香港教育大學
The Education University of Hong Kong

CELT Newsletter

Third Issue November 2018

The Theme of the Current Issue:

STEM EDUCATION

Feature Articles

- STEM Education: From the Perspective of a Singaporean STEM Educator
- Promoting and Practising STEM Education in Mathematics Lessons
- What Type of STEM Education Do Hong Kong Students Need?

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Centre for Excellence in Learning and Teaching
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Myths of STEM Education

Dr Ko Po Yuk
Director of Centre for Excellence in Learning and Teaching

Since the Hong Kong Government has promoted STEM education and encouraged schools to strengthen their curriculum and learning activities in Science, Technology, Engineering and Mathematics in its 2015 and 2016 Policy Addresses, STEM has become a key development project for many primary and secondary schools. In the past two to three years, the activities related to "STEM" have been overwhelming: teachers have devoted their efforts to designing or updating the curriculum of related subjects; different non-government organisations have provided STEM courses for nurturing not only teachers and students in schools but also the parents; colleges and universities hold various STEM courses and seminars; even tutorial centres and shopping malls are attracting people with the theme STEM! What is STEM? Why is it so important? As relevant development of STEM will be discussed in other sections of this newsletter, I would rather share with you the myths of STEM education that school teachers may have through my daily contact with them.

During my daily contact with teachers, I often hear them say that one of the difficulties in implementing STEM is that STEM covers the four disciplines of Science, Technology, Engineering and Mathematics. Quite a number of teachers and principals often think that the more subject areas are covered, the more "STEM" they become and the greater benefits will students have. In that way, does it really mean that STEM must be done in an interdisciplinary or project learning format? This is certainly not the case. Whether the curriculum design is appropriate and whether the lesson is effective should not be solely measured by the number of disciplines covered. The Report on Promotion of STEM education: Unleashing potential in innovation issued in 2016 by the Education Bureau states that the main goals of promoting STEM education include "developing a solid knowledge base among students and enhancing their interest in Science, Technology and Mathematics; strengthening their ability to integrate and apply knowledge and skills; nurturing their creativity, collaboration and problem-solving skills; and developing talents or experts in STEM-related areas to foster the development of Hong Kong." It can be seen that the focus of effective STEM curriculum and lessons still remains on the proper connection of relevant knowledge, skills, and attitudes. When designing a course or a lesson, teachers can make use of the contexts related to students' daily life experience, which allows students to learn relevant subject knowledge through different learning activities, and then apply relevant knowledge either to explain the phenomena seen in their daily life or solve problems. It would be challenging for students to get through the problem-solving process alone. They need to collaborate with others to unleash their creativity through "brainstorming" stage and "hands-on" experience. It is true that the use of an interdisciplinary model or a project-based learning model has more possibilities to integrate the four subject disciplines of

STEM, and even expand it into STEAM. However, other than the two proposed models, i.e. integrating relevant elements of other key learning areas apart from the learning activities based on one key learning area and integrating relevant learning elements in other areas of study through projects, the Education Bureau has also recommended that schools can adopt other appropriate models according to their different school contexts, students' interests and abilities, as well as the teacher's expertise. Even if the lesson is based on one single domain, it can still be very "STEM". Take the subject of General Studies in Primary School as an example. There are many topics related to Science and Technology in the curriculum, or related to relevant knowledge of daily life Mathematical concepts and mechanics having STEM-related elements. The content of the subject offer opportunities for students to observe, to design an experiment, to record the results, and to interpret the results through "hands-on" and "brains-on" learning processes. However, many frontline teachers said that when teaching science and other related topics, little chances are given to students on doing hands-on experiments in the classroom. Most of the experiments are still demonstrated by teachers. Or more often, students watch video clips provided by publishers. Students simply "observe" the experiments, rather than doing hands-on experiments. This limits students' opportunities for deep learning as well as fail to enhance their various STEM-related generic skills including adaptability, complex communication, non-routine problem solving, self-management, social skills and systems thinking (Bybee, 2010). Even if students have the chance of doing experiments, students can rarely have time to explain their findings in details, ask questions or have more discussion on the topics they are interested in due to the constraint of class time. Facing the situation mentioned, teachers should focus on increasing opportunities for students to do experiments in class, explain the phenomenon they see in their daily life, and trigger their curiosity about things happening around them so as to motivate them to apply knowledge to solve problems they encounter. If the students are competent enough coupled with the support of the school hardware, students could be allowed to propose solutions to the problem, and even transfer their ideas into finished products. Such teaching content will naturally require students to integrate the knowledge and skills of different subject disciplines to actualise the spirit of STEM.

I happened to read a news article related to STEM when I was writing this article. A young Singaporean inventor developed a series of kitchen utensils to help the blind cook in order to reduce their chances of being injured while cooking. The utensils he developed are not high-tech products, but have embedded many scientific concepts. For example, a water level indicator that prevents blind people from being scalded when pouring hot water or soup is a simple tool that has applied the principle of liquid buoyancy; another utensil that prevents blind people from cutting their fingers when cutting things with a knife is also a simple tool that uses the principle of leverage. The Singaporean young inventor said in an interview that he hopes the products he develops will be affordable to ordinary people, so he has abandoned the use of high technology to reduce the cost. The news reminds me that an important goal of education is to nurture care for humans in students and equip them with the knowledge and skills so that they could apply them to improve human life in the future. It is also the ultimate goal of STEM. Cultivating students' values and attitudes is precisely one of the most important functions of school education. Such temperament could not be systematically and completely nurtured by the training courses and activities offered by the commercial organisations in the market.

