report.

The rest of the report focuses on key lessons learned from the US's experiences, particularly those which are pertinent to Thailand's conditions. Section 3 makes recommendations to improve the IPST plan based on the US experiences. The IPST plan should include the four key elements: goals, outcomes, design, and implementation. In addition, (focus industrial) areas should be clearly defined and the proper size of the workforce in each area estimated. The IPST plan should also introduce technical STEM professional contents to K-12 students at different age groups. Further, it should identify specific and relevant resources in the US and the can benefit STEM development in Thailand and should reach out to Thai professional network such as ATPAC for assistances. Finally, assessment of the goals and outcomes, which is a key piece for continuous improvement and future directions, is missing and should be included in the plan.

Partnering with industries is vital to the success of any STEM initiatives. Examples of industry involvements in STEM are given in this report. STEM activities offered by reputed pharmaceutical and telecommunication companies such as Merck, GlaxoSmithKline, and AT&T are outlined. Three examples to promote STEM and/or enhance its quality in the US are provided. The first example is a project that promotes STEM among Native American in rural areas and Thailand can adopt it to address inequality between rural and urban populations on STEM education quality and resources. Independent and interdisciplinary undergraduate research which could be useful to Thailand is described. For the last example, features and practices at successful STEM schools in the US are provided. Potential STEM partners in the US for Thailand at the policy and practice levels are identified. The main body of the report is capped off with suggestions on the role of the Embassy in STEM education initiative in Thailand such as facilitation of collaborations with and assistances from US entities. Supplemental information on web addresses for different STEM programs, activities, and entities mentioned in the main body, and model pre-college STEM programs/activities and list of top STEM schools in the US is available in appendices. The report also accommodates a request by the Embassy to touch on STEM education in relation to smart cities which is a topic that is of political interest.

STEM Working Concept and Moving Parts

As humanity and world nations enter the 21st century and beyond, it is unquestionably clear that high-tech developments driven by the digital and information revolution will be the underlying imprints of the lifestyle of a nation's population, the core skills required by tomorrow's workforce, and the talents required to innovate and drive the competitiveness of the national economy. For any nation that wants to compete while caring for the welfare of its population and the growth of its economy, **Science, Technology, Engineering, and Mathematics (STEM) is an education initiative aimed at preparing the general public for the high-tech dominated lifestyle, the workforce to be equipped with the necessary 21st century skills, and the nation as a whole to be armed with ample talented thinkers and innovators necessary to improve its competitiveness in the regional and world markets.**

In the United States (US), STEM education has implications for workforce development, national security concerns, and immigration policy to improve competitiveness in technology development. History of STEM in the US is rooted in education and immigration debates in initiatives to begin to address the perceived lack of qualified candidates in STEM fields for high-tech jobs. The Committee on STEM Education (CoSTEM) was established as a government-wide initiative on STEM education in the US with the main goal to address shortfalls in federal government support of educational development and progress at all academic levels in the STEM fields. CoSTEM currently facilitates a cohesive national strategy, with new and repurposed funds, to reorganize STEM education programs and increase the impact of federal investments. The top three main foci of the initiative are:

1. to increase America's talent pool by improving K-12 science and mathematics education;
2. to strengthen the skills of teachers through additional training in science, mathematics and technology; and
3. to enlarge the pipeline of students prepared to enter college and graduate with STEM degrees.

Taken all the current strategic, tactical, and operational efforts of STEM initiatives in the US, this report will provide insightful information about the current STEM practice, activities, implementations and strategies in the US, and identify those that are applicable to Thailand. The outcome of this report is expected to recommend approaches to prepare Thai students with the basic building blocks they need to be successful in postsecondary and workforce pathways so they can generate ideas and translate them into innovative products and services.

Thailand's 5-Year STEM Master Plan: A Review

We took a critical look at the Thailand's 5-year STEM Master Plan, which was prepared by the Institute of Promotion of Teaching Science and Technology (IPST). We first summarized the essences of the IPST plan and then provided our candid views of the plan.

Key Features of the IPST Plan

Goals: In general, Thailand STEM plans (including IPST's) can be succinctly described as "STEM for Education" and "STEM for Workforce". The former is aimed at creating public awareness of and building knowledge in STEM-related fields for students and the general public. The latter is directed at building the necessary foundations for developing STEM-related skills for the workforce. The IPST Plan in particular sets three specific numerical targets, namely: 1) **50%** of next generation of high school students and vocational students to receive quality training in STEM education; 2) **50%** of the school teachers and vocational teachers in STEM become trained STEM teachers; and 3) **50%** of Thai workforce with medium skills or higher have training in 21^{st} century skills and they can apply the skills in their jobs.

Strategies and Scope: The IPST plan defines two key strategies to guide its implementation: 1) create public-private partnership on STEM education (PPP-STEM21) and 2) rely on each member of PPP-STEM21 to freely carry out its own existing STEM programs and/or to create innovative STEM programs. The PPP-STEM21 partners are to include related government agencies, private enterprises and non-profit organizations (local and/or international). The plan is to cover education at all levels (K-12, vocational, and higher education), and to include all schools, vocational colleges, universities and all non-formal institutes.

Proposed Programs: The IPST plan proposes seven 7 specific STEM programs, namely:

1. STEM public relation and formation of the PPP-STEM21 partnership;
2. STEM education centers in schools, vocational college, universities and private enterprises;
3. Training and development of STEM teacher by STEM ambassadors and STEM professors;
4. STEM curricula for basic education, vocational education and higher education;
5. STEM digital resources (iSTEM);
6. STEM competency evaluations; and
7. STEM workforce, STEM career development and STEM Hall of Fame.

Anticipated Outcomes and Estimated Budgets: The IPST plan estimates that the total of 3.25 million Thai citizens will be equipped with 21^{st} century skills by 2019. As part of the PPP-STEM21, it also anticipates participation from 30,000 schools, 400 vocational colleges, 150 universities, 50 government agencies, 100 private enterprises, 20 foundations, 20 associations, 20 countries, and 10 international organizations.

The total estimated budget for the 5-year plan is 21,214 million Bahts. The distributions of this estimated budget over the 7 proposed programs are (in million Bahts): 500 for STEM public relation; 3,196 for STEM centers; 16,368 for STEM experts; 50 for STEM curricula; 100 for iSTEM; 500 for STEM competency; and 500 for STEM workforce.

Key Success Factors: The plan proposes a formation of a National STEM committee consisting of members with high competency in STEM education and STEM workforce to oversee the plan implementation, monitor the progress, and recommend measures for improvement.

Review of the IPST Plan

The overall rationale driving and guiding the development of the IPST plan, although not unique, is crucial in bringing awareness of the importance of STEM education and STEM workforce in Thailand, particularly if Thailand aspires to compete effectively in ASEAN and world markets. The emphasis of using public-private partnership (PPP-STEM21) and the anticipated all-embracing and far-reaching participations from various projected partners are clearly a key to success of the plan. The 7 proposed programs appear to cover most, if not all, important elements that need to be brought together in this complex undertaking.