The winner of the Mathematical Science Award of the Shaw Prize 2018 is Professor Luis A Caffarelli. When asked about his views on STEM, he said that it is necessary to start with the school curriculum and the teaching content has to be closely related to the daily life of students in order to arouse their interest in STEM. Teachers are required to have the competence in making their teaching interesting and by making learning relevant to students so as to motivate them (Sing Tao Daily, October 3, 2018). I agree to Caffarelli's point because no matter which model the school uses to promote STEM, the content of the course and the teaching activities should be student-centered so that students can understand what they are learning and why they should learn. This kind of learning which is meaningful to students will arouse their interest in learning and they will be able to apply what they have learnt in the future. At the same time, teachers need to have the ability to reflect, and always review the content of the course and the relevance of the teaching activities. Science and technology are changing rapidly and so are the future STEM-related courses which will have to be revised and updated from time to time. Therefore, the establishment of professional communities that promote collaboration and communication among teachers is getting more and more significant. Capabilities of experts of one domain may be limited, but if we combine the expertise of different practitioners to optimise innovation, the effect will be more fruitful.

To meet the professional development needs of frontline teachers in STEM, the Centre for Excellence in Learning and Teaching has actively organised STEM-related professional development activities for teachers in the past year. One of the supporting themes of the "Support Programme on fostering Communities of Practice to enhance Small Class Teaching" commissioned by the Education Bureau was STEM Education. Our team worked with frontline teachers in a Learning Circle mode to develop a STEM lesson or module that aligns with the needs of individual schools. Our subject-based and classroom-based support model helps teachers develop effective lessons that can realise the rationale of STEM education. In the symposium "Teaching Excellence: Embracing innovation and tradition cum Featured Case Studies Sharing Session" held in mid-June, we invited Dr Teo Tang Wee, an Assistant Professor of the National Institute of Education, Nanyang Technological University, Singapore to be one of the keynote speakers, an expert of STEM education, to share her experience in Singapore with the local practitioners. The theme of this issue of the newsletter is "STEM Education". The articles include the observations and experiences of Dr Teo Tang Wee as a promoter and practitioner of STEM education, as well as the experiences and insight gained during the process of designing and implementing STEM lessons in the subjects of Mathematics and General Studies through the collaboration of frontline teachers and tutors of the Centre. There are cases from one subject discipline with STEM elements strengthened. There are also examples of integrating different subject disciplines in other cases. Whether STEM education can exert its maximum effectiveness depends very much on teachers' attempts in experimenting teaching innovations and constant reflection on the experience gained from practice. It is hoped that this newsletter will lead the education sector to further explore the possibilities of STEM education so as to respond to the challenges of different teaching innovations with confidence and professional knowledge.

Remark: The original article written in Chinese was first published in the CELT Newsletter Third Issue November 2018 (Chinese version)

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WALS International Conference 2018

WALS International Conference 2018 with the theme *"Lesson Study and Teacher Education: International Dialogue"* organised by the World Association of Lesson Studies was held in Beijing Normal University, China, from 23-26 November 2018. Over a thousand scholars and academics from 36 places presented their research studies in the format of Oral Paper Presentation, Poster Presentation, Symposiums, and Plenary Sessions.

Dr Ko Po Yuk, Director of Centre for Excellence of Learning and Teaching (CELT), with a team of seven of her colleagues and three secondary teachers conducted two symposiums entitled *"Learning Study in Hong Kong: Its salient features, development, and way forward"* and *"Establishing a Community of Practice: Experiences from Hong Kong Learning Study"*. A total of nine papers of both Learning Study and Lesson Study covering the topics of university-school partnership, inter-school professional learning communities, interdisciplinary lesson study in self-regulated learning, and integrating STEM in special education were presented. Apart from presenting papers, the colleagues of CELT had visited schools and observed lessons at kindergarten, primary and secondary sectors. The event has provided an opportunity for international dialogues and fostered wider networking among practitioners in Asia, Europe, UK and USA.

Teaching Excellence Forum 2018

Centre for Excellence in Learning and Teaching (CELT) and Chief Executive's Award for Teaching Excellence Teachers' Association jointly organised the first "Teaching Excellence Forum" on 27 January 2018. The Forum provided a platform for Principals, teachers and educators to share experiences in achieving excellence in teaching as well as views on developing outstanding teams.

With the theme of Establishing Schools of Teaching and Learning Excellence, the Forum attracted more than 200 principals and teacher participants. Dr Ko Po Yuk, Director of CELT, delivered a keynote speech. It was followed by a showcase for schools' achievements in excellent teaching and learning led by four awardees of the Chief Executive's Award for Teaching Excellence from four aspects – uniting excellent teachers, disseminating good practices, developing outstanding teams, and establishing schools of excellence. The four speakers were Mr Nam Ching Sze (Principal) of The Methodist Church HK Wesley College, Ms Cheng Lai Kuen (Vice Principal) of F.D.B.W.A. Chow Chin Yau School, Ms Wan Ngai Ting (Panel Chairperson) of Tak Sun School, and Ms Tse Siu Wah (Panel Chairperson) of Jockey Club Ti-I College. In the closing session, Professor Chiu Chi Shing, Co-Director (Development) of CELT, hosted an open forum and panel discussion. Three primary and secondary school Principals (namely Dr Tsang Wing Hong of Chiu Chow Association Secondary School, Dr Chu Kai Wing of CCC Heep Woh College, Ms Sit Fung Ming Joyce of Baptist (STW) Lui Ming Choi Primary School) were invited to share their views on establishing school of excellence, and the participants had a lively discussion about ways to achieve teaching and learning excellence in Hong Kong. The forum demonstrated that CELT is committed to inspiring more teachers and schools to pursue excellence in teaching and learning.