What seem to be missing are satisfactory details to 1) discern **clear overall goals** (not numerical targets) of the plan, 2) **connect the dots** (how effective would the proposed programs serve as a means to achieving the stated goals and how are the proposed budgets linked to the goals and reflect their priorities?), and 3) **justify the huge amount of total budget** and the subsequent distributions to the 7 proposed programs. There are also some overlooked issues that should be brought to bear. Specific comments and suggestions to improve the plan follow:

1. The most notable observation that can be made is that the IPST plan is heavily a supply-pushed (open-ended) planning (as opposed to demand-pulled or goals-driven), and almost-entirely quantity-based rather than quality-based. Using supply-pushed quantity-based planning, the IPST plan begins by setting seemingly arbitrary numerical targets (50% of the 2013 numbers) for STEM-trained students, STEM teachers, and STEM workforce, as well as estimating the numbers of partners expected to participate in various programs. Budgets are then estimated based loosely on those numbers. It is unclear how the various numbers could be convincingly justified, and how the budgets are estimated. Questions that often arise are: Why 50%? How would the proposed targets meet the overall goals of STEM initiatives? Why 500 million Bahts for the STEM public relations program, 3196 million Bahts for the STEM centers program, etc.? Would the distributions of budget as proposed accurately reflect the implied priorities that should be given to various goals? And so on. It is apparent that an open-ended planning such as that used in the IPST plan would have a hard time answering these questions or to convincingly justify the proposed budgets.
2. In goals-driven planning, **goals** should be first **clearly** stated and **priorities** should be **explicitly** assigned. The objective of any STEM initiative is generally three-fold: to bring STEM awareness and prepare STEM readiness for the general public for the 21st century livings; to prepare tomorrow's workforce; and to build the foundations for innovation and create a cadre of innovators to drive the economy toward an innovation-driven economy. For Thailand, what should be the priorities of these three goals? Considering that Thailand aspires to be a major player in the competitive world of ASEAN, Goals 2 and 3 should command the highest priority. Appropriate programs/projects/activities should then be designed and budgets allocated accordingly. The bases for estimating and justifying required resources for various parts of a STEM program should be easier to establish once goals and their priorities are clearly defined. For the IPST plan, STEM workforce is the primary instrument to achieve Goal 2, although various elements embedded in all other programs except STEM public relations indirectly contribute to the goal. Goal 3 is the culmination of the STEM experts, STEM curricula, and STEM centers programs. Goal

1 is mainly connected to STEM public relations, STEM curricula, STEM competency, and iSTEM programs.

In addition, STEM-related fields are quite diverse. It is not prudent to try to cover them all without establishing a clear priority, to do so would require too much time and resources to do them well. Instead, Thailand should focus on a few high priority areas that meet its pressing needs, and ones that Thailand could excel to give the country the best chance to compete. More specific recommendations pertinent to the IPST plan are given in the next section.

3. One of the two strategies in the IPST plan is to allow each partner in PPP-STEM21 to operate independently. While the strategy may provide flexibility and freedom to each partner which is conducive to creativity and innovation, it is also prone to redundancy which is the main source of inefficient use of resources. Tangible machineries for effective coordination would very likely be needed. Further, some guideline should be given to enhance the chance of success in meeting the desired goals. As an example, the White House recommends the following checklist for a job-driven STEM program: engage employers; offer work-based learning opportunities; make better use of data to drive accountability; measure and evaluate employment and earnings outcomes; promote a seamless progression from one educational stepping stone; break down barriers to accessing job-driven training and hiring; and create regional partnerships.
4. In the key success factors section, the IPST plan does not identify key performance indices (KPIs) to be used to measure the success of the plan. Measures should also be established to ensure lifelong learning of STEM education. Specific KPI-related recommendations can be found in the next section (Recommendation 8).

Recommended Items to be Added to Thailand's 5-Year STEM Master Plan

The primary objective for the STEM education in the US was a result of serious workforce shortage in its manufacturing sectors, in particular those in the Hi-tech industry with emphasis in the STEM-related fields. Studies conducted by the National Academies, commonly known as ***Gathering Storm***, concluded that a primary driver of the future economy and concomitant creation of jobs will be "**innovation**", largely derived from advances in science and engineering. The report went on to point out that while only 4 percent of the US workforce is composed of scientists and engineers, this group disproportionately creates jobs for the other 96 percent. Even today manufacturing industry is facing a serious workforce shortage: 63% in the *Aerospace and Defense* industry; 45% in the *Energy* sector, and 63% in the *Life Sciences* industry. In total, the National Academies reported a shortage of STEM workers, ones with US college degrees, to be 3 million by the year 2018.

For Thailand to be competitive within ASEAN (AEC), Asia Pacific communities, and globally in the next two decades, it is obvious that increasing STEM workforce is definitely one of the key mandates that the Thai government has to focus on. For our STEM programs and investment to be effective, it is essential that Thailand must first identify its areas/fields of workforce shortage as one of the main goals to overcome by the introduction of any STEM program. While some of these Hi-tech or STEM fields may have yet to be identified, a forward looking projection must be decided now. Among those that might be of interest for Thailand are microelectronics (backbone industry for all other Hi-tech industry), sensor technology, solar cell, advanced materials, aerospace, healthcare, and energy, etc. Once these target technologies and industry have been identified, short-term and long-term programs for future STEM workforce of Thailand can be designed, implemented, and assessed and evaluated.

Apart from the rationale for Thailand's STEM Master Plan, the following specific items should be added.

1. The STEM Master Plan **should describe an overall framework of the plan** starting from important high-level elements: *goals, outcomes, design,* and *implementation* (See more in 2). The framework serves two purposes: 1) for communicating different hierarchy and categories of proposed actions and 2) for creating a roadmap that will help monitoring, and providing self-awareness, assessment and continuous-improvement of the STEM agenda.
2. The Master Plan **should include common categories and vocabularies for each of the STEM elements**. For examples, **the Committee on Integrated STEM Education of the US National Academy of Engineering and National Research Council** suggested the following:

    - **Goals** may include 1) developing STEM workforce, 2) building STEM literacy and competencies, 3) increasing engagement and interests in STEM. Note that the three levels can be addressed as short-term to long-term goals at the level of K-14 education.
    - **Outcomes** refer to student learning and achievement including STEM-related employment, STEM-course taking, and understanding across STEM disciplines.
    - **Design** is concerned with how STEM-specific education should be integrated into current educational system in the most effective ways. This requires understanding of subjects that

are connected, disciplines that are dominant, and appropriate duration, scope and complexity to introduce.

- **Implementation** includes different levels of focuses: 1) instructional methods, e.g., problem-based technique; 2) types of educator supports, e.g., pre-service and in-service professional development, professional learning communities; and 3) learning environments, e.g., team teaching, partnering with other STEM schools.