Symposium on "Teaching Excellence: Embracing Innovation and Tradition" cum Featured Case Studies Sharing Session

The Centre for Excellence in Learning and Teaching (CELT) organised a symposium entitled "*Teaching Excellence : Embracing innovation and tradition*" *cum Featured Case Studies Sharing Session* on 16 June 2018. The event was kicked off by the Professor Tsui Kwok Tung, Associate Dean (Quality Assurance and Enhancement) of Faculty of Education and Human Development, followed by the word of encouragement from Dr Lau Hung-cheong, Senior Education Officer of the Education Bureau.

In the morning session, Dr Teo Tang Wee, an Assistant Professor of the National Institute of Education, Nanyang Technological University, Singapore, and Dr Chang Huei Cheng, Taipei Municipal Zhongshan Girls High School, Taiwan, were invited to be the keynote speakers, sharing their experience on STEM education in Singapore, and a new approach of "Share Start" and Flipped education in Taiwan respectively.

In the afternoon session, there were featured case studies sharing session and two parallel workshops. The seven parallel sharing sessions covered the themes of "STEM education", "e-Learning" and "self-regulated learning" in teaching Chinese Language, English Language, Mathematics, General Studies, and Humanities subjects. Teachers from more than twenty schools shared their experiences of the one-year collaboration with teachers of cluster schools and school-university partnership in achieving excellence in teaching. The two workshops "*A STEM curriculum framework to guide design and implementation*" and "*Practical ways of implementing Share Start*" which followed were conducted by the two keynote speakers, Dr, Teo and Dr Chang. The parallel sharing sessions and workshops had provided a platform for teachers and educators to exchange ideas of both education innovation and tradition.

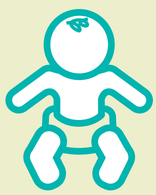
The whole-day event had attracted approximately 500 participants, including government officials, educators, principals and teacher participants, from Hong Kong and Macau. It is hoped that the event will inspire more teachers and schools to continue their effort in pursuing excellence in teaching and learning.

STEM Education:
From the Perspective of a Singaporean STEM Educator

Dr Teo Tang Wee
Associate Professor, National Institute of Education,
Nanyang Technological University, Singapore

My relationship with STEM (Science, Technology, Engineering and Mathematics) dates back to 2006 when I joined the first STEM school in Singapore as a chemistry teacher. At that time, the word "STEM" was never heard of in Singapore. However, the school was modelled after a STEM high school in the United States to offer specialised and advanced mathematics and science curriculum for students identified to be gifted or highly talented in these disciplines. The vignette below was a recount of a Grade 8 Integrated Science lesson which I taught in the Singapore STEM school. The theme of the course, which lasted for one semester, was "Materials" so I brought in a diaper to set the context for teaching about polymers and chemical bonding. This was my early attempt at teaching a STEM curriculum.

After a stint of 18 months of teaching at the STEM school, I pursued my doctorate studies in the United States. I chanced upon an opportunity to conduct a case study of a STEM school chemistry teacher who attempted to do inquiry-based curriculum reform. I shadowed the chemistry teacher for 18 months in this school and even stayed at the student dormitory to learn about STEM school students' learning in the residential STEM school. After I returned to Singapore to begin my academic career at the National Institute of Education, I was involved as a co-Principal Investigator on a research project that supported teachers at the second STEM school to adopt Investigative Case-based Learning approaches in designing and enacting science lessons. Having an interest in feminist science work, I offered an undergraduate elective course on Gender Issues in Science, Engineering, and Technology for two



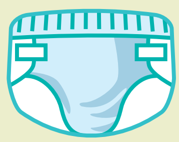
Teacher: Predict how many beakers of water would this baby diaper be able to hold?

Student 1: One!

Student 2: 20!

Student 3: 5!

Students(in chorus): 100!



Teacher: Let's test this out. [The teacher filled several beakers of water and poured them on the baby diaper. Gradually, the diaper swelled up and overflowed after about 20 beakers of water.]

Students: Wow! Amazing.

Teacher: What is "holding" the water? Can you reverse the process and reuse the diaper?

semesters. In 2014, my co-edited Special Issue on Critical Issues in STEM Schools was published in the journal Theory Into Practice. This special issue featured articles that offer critical analyses of STEM schools around the world, including Singapore, the United States, Australia, South Korea, and the Philippines. Specially, it discussed the tensions and challenges in being a STEM school teacher and STEM curriculum making, and issues of racial and gender discrimination for STEM school teachers who are minority, and equity issues. More recently, my Masters student had completed a study about the tensions and challenges international students confront as non- native English speakers learning science in an English-speaking context. I have also designed and validated a survey that measured changes in students' views while participating in a STEM camp designed by a large international non-profit organisation that is mandated to promote more women in science in Singapore. The constructs measured include students' views about participating in the STEM camp, attitudes toward STEM, self-concept in learning STEM, construction of STEM-identity, and their STEM career decisions.

My Observations of STEM Schools

Having taught and researched about STEM schools in the U.S. and Singapore, I have made a few common observations about STEM school curriculum, teachers and students that are catered to the gifted and/or talented students.