3. The STEM Master Plan should **clearly define focus areas and the number of workforce** of each STEM professional that Thailand will train under this proposed Master Plan. Most STEM programs in the US are technical area and industry specific, thus for Thailand's STEM programs to be effective, these technical areas and industry, to be focused, must be closely linked to Thailand's future economic plan and direction.
4. The Master Plan for STEM **needs to define a clear set of tangible goals** to be accomplished within a given specific and reasonable timeframe so that evaluation and assessment can be made. The US STEM program has a timeline of 10 years to accomplish its goals and tasks and clearly include the expecting outcome to be fully implemented by the local States governments.
5. The STEM Master Plan of Thailand **needs to include technical (STEM professional content),** and the focused age groups for each of these industry-focused areas, and how these proposed education programs will link to the target industry of interests.
6. As most US STEM programs are being developed and implemented at the States level, namely the State universities and local K-12 schools, it is imperative that **Thailand and the Royal Thai Embassy develop closed collaboration and partnership with the States governments** for STEM programs.
7. **Exchange of STEM ambassadors for mutual interests and learning between Thailand and the US** can be done with successful STEM programs in many States universities and high schools. Each of these programs has its unique teaching approach to teach, train, and prepare their students for their future STEM professionals. Many States' universities and colleges have interesting educational programs to train not only K-12 students, but also teachers for STEM education. Sister STEM High School Program and Partner STEM Education Center are two simple approaches that Thailand can use to learn from the existing US STEM education. To start, Thailand can tap its resources of Thai professional networks (such as ATPAC), whose members are in many State universities to help launch these STEM partnership programs. A list of top STEM high schools (ranked by the US News and Education) in the US is given in Appendix B.
8. The STEM Master Plan of Thailand **needs to clearly include program assessment plan**, technical aspect in particular. This requires the development of evidence-based criteria for identifying effective STEM schools and programs. Since the STEM workforce taught and trained under the proposed plan is aimed to support the STEM industry, assessment of the program should therefore be evaluated totally by representatives of the industry (the users). Please note that most successful STEM programs are industry specific, assessment of each STEM program should therefore be evaluated by professionals and technical people from that particular industry.

Link with High-Tech/Relevant Industries

The quality of STEM education should go beyond the education itself, but need to include the linkage to industries as well. The following are some examples from selected US industries in promoting STEM education.

PhRMA Member Company (Biopharmaceutical)

Innovative biopharmaceutical companies invested over $100 million in STEM education impacting over 1.6 million students and 17,500 teachers across the US since 2008. Eighty-five percent of industry-supported STEM education programs focused on the K-12 levels and are aimed at improving the preparation of both students and teachers. Figure 1 depicts the STEM programs initiated by the 24 PhRMA member companies across the US.

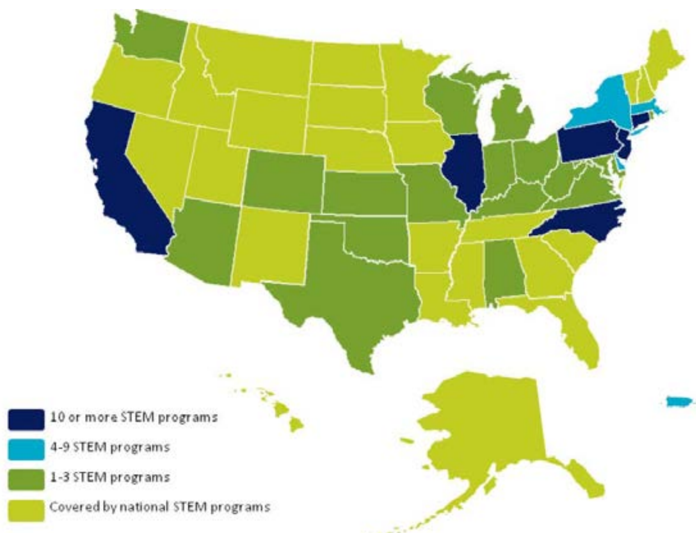

Figure 1: STEM Programs Distribution Supported by the Biopharmaceutical Industry

Their STEM activities to name a few are:

- **The Amgen Biotech Experience** supports scientific discovery for the classroom, a hands-on educational outreach to middle and high school and college students and teachers for more than 20 years through its pioneering Biotech Experience program.
- **Eli Lilly Foundation** supports for the Indiana Science Initiative (I-STEM) with a statewide approach to reforming K-8 science education through a set of inquiry based hands-on science curriculum.
- **GlaxoSmithKline's Science in the Summer** helps children "grow into science" by providing free classes and hands-on experiments at local libraries and other community venues to help foster interest in the sciences among elementary school children.
- **The Merck Institute for Science Education** supports professional development for science educators for the past 20 years providing education, workshops, support coaches, and family science activity nights for partner school districts in New Jersey and Pennsylvania.

- **Bayer Corporation's Making Science Make Sense Program**, an award-winning effort to advance science literacy and inspire student interest in science, Making Science Make Sense (MSMS), was initiated more than 40 years ago. The program leverages more than 1,000 employee volunteers and strategic national and local partnerships to fundamentally change the manner in which science is both taught and learned.
- **Lundbeck's Partnership with Perspectives/IIT Math & Science Academy** partnering with Perspectives/Illinois Institute of Technology Math and Science Academy in Chicago, Illinois, to provide students with access to hands-on experiments in quality laboratories as well as access to Lundbeck employees who volunteer as mentors to the students at the charter school.

Aspire Mentoring Academy (Telecommunication)

AT&T's $350 million investment in teaching science, math skills and its relevance by its employees and third parties to the outside world through online e-mentoring focused on STEM disciplines to high school students with success leading to college and career readiness. The activities include:

- **Junior Achievement**, worldwide job shadow initiative **–** By 2010, the job shadow initiative reached more than 65,000 students in more than 211 cities. AT&T employees have volunteered more than 200,000 hours for Job Shadowing, to help students learn and prepare career options; and what it takes to be successful in today's workforce.
- **Nanodegree Program** through Udacity, students are fully recognized for entry-level jobs at AT&T and up to 100 graduates will be placed in paid internships at AT&T.
- **ConnectED** initiative provides 50,000 students in Title 1 schools, free mobile broadband access for educational devices, mobile device management, network filtering and teacher professional development for three years for each selected schools. The initiative connects 99% of classrooms to enable next-generation digital learning.
- Internship programs through **Genesys Works** to support more opportunities for high school students to experience meaningful year-long internships in businesses across the country.
- **YouthBuild** programs in the US and across the globe, low-income young people learn construction skills to help build affordable housing and other community assets such as community centers and schools.
- **NACME** ensures American competitiveness in a flat world by leading and supporting the national effort to expand US capability through increasing the number of successful African American, American Indian, and Latino women and men in STEM education and careers.
- **Girls Who Code** works to inspire, educate, and equip girls with the computing skills to pursue 21st century opportunities.
- Various sponsoring programs such as 2014 Tesla STEM High School enrichment project in Washington focused on environment issue (ocean acidification in the Puget Sound), 2015 High School's DECA State Conference competition in WA with focus on business minded career, etc.

In summary, there are mutual benefits to promote STEM education through industries and school/university collaborations. For the school, students have the opportunity to see applications of STEM in the real world and the chance to interact with professionals in STEM-related fields. For the company, it laydowns the necessary skills for the 21st century and develop STEM talents into the future workforce. Ultimately, sustainability of STEM education will mostly likely be achieved through capitalizing industry partnership and industry sponsored programs.

Examples of STEM Projects in the US.