1 There is some form of STEM integration somewhere in the curriculum

Contrary to what most people would expect of a STEM school, the curriculum is not fully integrated. There are courses which are more integrated in nature. For example, in the U.S. STEM school where I did my doctorate research study, there is an integrated science course called Methods of Scientific Inquiry. This course is a first-year course that is compulsory for all students (aged 16). However, when the students choose their majors in the second and third year, the science courses are taught separately as Physics, Chemistry and Biology.

At the STEM school where I used to teach, there was an integrated science course for Grade 7-8 (aged 13-14) students. However, it did not explicitly integrate technology, engineering, or mathematics with the sciences.

2 STEM students have the opportunity to perform authentic independent research projects

While the regular classroom curriculum is not necessary STEM integrated, students get a lot of opportunities to participate in independent research projects under the mentorship of their teachers who are highly qualified with a graduate degree (Masters or PhD) or experts in external agencies such as national or university research laboratories. In the U.S. and Singapore STEM school where I did my research or taught, students could work with real scientists in the laboratories to learn how it is to perform experiments, publish and present their work. These are invaluable experiences afforded to STEM school students which may not be as accessible to other students.

3 STEM school teachers have strong subject matter knowledge

Surprisingly, the U.S. STEM school had about 50-percent of teachers with a doctorate degree and 100-percent of them with a Master's degree. It is perhaps advantageous to have a strong subject matter knowledge in integrating the subject with other disciplines as integration requires teachers to have a deep understanding of the content and concepts in order to see the patterns, trends, and connections.

At this point, I am sure some teachers may wonder if they can actually do a good job in STEM teaching without a PhD or Master's degree in STEM? My response is certainly! A STEM degree or graduate degree programme is new and only a handful of universities in the world offers it. This means that few teachers in the world is truly trained to design, plan and teach a STEM curriculum. But this does not stop some really good teachers I have seen and worked with to teach STEM. Personally, I have had the privilege of knowing and working with a few primary school teachers in Singapore who are teaching STEM lessons. One of them has a degree in business. Every year, he sets a personal goal to try a different project to teach in innovative ways. He has adopted flipped teaching, augmented reality, robotics, and role-playing games in teaching his STEM and science lessons to interest and motivate his science students. To describe a specific example, he taught his students how to use WeDo 2.0 to build and programme a robot to travel exactly 2 metres. In the process, students learned about simple coding, perform simple mathematical calculations to make sure that the robot travelled exactly two metres, made predictions and approximations. They learnd about experimental design in choosing the best combination of motor power and duration to give the desired distance. Finally, the students evaluated their group performance. In this simple case example, one can see the applications of STEM from an integrated lens. In the process of designing and enacting such a lesson, this teacher has mutually benefitted from trialling and troubleshooting. His STEM professional wisdom developed with the students' participation in STEM.

The journey to STEM education for an educator is not quite the same for everyone. Some teachers teach in a STEM school for exceptionally bright and motivated learners, of which many of them may move on to become producers of STEM knowledge and innovations. In other cases, they could be teaching students who will become consumers of STEM knowledge and innovations in their bid to make informed decisions that benefit themselves, their families, and the community they live in; that is STEM-literate citizens. We can contribute to the STEM education of our future generations in different ways.

Promoting and Practicing STEM Education in Mathematics Lessons

Dr Law Huk Yuen

Guest Lecturer of CELT

In line with the promotion of STEM education in Hong Kong and the further development of students' advantage in Mathematics, the updated and revised Mathematics curriculum will be implemented in Key Stage One (i.e. Primary One to Primary Three) in the academic year of 2019-20 starting from Primary One. STEM Education encompasses the development of students' knowledge and skills in different disciplines of integrated and applied Science, Technology, Engineering, and Mathematics. However, adding STEM elements to the tight curriculum framework will undoubtedly bring many challenges to teachers of Mathematics. Perhaps what make the teachers feel confused are the types of STEM elements to be included and how to integrate them into a Mathematics lesson.

On June 16, 2018, I was invited by The Education University of Hong Kong to host a case-sharing session on Mathematics for the "Support Programme on Fostering Community of Practice to enhance Small Class Teaching". On that day, Mathematics teachers from three primary schools including Po Leung Kuk Tin Ka Ping Millennium Primary School, Lam Tin Methodist Primary School, and Yuen Long Government Primary School shared their teaching experience of a research lesson on calculating "surface area" conducted at Primary 4 using the "School Parking Lot", "Wind turbine", and "Real estate" as topics for investigation respectively. Since I participated in the support programme of Po Leung Kuk Tin Ka Ping Millennium Primary School in the past year, I would like to share some ideas on how to practice STEM education in the Mathematics lessons through my observation and experience working with the school teachers.

Integrating STEM elements into Mathematics lessons is not only a new attempt, but also a new challenge even for experienced teachers. In order to make it easier for everyone to understand the subtle changes in perception that the teachers had experienced through participating in the new attempt, I have divided the process experienced into three stages:

Stage 1: Pre-lesson Enquiry

▲ The teacher used the school parking lot as an example for enquiry.

The expressions from the eyes of the participants during the first co-planning are unforgettable. Their eyes clearly indicated how confused they were about integrating STEM elements into a Mathematics lesson. As a new attempt, their confusion was understandable. Even so, I did not consider the meeting as a venue for lectures.