In recent years, it has become clear that Thailand suffers from inequality in various aspects including education. Resources, opportunities, and quality of STEM education in rural areas do not measure up to those in urban areas. For example, prominent schools and universities in Thailand are usually in major cities. Both human and physical resources, such as number and quality of teachers/staff and learning facilities, in rural schools tend to be subpar. Limited school funding, low family income, and distance from learning resources result in less opportunities for learning. The quality of STEM education is strongly tied to resources and opportunities. The US has put tremendous resources to ensure that underrepresented groups such as minority, women, and people with disabilities have received adequate opportunities for STEM experiences through extracurricular activities. As a result, there are numerous STEM outreach programs in the US for this purpose. There are several rationales for STEM promotion in the US among underrepresented groups. One is underrepresented groups already are or will be substantial workforce to the country. For example, women make up about 50% of the STEM workforce.

Another weakness in STEM education in Thailand is lack of creativity among K-12 and undergraduate students and teachers due to inadequate and/or prescribed research trainings. Limited opportunities are given to K-12 students and teachers particularly at high school level to engage in cutting-edge research conducted by university faculty. Undergraduate students do not get involved in research until their senior year and unfortunately most of their research projects are prescribed. Minimal learning takes places when students conduct research by following instructions and/or set plans. In the US, independent research is promoted among high school students and teachers, and undergraduate students. Research experiences are offered to undergraduate students at large, not only in their senior year. In addition, research in Thailand is very disciplinary oriented at every level resulting in limited innovative growth and developments. Interdisciplinary science and technology is at an embryonic stage in Thailand. The country cannot be a key player in science and technology without embracing interdisciplinary culture. Interdisciplinary and crosscutting efforts in STEM have been promoted in several sectors in the US including academics, government, and industry along with resource allocations in the last two decades. The efforts and resources led to new fields such as nanotechnology, sustainability, and biomedical engineering and associated innovations. A more recent example is the field of nanobiotechnology which is based on a combination between nanotechnology and biotechnology.

There are STEM focused schools in Thailand but the global vision of goals of these schools is not clear. It is unclear whether these schools cover professional developments including soft skills such as leadership and communication. It seems these schools emphasize on STEM contests (Olympics) and university entrance as outcomes and informal assessment tools. Assessment along with other aspects such as school leadership and parental involvement are examples of key elements for successful STEM schools in the US (examples are listed in Appendix B). Success of the schools is not solely indicated by test data.

This section of the report covers specific examples of STEM projects in the US that can and should be implemented in Thailand. The examples are based on discussion above on what Thailand lacks and needs to enhance its STEM profile and stature. They are grouped in three categories: inequality in STEM education; independent and interdisciplinary research; and promising practices for successful STEM schools.

Inequality in STEM Education

Nurturing American Tribal Undergraduate Research and Education (NATURE). The NATURE program is funded by the National Science Foundation (NSF) and State of North Dakota through the North Dakota Experimental Program to Stimulate Competitive Research. The program is designed to build new and strengthen existing pathways for American Indian students to pursue careers in STEM fields. It is based on a partnership among tribal colleges and research universities in North Dakota. It has several major components including the following examples.

1. *University Summer Camp*, which introduces tribal high school graduates (summer immediately after high school graduation) and college students to STEM disciplines and career opportunities, and provides opportunities for them to experience campus and city life.
2. *Sunday Academy*, which once a month (on a Sunday) gathers high school students, who are presented with practical problems involving simple STEM concepts with the focus on analytical and quantitative thinking processes.
3. *Tribal College Undergraduate Research Mentoring*, which provides a semester long research training for tribal college students who are co-advised by a tribal college faculty and our university faculty.

Note that there are programs similar to NATURE all over the US targeting different minority groups such as **Summer Engineering for Kids (SEEK)** and **South Dakota GEAR UP**.

Independent and Interdisciplinary Research

Independent and interdisciplinary undergraduate research (IIUR). IIUR is one of the main tools used to infuse interdisciplinary culture at early stages particularly undergraduate level. Emphasis has been put on interdisciplinary research in the US but mostly at graduate, postdoctoral, and faculty levels. Interdisciplinary research should also be promoted at undergraduate level in which the students tend to narrowly focus on their own fields. Here is an example of the IIUR at North Dakota State University that was completed several years back. Undergraduate students from different programs such as civil engineering, chemistry, microbiology/biotechnology, and/or polymer/material sciences programs were recruited to participate in a two consecutive semester long IIUR project. Students were given a STEM research topic such as environmental remediation which requires knowledge from disciplines that they were in. They were introduced to research methodology starting from literature search, designing and conducting experiments and presenting findings. They were asked to work independently as a team, come up with their own experimental plan and design, and solve problems on their own. Faculty stepped in only when they faced technical obstacles that could not be solved among themselves. This type of research training helps them develop a thinking process and solving skills for actual problems, two of the notable deficiencies in most undergraduate students. IIUR can also be applied to high school students and teachers.

Undergraduate research in the US normally does not have a requirement on class standing. NSF funded research experiences for undergraduates projects/sites are open to students at all levels from freshmen to senior throughout the country. Attracting students into STEM research requires proactive approaches. Interdisciplinary and independent research can be implemented in high schools and universities with minimal funding. Some research universities in the US have top notch faculty invite high school students that are accepted to their universities via phone call and e-mail to join their research group once the students are on campus.

Promising Practices for Successful STEM Schools

In 2011, NSF has commissioned a study to identify highly successful K-12 schools and programs in STEM. The objectives of this study were to:

- Outline criteria for identifying effective STEM schools and programs; and
- Identify which of those criteria could be addressed with available data and research, and those that required further work.

Measuring the success of STEM can be challenging as several factors can confound the identification of effective STEM schools. Student- and school-level achievement test data are the most widely available measures for accountability purposes but they do not tell the whole story of success. Success by itself can be defined in many ways and can occur in many different types of schools and settings, with many different demographics of students.

Two key aspects of practice that are likely to be found in successful schools are: 1) instruction that captures students' interest and involves them in STEM practices and 2) school conditions that support effective STEM instruction. Key elements that might be able to guide educators and policy makers towards this type of STEM instructions include:

- A coherent set of standards and curriculum – The adoption of common standards and provide an opportunity to focus teacher preparation and professional development opportunities on material that will be pertinent to their work;
- High-capacity teachers to teach in their discipline – In any discipline, effective professional development should focus on developing teachers' capabilities and knowledge, address teachers' classroom work and the problems they encounter, and provide adequate opportunities for teacher learning over time; and
- A supportive system of assessment and accountability – This system must focus not only on student outcomes but also on teacher practices. For instances, to assess the objectives, the Illinois Mathematics and Science Academy include course surveys for every teacher, faculty and staff trained in classroom observations, and external reviewers to evaluate selected departments annually.

Successful STEM instructions require not only qualified teachers but also supporting school cultures and conditions. The elementary schools that improved student learning in mathematics and reading shared five common elements:

- Strategic school leadership;
- Quality of the faculty and staff recruited to the school and the quality of ongoing professional development;
- Strong parent-community ties;
- Student-centered learning climate; and
- Instructional guidance with the emphasis on curriculum organization, the nature of academic demand, and the resources accessible to teachers to advance learning.

Potential Partners in the US.