During the meeting, I tried to adopt the concept of an action research to encourage and guide the teachers to explore the relevant elements of STEM education in the Mathematics lesson, which include hands-on activities, capacity for open-ended classroom discussions, and designing extended tasks (in the form of project work). In addition to these, I particularly emphasised that the design concept of the teaching topic should be based on and developed from students' daily life (including school life) experience. Otherwise, it will greatly reduce the students' desire to participate in the discussions and their interest in collaborative learning. The outcome of the co-planning meeting was to take the parking situation in the school parking lot as the selected topic for investigation. Students would be requested to use the school basketball court as a blueprint for the new parking lot and to design a new plan that could park the appropriate number of private cars and school buses.

Stage 2: Classroom Practice

▲ Students discuss how to make full use of the space to park vehicles.

The teaching design of the topic covers a double lesson. Due to the time constraint, I was only able to observe the second lesson. From the teacher, I had learned that in the first lesson, students had watched a self- learning video to revise the dissecting method and the filling method through using different combinations of rectangles with various areas. They then discussed how to design a different parking mode for the new parking lot on iClass, an e-learning platform. The second lesson started with group discussion about the design of the new parking lot. After discussion, the student representatives from each group reported their design and explained the rationale of the design to the whole class. The presentation showed that some groups used the filling method to fill up all the parking space with vehicles, while other groups created space for the driving lane in the new parking lot.

Not only the performance and the active participation of the students in the class discussion impressed me, but also the fact that they could further explore some hypothetical issues behind the design under the guidance of the teacher (for example, the adjustment of the relative number of school bus and private car parking spaces due to the changes in the number of students and teachers). After the lessons, students were given the opportunity to turn the outcome of their discussion (i.e., their designs of a new parking lot) into a model.

Stage 3: Post-lesson Reflection

In the post-lesson conference, the teachers actively proposed different ideas that could further improve the lesson design. But for me, the most important part of the post-lesson conference itself is not only limited to the improvement of the teaching plans and pedagogy, but the changes of the teachers themselves through the process of planning and implementation. I had felt the changes during the sharing and reflection of the teachers during the post-lesson conference. In the sharing session held on June 16th, I had noticed one of highlights of their reflection on one of the PowerPoint slides, "In the process of promoting STEM education, both students and teachers should be bold enough to make new attempts, not to be afraid of making mistakes or encountering failure (embarrassment). That is the way how we step out of our comfort zone to embrace teaching innovations.”

Conclusion

The teaching elements of STEM education should include inspiration (based on the students’ experience), improvement (continuous attempts to revise the original design in an innovative way), integration (through the reorganisation of ideas and integration of relevant knowledge across different subject disciplines) and inquiry (encouraging students to try out different attempts through experiments). In short, we can summarise the concept of lesson design of STEM education into "4Is", i.e. “Inspire”, “Improve”, “Integrate”, and “Inquire”.

The integration of STEM in the subject of Mathematics is both a challenge and an opportunity. The challenge is as a new attempt, teachers need to rethink the position of STEM itself in Mathematics education in a professional and open manner on the one hand, and they will require appropriate and relevant support on the other hand. The opportunity is that adding STEM elements in Mathematics lessons will further enhance teachers’ awareness to create a more meaningful ecology of learning for students and provide more dialogic space in class so as to nurture and develop innovative ideas from imagination and life experience. The experience of Tin Ka Ping Millennium Primary School is a good example for providing us with a direction to further reflect on our instructional design.

Remark: The original article written in Chinese was first published in the CELT Newsletter Third Issue November 2018 (Chinese version)

What Type of STEM Education Do Hong Kong Students Need?

Dr Chan Hok On, Angus
Guest Lecturer of CELT

To many people in Hong Kong, the word, "STEM" is a new item that was firstly introduced in the Hong Kong Government Policy Address 2015. However, early in the US-Soviet space rivalry in the 1950s and 1960s, the Western education sector had already raised the concern that it was necessary to strengthen the emphasis on the subjects of Science, Technology, Engineering, and Mathematics so as not to fall behind. Until the 1990s, the National Science Foundation first integrated related mathematics and science subjects and named it as "SMET", which is later reorganised in 2001 as "STEM" today (US Department of Education, 2013; Bybee, Rodger Sep, 2010).

Hong Kong's initiative in promotion of STEM education

The Policy Address in October 2015 proposed to strengthen Science, Technology, Engineering, and Mathematics (STEM) education in primary and secondary schools. Followed by the Education Bureau announcement in December 2016, the report "Promotion of STEM Education – Unleashing Potential in Innovation" has listed the following six final recommendations about STEM education in primary and secondary schools after the Education Bureau conducted consultations from the end of 2015 to the beginning of 2016.