STEM Policy

At the policy level, at the directive of President Obama, the Federal STEM 5-year Strategic Plan was produced and presented to the Congress on May 2013. The most prominent players in the development of this strategic plan are the Office of Science and Technology Policy (OSTP)--represented by the National Science and Technology Council (NSTC), NSF--represented by Directorate for Education and Human Resources (EHR), the Department of Education (ED) and the Smithsonian Institution. In addition, nine other federal departments/agencies serve as members of the policy and planning committee. These include National Aeronautics and Space Administration (NASA), Department of Agriculture (USDA), Department of Defense (DoD), National Institute of Health (NIH) in the Department of Health and Human Services, Department of Transportation (DoT), Department of Interior (DoI), Department of Homeland Security (DHS); and Environmental Protection Agency (EPA). If Thailand would like to seek assistance and/or partnership at the policy level, OSTP (specifically NSTC), NSF (specifically EHR directorate), and ED would obviously be the most appropriate allies to pursue.

In addition, there is an organization called **STEM Education Coalition**, which is an alliance of more than 500 education, professional and business organizations to represent the widest and most unified voice in advocating for policies to improve STEM education at all levels. The leadership council consists of **National Science Teacher Association** as chair, and 39 business and professional organizations as co-chairs and council members. These include the like of Microsoft, ExxonMobil, **Battelle**, **National Consortium of Secondary STEM Schools**, **National Education Association**, **American Association of Colleges for Teacher Education**, **Education Development Center, Inc.**, and **Hands-on Science Partnership**, to name only a few. Thailand would be well served if she becomes a member of the coalition. One important member of STEM Education Coalition is the **American Association for the Advancement of Science (AAAS)**. AAAS plays a key role in advancing and advocating STEM policies in the US. It could also serve as a useful ally for Thailand with regards to policy formulation. A full list of affiliate members of the coalition which could serve as a valuable resource to seek partnership (both at the policy level and the programs/projects/ activities levels) is given in the **link**.

STEM Programs, Projects and Activities

At the program level, NSF, ED and the Smithsonian have also received mandates and funding (from the Federal STEM Strategic plan) to carry out prominent national STEM programs. They would indeed serve as great resources should Thailand seek their alliance.

The Department of Education plays a principal role in improving P-12 STEM education by fostering partnerships among schools universities, science and technology (S&T) agencies and businesses to innovate teaching and learning. The Department also invests additional $80 million to support the goal of producing 100,000 new STEM teachers, and $35 million to launch a pilot STEM Master Teacher corps and to create new STEM innovation networks to better connect school districts with local, regional and national STEM resources. Finally, ED also collaborates with all agencies in CoSTEM to ensure that Federal assets in S&T are fully utilized in the improvement of P-12 STEM education.

NSF focuses on improving undergraduate STEM education. It invests $123 million to improve retention of undergraduate in STEM fields, and plan to invest another $325 million to expand graduate fellowship programs and to create a new National Graduate Research Fellowship. In so doing, NSF will use a common infrastructure at NSF to reach more students and offer greater opportunities to address national needs and mission-critical workforce needs for CoSTEM agencies. NSF also launches **Successful STEM Education Initiative** which can provide a useful resource to building successful STEM education programs.

The Smithsonian Institution receives $25 million to improve informal STEM education by working with NSF, ED, other CoSTEM agencies (such as NASA, DoI, USDA, NIH and National Oceanic and Atmospheric Administration (NOAA)), and other science partner agencies to harness their unique expertise and resources to deliver evidence-based materials and curricula, and online resources to align to what students are learning in the classroom.

At the project/activity level, there are several STEM education centers at various academic institutions. The most notable is the STEM Program at Virginia Tech (VT-STEM), which is devoted to STEM education at all levels from K-12, undergraduate to post-graduate. Other examples include STEM Education at Ohio State University (Dept. of Teaching and Learning); STEM Center for Outreach, Research and Education at Texas Tech University, Texas; and Leonard Gelfand STEM Center at CWRU (which focuses on K-12 STEM education). There are also many NSF Centers of Excellence in STEM education at various universities Examples include California State University, CA; Citadel, SC; Jackson State University, MS; University of Texas Pan America, TX; Towson University, MD; California Polytechnic State University, CA; Central State University, OH; to name only a few. A more **comprehensive list** of these centers is compiled by Southern Illinois University

If Thailand would like to seek partnership at the project/activity level, the VT-STEM at Virginia Tech (Surot Thangjitham, **surot@vt.edu**), the STEM program at the Ohio State University (Nongnuch Inpanbutr, **Inpanbutr.1@osu.edu**), the STEM center at Texas Tech (Rattikorn Hewett, **rattikorn.hewett@ttu.edu**) and/or the Gelfand STEM center at CWRU (Vira Chankong, **vira@case.edu**) could be a good starting point, since there is an ATPAC member to help coordinate and facilitate at each of the those centers. Other Centers of Excellences in STEM education can certainly provide good opportunities for strong partnerships.

One of the best organizations to collaborate with particularly with respect to non-formal education is the **Tech Museum of Innovation** in San Jose, CA. This is probably the best science museum to inspire the innovator in everyone (mission of the Museum). The best contact person here is Prinda Wanakule (Educational Programs Manager).

It should be aware that the central government (Federal) of the US has no direct control in running education system, but rather, the States have total responsibility on quality assurance of all education, from K-12 to college studies. As such, all STEM programs, currently in place, are under States government, and Thailand should focus on working with the State governments rather than the Federal government except at the national policy level. Every state has an organized STEM program that can be tapped into. Here are some examples: **California STEM Learning Network**; **Indiana STEM Resource Network**; **Maryland Science Center**; **Arkansas STEM Coalition**; **Massachusetts Life Science Center: STEM Education**; **South Carolina S^{2}TEM Center**; to name only a few. A complete list of state-by-state STEM centers, a one-stop-shop for STEM information, can be found at **STEM Connector**.

Roles of the Royal Thai Embassy

The Royal Thai Embassy has important roles to play in advancing STEM education in Thailand. In general, the Embassy is the natural prime mover of Science Diplomacy particularly related to STEM education. In going forward, STEM-related players in Thailand would greatly benefit from collaborations with diverse potential partners in the US. Assistance from the Embassy to fast-track and facilitate leveling pathways to strong and timely partnerships would make such collaborations not only possible but also very fertile and fruitful.

The embassy should take a leadership role in making appropriate “connections” between Thai and US entities. This can be done by providing support, through the Office of Science and Technology (OSTC), to be a leading unit to foster STEM initiatives and coordinate relevant tasks. OSTC should aim to become a STEM resource center for information sharing about needs, opportunities and activities of STEM in Thailand. By instrumenting linkages or organizing “regular” meetings between knowledgeable Thais in both countries, OSTC can “continuously” help the Thai government address certain STEM issues (e.g., from the findings and past experience in the US).

The following is a list of what the Royal Thai Embassy should do specifically to promote STEM education for Thailand.

1. As described in the STEM report that all STEM activities and on-going projects in the US are at the States level, mostly at the State Universities and local K-12 schools, the Royal Thai Embassy should seek collaboration with the State governments for STEM education. While the US foreign policy currently excludes any form of Government-to-Government collaboration between Thailand and the US due to our current irregular political situation, it does not preclude State governments from working with Thailand. Among the States that might be of interests are New York, California, Massachusetts, Washington, Virginia, Maryland, New Jersey, Texas, Ohio, and North Carolina. These are the States that have significantly invested on its education and the STEM education, and has attracted many high tech industries. For this program, the Embassy can solicit assistance from ATPAC members to help develop the proposed collaboration. Most of these States are also home of the top 25 STEM high schools on the US.
2. The Royal Thai Embassy should work with Thai professionals (ATPAC and others) who are currently working with the State Universities and encourage them to submit proposals to various US funding agencies for joint development of STEM education between Thailand and the US universities and local K-12 schools.
3. Exchange of STEM teachers and students between Thailand and the US is another interesting program that the Royal Thai Embassy can promote with focus given to US K-12 and college students of Thai decent. The program can also focus on female students as it is one of the priorities of the US government.
4. As many US industries are involved with STEM education and training, the Royal Thai Embassy can reach out to these US companies that are presently doing business in Thailand to have STEM education and training program for Thai students. For this program the Embassy can solicit participation and partnership from the Thai-American Chambers of Commerce.

5. At present, Thailand has provided funding to (have contracted) Columbia University (Teachers College) in New York and University of North Carolina (Keenan School of Business) to help develop STEM education for Thailand. If there is further funding for STEM from Thailand, these resources may be utilized as matching fund, attracting U.S. entities to co-fund our STEM programs or projects. The program and request for proposal with matching fund should be made public. This form of soliciting proposals can widen opportunities for suitable counterparts in the U.S. The Royal Thai Embassy can help in identifying and coordinating with a co-funding agency in the U.S.
6. Many US universities, in which some of our ATPAC members are presently working, also have STEM programs and closely tie to K-12 schools of that State. Through collaboration between the Royal Thai Embassy and these universities, these ATPAC members can assist the Embassy in extending these STEM programs to Thailand. At present, there are existing STEM education programs at ATPAC members' university such as at Ohio State University, Case Western Reserve University, New Jersey Institute of Technology, University of Washington (in Seattle), Texas Tech University, Virginia Tech., North Dakota State University, University of Arizona, etc.

Appendix A: Lists of Websites

Recommended Items to be Added to Thailand's 5-Year STEM Master Plan

- The Committee on Integrated STEM Education of the US National Academy of Engineering and National Research Council, http://www.nap.edu/catalog/18612/stem-integration-in-k-12-education-status-prospects-and-an

PhRMA Member Company (Biopharmaceutical)

- The Amgen Biotech Experience, https://www.amgenbiotechexperience.com/
- Eli Lilly Foundation, http://www.indianascience.org/
- GlaxoSmithKline's Science in the Summer, http://www.scienceinthesummer.com/
- The Merck Institute for Science Education, http://www.mise.org/
- Bayer Corporation's Making Science Make Sense Program, http://www.bayerus.com/MSMS
- Lundbeck's Partnership with Perspectives/IIT Math & Science Academy, http://www.lundbeck.com/us/our-commitment/communityinvolvement/

Aspire Mentoring Academy (Telecommunication)

- Junior Achievement, http://www.ja.org/
- Nanodegree Program, http://about.att.com/content/csr/home/blog/2014/06/efficient_accessibl.html
- ConnectED, http://about.att.com/content/csr/home/people/at-t-aspire/mobilizing-learning/connected.html
- Genesys Works, http://www.genesysworks.org/
- YouthBuild, https://youthbuild.org/
- NACME, http://www.nacme.org/
- Girls Who Code, http://www.girlswhocode.com/

Inequality in STEM Education

- Nurturing American Tribal Undergraduate Research and Education (NATURE), http://www.ndepscor.nodak.edu/NATURE/
- Summer Engineering for Kids (SEEK), https://www.nsbe.org/Seek/About-SEEK.aspx
- South Dakota GEAR UP, http://sdgearup.org/

STEM Policy

- STEM Education Coalition, http://www.stemedcoalition.org/
- National Science Teacher Association, http://www.nsta.org/
- Battelle, http://www.battelle.org/
- National Consortium of Secondary STEM Schools, http://www.ncsss.org/
- National Education Association, http://www.nea.org/tools/lessons/stem-resources.html
- American Association of Colleges for Teacher Education, http://handsonsciencepartnership.org/
- Education Development Center, Inc., http://www.edc.org/
- Hands-on Science Partnership, http://handsonsciencepartnership.org/

- American Association for the Advancement of Science, http://www.aaas.org
- List of affiliate members of the coalition link, http://www.stemedcoalition.org/wp-content/uploads/2011/01/Affiliate-List-PDF11.pdf

STEM Programs, Projects and Activities

- Successful STEM Education Initiative, http://www.successfulstemeducation.org/
- Comprehensive List of STEM Education Centers, http://batchgeo.com/map/1bf6f8437019436850e9be2b60144a7e
- Tech Museum of Innovation, https://www.thetech.org/
- California STEM Learning Network, http://www.cslnet.org/
- Indiana STEM Resource Network, https://www.istemnetwork.org/
- Maryland Science Center, http://www.mdsci.org/
- Arkansas STEM Coalition, http://arkansasstemcoalition.com/arkansas-stem-centers/
- Massachusetts Life Science Center: STEM Education; South Carolina S2TEM Center, http://www.masslifesciences.com/resources/stem/
- STEM Connector, https://stemconnector.org/state-by-state

Appendix B: Model Programs and List of Schools

Centers for Pre-College Program, a Model for Thailand

To pave a solid foundation for STEM to our future workforce, it is critical to start early, preferably in the elementary level, and continue into their secondary school education, and college. In this knowledge-based global economy, students and teachers must become leaders of learning for the development of content skills, knowledge, and interest in STEM because of the demand for a highly qualified workforce. Center for Pre-College Program, established at New Jersey Institute of Technology 35 years ago and has been playing a crucial role today for STEM education in the State of New Jersey, is a good model that Thailand can use to train teachers to integrate STEM curricula into their teaching as a way for students to apply classroom lessons to real life problems. The core of this program rests on three distinct, yet interrelated, components of teaching and learning:

- Instruction: How should we teach?
- Curriculum: What should we cover?
- Assessment: How should we measure student learning?

To elaborate these three interrelated components, the following provide some of its basic principles:

Instruction:

- Teachers need to base their teaching not on a preset philosophy, or a set of program prescriptions, but on what would best help their students learn,
- Teachers can teach skills, but if students do not have background knowledge, mastery of new knowledge and higher-order thinking might be impossible, and
- Teachers need to teach the skills, but they must teach skills through content.

Curriculum: Educators must not view curriculum development as a static finished product, but rather a continuous, never-ending, and collaborative process, which allows for “continuous program improvement.

Assessment: Most assessment at the K-12 level is summative, i.e. at the end of a chapter or marking period, end-of-course exams, yearly state-wide assessments, etc. Assessment should be formative. Assessment before, during, and after a lesson or series of lessons is necessary to demonstrate whether each student has acquired targeted skills and knowledge. One of the most important tasks that each Center for Pre-College program does is the development and analysis of teachers’ standards-based lesson plans and assessment of student work products. This is to determine whether students attain the skills and knowledge specified by the relevant standards during and after the lesson. Intervention may include regular schedule of workshops during the school year and a summer component to provide teachers with training on identified need areas to support their teaching.