1. Renewing the curricula of the Science, Technology, and Mathematics Education Key Learning Areas (KLAs)
2. Strengthening the provision of quality learning experiences to students through support to schools on whole-school curriculum planning and collaboration with relevant organisations
3. Providing KLA-based and cross-KLA learning and teaching resource materials to schools
4. Enhancing professional capacity, knowledge transfer and cross-fertilisation among schools and teachers for building communities of practice on STEM education
5. Synchronising contributions from different community key players to enhance the promotion of STEM education in the territory
6. Adopting actions to continuously review the development of STEM education, consolidate good practices for dissemination and generate knowledge for transfer

In the past few years, STEM education in Hong Kong has probably been developed in accordance with the above guidelines. By 2018, the curriculum guides of relevant subjects have been updated to align with the development of STEM education, including the subjects of Integrated Science of Secondary Schools, Mathematics of Primary Schools, Mathematics of Secondary Schools and General Studies of Primary Schools. In addition, after the announcement of the Policy Address 2016, the government issued a one-off allowance of HK $ 100,000 to each primary school to support school-based activities of STEM education. In Policy Address 2017, it proposed to issue HK $ 200,000 of similar grant to each secondary school for the same purpose. Schools began to purchase equipment, after-school training courses and STEM teaching resources. Sponsoring Bodies of some schools provide additional resources for the schools to establish STEM Laboratories or Maker Space at school and as a result, many STEM related projects have been developed. The learning content of STEM varies among different schools, from traditional scientific experiments to other cold knowledge like that of "Sidewalk Scientist" (a television programme); learning activities vary from robot programming to Aquaponics system; and from playing leaflute to 3D printing. Any possible scopes related to Mathematics and Science become topics for school projects. From an optimistic point of view, a great variety of ideas have been generated, yet some people are confused about how to proceed further after the fresh experiences.

The Myths behind the Scene

The excitement and post-excitement confusion of STEM education may stem from the following issues that need to be clarified:

1 Is there a standard definition and scope for STEM education?

Studies (Australian Council of Learned Academies, 2012) reveal that when promoting STEM education in different countries or regions, it is usually a direction for policy, and hardly any deliberate attempts have been made in defining the standards and scope of STEM education. On the contrary, there are different focuses of STEM development even within the same region or country. Therefore, when some people say that the United States focuses on science learning, Europe focuses on engineering training, and Asia focuses on programming and robotics, their comments are a partial view of the whole picture. The phenomenon of implementing STEM education in various ways by different schools and organisations in Hong Kong is not unique.

2 Is STEM a government policy or a curriculum model?

The same study (Australian Council of Learned Academies, 2012) has pointed out that the ultimate aims of the policies in promoting STEM or similar initiatives in different countries are the employment capacity of the nations and the overall competitiveness in technology and innovations of the country. From my point of view, all countries have mentioned about the emphasis on the subjects of Mathematics and Science, but neglecting the curriculum planning of STEM education. That is the reason why it becomes a myth whether STEM education is a slogan or a specific curriculum model.

In general, apart from some of the implementation principles stipulated by the Hong Kong Education Bureau, STEM has not become a central curriculum in Hong Kong. The responses of different groups or organisations, companies or individuals in the community of STEM education are based on their own professional advantages regardless of their motivation. For example, the long-established Aquaponics institutions have promoted the selling of Aquaponics systems under the name of STEM in recent years. Computer programming companies are now offering after-school courses to schools in the name of STEM. Of course, more and more new organisations, new companies and new experts have emerged in the boom of STEM education according to their expertise. Finally, people cannot help but ask: What is the positioning of promoting STEM education in Hong Kong? What are the short-, medium- and long-term strategies? Will there be a STEM curriculum framework for schools? I believe that even if there are no answers to the questions above, it is necessary to at least clarify some related concepts and select an orientation of STEM education suitable for Hong Kong.

S.T.E.M or STEM

It is a common phenomenon in the diverse ways of implementing STEM education all over the world, yet some countries or regions that have implemented STEM education long ago, such as the United States, have already learned the lesson and are working hard towards the synthesis and practicality of STEM education (AAAS, 1989, AAAS, 1993; NRC, 1996). In fact, it has long been pointed out that the different science and technology disciplines that are separated into different subjects today are originally derived from the same discipline, general education (Bonser & Mossman, 1923; Savage & Sterry, 1990; ITEA, 1996). The introduction of STEM education is not limited to the emphasis on existing Science, Technology, Engineering, and Mathematics. As Elaine (2014) stated:

> *STEM is a curriculum based on the idea of educating students in four specific disciplines — science, technology, engineering and mathematics — in an interdisciplinary and applied approach. Rather than teach the four disciplines as separate and discrete subjects, STEM integrates them into a cohesive learning paradigm based on real-world applications.*

After nearly 20 years of development, the integrated or interdisciplinary STEM courses today generally comprise the following characteristics:

1. **Comprehensive and integrative, that is providing a comprehensive topic that allows students to learn or apply their knowledge skills in Science and Mathematics (Kennedy et al., 2014)**
2. **Solving real world or daily life problems as the point of departure (NAE and NRC, 2009)**
3. **An innovative and hands-on opportunity to solve problems with STEM-related knowledge and methods coupled with creative thinking (Hoachlander & Yanofsky, 2011)**

These characteristics are beneficial to the promotion of STEM education. Imagine that if you simply advocate STEM in its general terms, that is, everything related to Science, Technology, Engineering, and Mathematics is collectively referred to STEM, then learning science is STEM education, studying technology subjects is STEM, attending Mathematics lessons is equivalent to attending STEM lessons. If that is the case, there is no need to propose STEM education. To put it in another way, when anything related to Mathematics and Sciences is stained with the aureole of STEM, the following situation may occur. A classmate who is taking a rest on a chair after lunch can be considered as undergoing a process of STEM learning as teachers of different subject disciplines can apply their subject knowledge to teach the so-called "STEM" to their students. The Science teacher can explain that the reason why the student feels tired is due to the reduction of blood supply to the brain as the blood is concentrated in the stomach for digestion. The Mathematics teacher may remind students that the chair is designed at the height ratio of the average students. The Technology or Engineering teacher can analyse that the material of the chair is strong enough to support the weight of the classmate so he can feel safe sitting on the chair. In such a way, a STEM lesson is conducted. This is a simple example showing that a generalised, fragmented, and inconsistent STEM curriculum does not make much sense in teaching.

Sanders (2009) has pointed out that STEM education raises a query about the effectiveness of traditional science and technology education. The fact that science and technology have been taught as discrete subjects in traditional education, many students have lost their interest in these subjects in early years, thus exit from the STEM pipeline. Sanders (2009) has also pointed out that in the case of the United States, a lot of reforms in individual science and technology subjects have been proposed in the past 20 years, yet the number of students dropping STEM learning has not been decreased. In the Obama era, one of the goals of the "No Child Left Behind" Act is to prevent students from falling behind in Mathematics and Science, but the problem of insufficient student intake in STEM subjects in teacher education was encountered. Therefore, interdisciplinary integration and practical application of STEM education, rather than education students with discrete subjects, is the way out for STEM education in the United States, and Hong Kong should take their experience as a frame of reference.

STEM and Maker

I have mentioned about the fragmented S.T.E.M. education above. Now let us look at the more meaningful integrated STEM education which includes the three common characteristics mentioned. Problem-based STEM courses with hands-on and minds-on activities which provide students the opportunity to apply knowledge and skills of Science and Mathematics, to learn about the relationship of relevant knowledge among different subject disciplines, and more importantly, to learn how people solve daily life problems. These characteristics can be illustrated by a STEM case of General Studies in one of the primary schools supported by CELT in 2017-18.

Topic	An edible environmentally-friendly adhesive (Key Stage 2)

Problem-based

Adhesives (Super Glue) available in the market have stated clearly on the label that they contain different chemicals. They usually emit a pungent odor when used. There are also cases showing that some people inhale and abuse this substance. Therefore, students have identified a problem for inquiry:

- How can we make a more environmentally-friendly adhesive that is less harmful to humans?
- How can we design and make utensils containing environmentally-friendly adhesive?

Integrated elements

The questions have triggered the learning in the subject(s) of **Science**

1. What are the natural adhesives used in ancient and modern China and overseas?
2. How can we test the effectiveness of the newly-made adhesive?
3. What scientific concepts and process skills will be learned in the process of inquiry and production?

Technology or Engineering

1. How can we compound and produce an adhesive with natural materials?
2. How can we store and contain the adhesive?
3. How do we learn about the design cycle during the production process?

Mathematics

1. What is the relationship between reliability and the number of tests?
2. How can we apply the mathematical concept of "average value"?
3. How can we get the average value from the tests?
4. How can we help students value data gathered?

Hands-on and minds-on opportunities

1. Hands-on activities of mixing of different natural materials, observing and recording the effectiveness of different finished products
2. Searching and analysing suitable materials for adhesive specimens and test receptors
3. Hands-on production of the adhesive specimens
4. Hands-on experience in conducting a fair test
5. Monitoring the testing process and identifying loops
6. Designing and making containers for the adhesive

It is not difficult to find that such an integrated STEM curriculum will eventually produce final products which are scientific, technological, innovative and can be used to solve daily-life problems. In other words, it leads to the development of makers concept.

Maker learning or maker movement is based on hands-on experiential learning to design and produce with creativity (Kylie Peppler, Sophia Bender, 2013). Maker learning is a kind of enquiry learning model with the underpinning of constructivism to solve problems by generating hypothesis, conducting inquiry, testing and refining etc (Erica & Kimberly, 2014).

It is always right to insist on doing well in the traditional S.T.E.M. disciplines insistently, and should continue to do well during the class time of each subject. However, if we only take learning the existing discrete knowledge of Science and Mathematics as the ultimate goal of STEM education, we may ignore the greatest value of STEM itself: it actually provides students with interdisciplinary learning opportunities for problem solving, creativity, hands-on and minds-on life experience. This enriched life-based and cross-disciplinary learning output will far exceed that of the existing Science and Mathematics curriculum content. The author believes that the greatest difference is that the interdisciplinary STEM curriculum is closer to the notion of makers, as Lin Kunyi (2014) states:

> *The prevalence of Maker in recent years highlights that the education system should emphasise on the integration of theories and practice while avoiding only learning knowledge of discrete subjects.*

Apart from discussion of teaching effectiveness, there are social needs for STEM education, especially the STEM education in Hong Kong developing towards an integrated maker teaching or creative technology teaching direction. However, this aspect is not the scope of this article as this paper aims at discussing the positioning of STEM in basic education. Therefore, another ambiguous aspect of STEM education in Hong Kong, namely the relationship between STEM education and coding, will be discussed in the following section.

The relationship between STEM and Coding

Coding is another terminology that unexpectedly appeared in the policy documents of the government. In 2014, the Education Bureau published The Fourth Strategy on IT in Education Consultation Document, which proposed to incorporate computer coding as an integral element in basic education. It was later summarised in the final version of The Fourth Strategy on IT in Education (Education Bureau, 2015) published in 2015 as follows:

> *EDB will continue to enhance students' problem-solving skills through equipping them with programming-related capabilities (e.g. computational thinking, modeling, coding, testing, and analysing).*

Coding is one of the most commonly used methods of cultivating computational thinking. The ultimate goal of cultivating computational thinking is not to nurture computer programmers, but to let students learn the procedure of solving problems and the logic of thinking. More importantly, science and technology learning must not be separated from information technology when promoting STEM education. It can even be said that information technology is the most important component of future technological development. Therefore, based on the demand of reality, the STEM curriculum designed for the next generation cannot lack the training of computational thinking, nor ignore the overall planning of the coding training program, as the Apple website points out:

> *Coding is essential to help students thrive in a future driven by technology.*
>
> Checked from: https://www.apple.com/education/teaching-code/

In addition, many studies have pointed out that the skills training of computational thinking can be applied to a wide range of problems and situations in different dimensions, and it is naturally more suitable to be integrated into the interdisciplinary STEM curriculum with the component of maker. These studies also point out that the problem-solving type of STEM curriculum will in turn help to train students' computational thinking skills (Guzdial, 1994; National Research Council, 2011; Repenning, Webb, & Ioannidou, 2010; Sengupta, Kinnebrew, Basu, Biswas, & Clark, 2013; Wilensky & Reisman, 2006).

Here is a simple example illustrating how computational thinking can help STEM learning. Debugging is an important concept in computational thinking. Students have to find out the problems that interfere the program from running effectively. During the process, students can debug by using different strategies of debugging such as **interactive, control flow analysis or profiling**. Similarly, there is an opportunity to apply the maker component of STEM practice to find out the reasons why the finished product cannot achieve the desired effect, and use the strategy to debug and improve the finished product until it reaches the expected effect as designed in the plan. With regard to the “environmentally-friendly adhesive” learning activity mentioned above, students can use the debugging procedure and strategies to trace the root of the problem when they find that the effectiveness of the adhesive produced is not as good as that of the “Super glue” used in the control experiment. They can investigate the relationship between test substances (different powders) and receptors (wooden clips) (interactive), or reviewing the process when water is added to the mixture and cooling control (control flow analysis) to find out the cause of the problem. This example responds to one of the three STEM learning objectives mentioned: “Different Thinking Strategies.” Debugging is a skill and also a thinking strategy learned from computational thinking, which is very helpful for learning STEM. Undoubtedly, the benefit of learning coding in assisting the learning of information-technology-based and integrated STEM is beyond articulation.

Implementing computational thinking education and STEM education at the same time without clear explanation of their roles makes the myth of STEM education more mythological. The following question-and-answer section may help clarify the double myth.

Is coding STEM education?

Learning coding has two major functions: the first one is mastering a computer program for STEM activities, and the second one is learning computational thinking (computer way of thinking) will help learning the problem-based STEM knowledge and skills. However, neither coding nor computational thinking are equivalent to STEM.

Is coding equivalent to computational thinking?

There are various methods to learning computational thinking: through logic games, activities, or learning a series of computer programs. In other words, whether you have a computer with you or not, you can learn to think like a computer.

The concerns and questions about the relationship between coding and STEM may be more than those mentioned, but clarifying these issues is important for the school to decide on the direction of STEM to be adopted. Apart from linguistic and mathematical abilities, coding has become a fundamental competence to be nurtured. It is very helpful for STEM learning and useful for solving daily life problems. Therefore, for the benefit of a long-term STEM curriculum structure in Hong Kong, the training of coding in primary and secondary schools is indispensable.

Conclusion

Issues related to STEM education are far more than those discussed above. However, if consensus of these basic concepts or problems has not been reached, it may not be possible to further promote the overall development of STEM education systematically and orderly in schools of Hong Kong. We have reviewed the implementation of STEM education in Hong Kong, tried to discuss several important STEM-related concepts and tried to suggest a direction of STEM education for consideration. It is hoped that passionate scholars and teachers will seriously consider the opinions suggested and then work collaboratively together to establish a STEM curriculum and standards for primary and secondary schools in Hong Kong without much hesitation.

Remark: The original article written in Chinese was first published in the CELT Newsletter Third Issue November 2018 (Chinese version)

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Professional Support Services for Schools

Establishing professional learning communities in schools is one of the effective means for enhancing the professional development of teachers. Based on the specific needs of individual schools, CELT offers professional school-based support services to help teachers build a platform for collegial dialogues and collaboration among peers, and pooling the wisdom of members to optimise learning and teaching.

CELT mainly provides four types of school-based support services:

Staff Development Day

It is a three-hour seminar introducing theories and practices of various educational issues and / or pedogogies tailor-made to meet the needs or major concerns of individual schools.

Learning Study Consultancy Service

Learning Study is a multi-functional instructional and research activity guided by theory that allows teachers to attain the maximum effectiveness of daily professional development activities (such as co-planning of lessons and peer lesson observation). CELT conducts learning study with teachers in a collaborative mode to enhance the professionalism of teachers and to help students master the learning content more effectively as well as to enhance their interest in learning. At the same time, this helps schools establish a culture of collaboration, innovation and peer lesson observation.

Lesson Observation and Evaluation Consultancy Service

- Through the university-school partnership, we help teachers identify the learning difficulties of different subjects and co-plan the lesson design together. Through observation and evaluation of an open lesson, a platform for collegial sharing among teachers will be established to help schools develop a high-quality lesson observation culture.
- We collaborate with teachers to design, implement and evaluate lessons with a view to enhance teacher professional development, and optimise teaching and learning pedagogy.

Seminars and Workshops

Topics Include:

- The rationale and practice of Small Class Teaching
- Self-Regulated Learning
- Cooperative Learning
- Questioning techniques and feedback
- Catering for Learning Diversity

For details of the above support services and fees, please visit CELT website (www.eduhk.hk/celt) or contact Ms Lam, the Executive Officer(Tel: 2948 6398).

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