Assessment and Evaluation of STEM Programs

Instruments to measure students' and teachers' attitudes and interests toward STEM, knowledge of careers in engineering, teachers' readiness, and their concerns about implementing innovations (i.e., new curriculum, new instructional practice, etc.) have been developed. Each instrument developed for a specific age group or grade has been found to be reliable and has been used successfully and extensively. For a formative evaluation, classroom visitations are conducted to observe teachers' classroom implementation, with feedback and solutions for unforeseen problems encountered.

These existing programs in some US institutions can assist Thai educators in the successful implementation of the STEM programs for Thailand. It should be noted that there is no formal means of assessing and evaluating all the STEM programs today. Successful STEM high schools in the US, those listed earlier, take into consideration *a combination of AP (Advanced Placement) courses that their students took and passed, and the top colleges that their students got accepted*. All these top STEM high schools believe in the following similar missions:

1. To provide students a challenging learning environment focused on mathematics, science, engineering, and technology;
2. To inspire joy at the prospect of discovery, and to foster a culture of innovation;
3. Critical thinking and problem solving skills are vital in addressing the complex societal and ethical issues of today; and
4. Research stems from a combination of fundamental knowledge, individual creativity and curiosity.

Samples of Early College Preparatory STEM Programs

The following are samples of four-week STEM programs in Science and Technology offered during the summer at some US universities to K-12 students for the introduction of STEM and STEM-related career:

- Woman in Engineering and Technology Initiatives FEMME Program
  - Environmental Engineering -4th Grade
  - Aeronautical Engineering -5th Grade
  - Mechanical Engineering -6th Grade
  - Chemical Engineering -7th Grade
  - Biomedical Engineering -8th Grade
- Environmental Science and Engineering Program (ESEP) -4th Grade
- Explore Careers in Technology and Engineering (ExCITE) -7th Grade
- Medical Robots (MEDIBOTICS) -8th Grade
- Fundamentals of Physical Sciences (FPS) -9th through 11th Grade

Similar programs can be developed at Thai universities for K-12 students as well.

STEM-Focused Schools

Three categories of STEM-focused schools that have the potential to achieve desired STEM education outcome are: selective STEM schools, inclusive STEM schools, and schools with STEM-focused career and technical education (CTE).

Selective STEM Schools: Selective schools are typically high schools that organized around STEM disciplines and have selective admission criteria. There are four types of selective STEM schools: (1) state residential schools, (2) stand-alone schools, (3) schools –within-a-school, and (4) regional centers with half-day courses. There are about 90 selective STEM schools in the US These schools support student learning with expert teachers, advanced curricula, sophisticated laboratory equipment, and apprenticeships with scientists. Examples of these schools include:

- North Carolina School of Science and Mathematics, http://www.ncssm.edu/
- Illinois Mathematics and Science Academy, https://www.imsa.edu/
- Brooklyn Technical High School, http://www.bths.edu/

Inclusive STEM Schools: Inclusive schools emphasize around STEM disciplines but have no selective admissions criteria. These schools intend to serve a broader population while seek to provide similar experiences to those at selective schools. Inclusive STEM schools operate on the premises that math and science competencies can be developed, and that students from underrepresented demographic groups need access to these opportunities. Examples include:

- High Tech High, a set of schools in southern California, http://www.hightech-high.org/
- Manor New Technology High School in Texas, http://mnths.manorisd.net/
- Denver School for Science and Technology in Colorado, http://www.dsstmodel.org/
- Oakcliff Elementary School in Georgia, http://www.oakcliffes.dekalb.k12.ga.us/

Schools and Programs with STEM-Focused Career and Technical Education (CTE): The goal of STEM-focused CTE is to prepare students for STEM-related careers with the broader goal of increasing engagement to prevent students from dropping out of school. STEM-related CTE serves mainly high school students and can take place in regional centers, CTE-focused high schools, programs in comprehensive high schools, and career academies. As an example, the Dozier-Libbey Medical High School (https://dlmhs-antioch-ca.schoolloop.com/) in California provides a 4-year program that prepares students for health-related careers with strong emphasis on mathematics and science.

The top five STEM high schools in the US as ranked by the US News and Education are:

1. High Technology High School in Lincroft, New Jersey (STEM index 98.3, http://www.hths.mcvsd.org/),
2. Thomas Jefferson High School in Science and Technology in Alexandria, Virginia (96.9, https://www.tjhsst.edu/),
3. BASIS School in Scottsdale, Arizona (96.3, http://basisscottsdale.org/),
4. Middlesex County Academy for Science, Mathematics and Engineering Technologies in Edison, New Jersey (92.3, http://www.mcvts.net/edison), and
5. Whitney High School in Cerritos, California (90.7, http://www.edline.net/pages/whitneyhs).

These high schools generally have a low faculty to student ratio. For the case of the High Technology High School in Lincroft, NJ, total student enrollment is 280 with 22 faculty members, thus having a 13:1 for faculty to student ratio. The Thomas Jefferson High School in Virginia, known in short as TJ, is also known for its STEM program. Majority of its graduates are accepted into top ten colleges of the US. One-thirds of its faculty members have Ph.D. These are some of the unique features of these outstanding STEM high schools of the country.

To create a quality STEM program in our K-12 education, Thailand can learn from successful US STEM high schools as listed above. It is suggested that we create a US-Thailand Sister High School Program in STEM. The program should include exchange of faculty members and students, joint curriculum development, exchange of summer internship with both US and Thai industry, and jointly develop standards and assessment programs for STEM education. As AEC is due to start at the end of 2015, the Sister STEM High Schools Program can also be developed as a multi-lateral program, including other countries in AEC.

Appendix C: STEM in Relation to Smart Cities

The IESE Business School, the graduate business school of the University of Navarra in Spain, **ranked smart cities** (http://www.iese.edu/research/pdfs/ST-0366-E.pdf) from 148 cities based on 10 different dimensions, including governance, public management, urban planning, technology, the environment, international outreach, social cohesion, mobility and transportation, human capital and the economy as follows:

1. London
2. New York City
3. Seoul
4. Paris
5. Amsterdam
6. Vienna
7. Tokyo
8. Geneva
9. Singapore
10. Munich

…

84. Bangkok

…

148. Calcutta

The description of the ten gauging dimensions and key to determining opportunities are:

1. ***Governance***: The citizen is the point of contact for solving the challenges facing cities. Significant factors include the level of citizen participation and the ability of authorities to engage business leaders and local agents. Auckland is the top city in this area.
2. ***Public Management***: The actions to improve the city administration's efficiency, including the design of new organizational and management models, are considered. Tokyo is the best in this area.
3. ***Urban Planning***: To improve the livability of any territory and to commit to smart growth, local master plans and the design of green areas and public spaces are taken into account. New methods of urban planning should focus on creating compact, well-connected cities with accessible public services. Berlin is the top ranked city for its planning.
4. ***Technology***: Technological development enables cities to be sustainable over time, expand the competitive advantages of their production system and improve the quality of employment. London ranks first.
5. ***The Environment***: It is imperative to improve environmental sustainability by supporting green buildings and alternative energy, efficient water management, and policies to help counter the effects of climate change. Zurich, Geneva and Basel are the greenest cities.
6. ***International Outreach***: Cities that want to progress must achieve a prominent position on the world stage. Expanding a city's international outreach involves improving its brand by means of

strategic tourism plans, attracting foreign investment and stepping up its presence abroad. London ranks first once again.

7. ***Social Cohesion***: Concern for the social environment requires an analysis of immigration, community development, care for the elderly, inequality, health system efficiency, public safety and more. Eindhoven is the most socially cohesive city.
8. ***Mobility and Transportation***: Getting around cities, which are often large, and facilitating access to public services are great challenges for the future. Berlin is in the lead.
9. ***Human Capital***: The main goal of any city should be to improve its human capital. This means that it should be able to attract and retain talent, create plans to improve education, and boost creativity and research. Tokyo ranks first.
10. ***The Economy***: To promote a city's economic development, this area includes strategic industrial plans, initiatives to spur innovation and entrepreneurship and more. New York is the economic capital.

In 2014, London is the smartest city while Calcutta is the least smart city. Bangkok is ranked number 84 while our neighbors such as Seoul, Tokyo, Singapore and Hong Kong are among the top noted smartest cities. Singapore moved up from 18th place in 2013 to 9th place in 2014 and and Hong Kong from 32nd place in 2013 to 17th place in 2014 largely due to improvement in the Human Capital, Environment, Mobility & Transport and Technology.

Figure A1 illustrates a quick interpretation and a guide to compare some cities' profiles of different index dimensions. The top ten cities have key dimensions spread out in scales. Bangkok and Singapore seem to have similar graphical analysis origins, but Bangkok is limited in a couple of key dimensions.

The government buzzing interests over "smart cities" can then be associated to STEM. For Thailand in particular, the human capital factor where the proportion of population is highly correlated to the levels of education and how to retain talent pools and boost creativity and research MUST significantly be improved. Technological development enabled cities is also another important factor related to STEM; and to be sustainable over time. Additionally, for non-STEM related factor also points to the public management dimension where city's or country's public finance and its administration's efficiency affect citizen's standard of living and city sustainability.

For Thailand to become evolved in smart city technology, it must consider meeting these top criteria:

1. Adoption of connected applications from efficiently allocate parking spots to efficiently street lighting to proactively collect garbage when the bin is full to public transportation systems integrated with real-time monitoring traffic and weather data.
2. A right political will/structure where a city is not made up of different networks. Some system pairings make sense such as public transportation with traffic management system, city security camera with public safety response centers, etc. thus the goal is to engage in centralized management systems/platform. It is important for city's structure to break out of the "silos" between different departments in municipalities and embrace these interrelationships.
3. An open standard on centralized platform that provide appropriate analytics and tools that make the city a better place to live. Examples are studying automobile accidents to improve roads so that that they are safer for pedestrians, or the use of usage data to improve energy grids, or improve sanitation and increase safety for citizens. Cisco, IBM, Ericsson and Jasper are among the companies that are developing these standard platforms

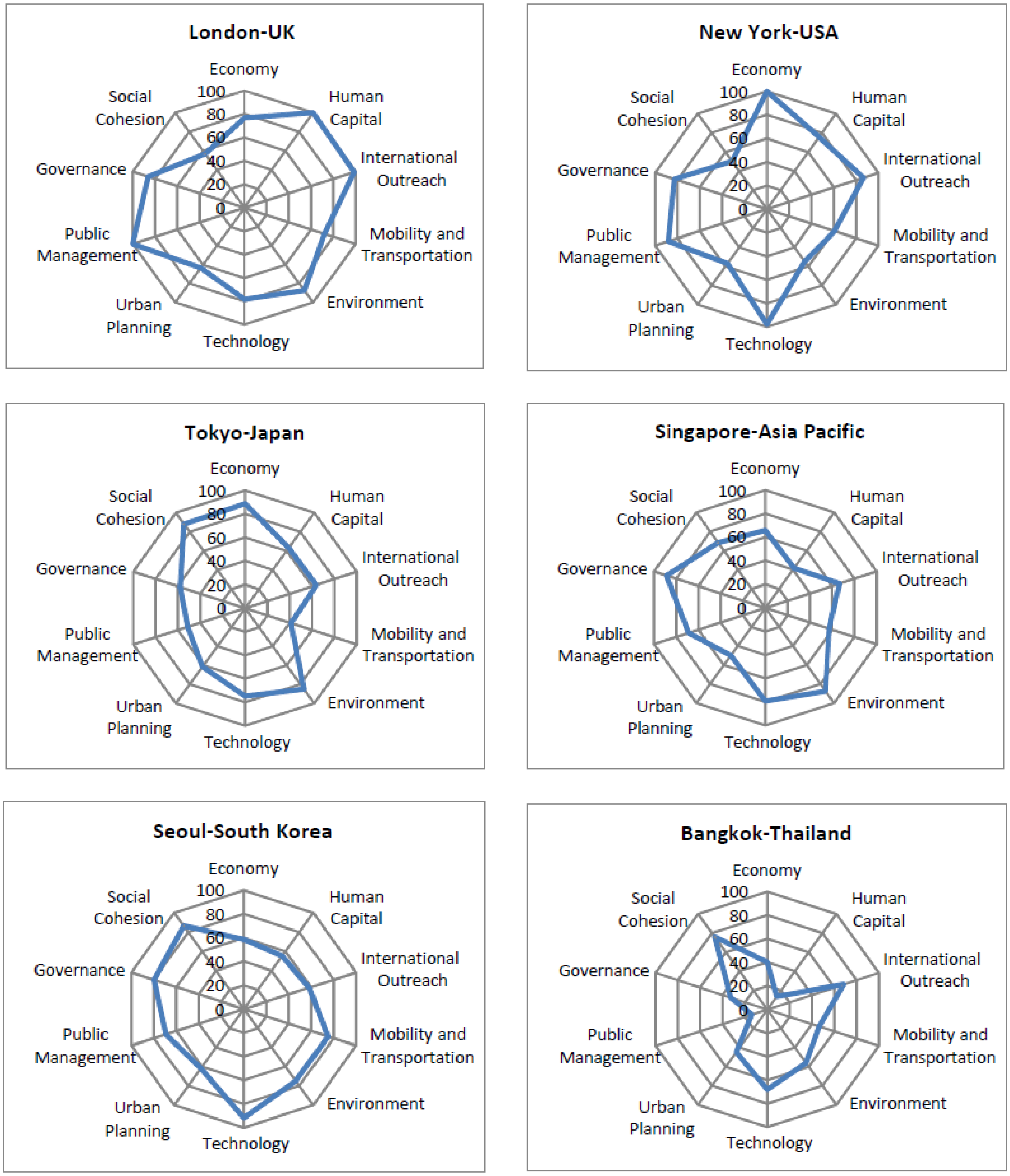

Figure A1: Cities in Motion Index Profiles Examples

In summary, accelerating STEM education can help improve the lack of human capital and technology index dimensions. For city of Bangkok, an increase in the synthetic index by a few notches (from 20 to 40 in human capital or 65 to 85 in technology) could put the city in a better position to compete and sustain the technological advancement of Internet of Things (IoT) such as that of smart cities.

Appendix D: Contributors

This project report will not be made possible without contributions from various individuals as listed below:

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