

The Out-of-School STEM Ecosystem in Hong Kong

An exploratory and investigative study 2015/16



Croucher Foundation
裘槎基金會

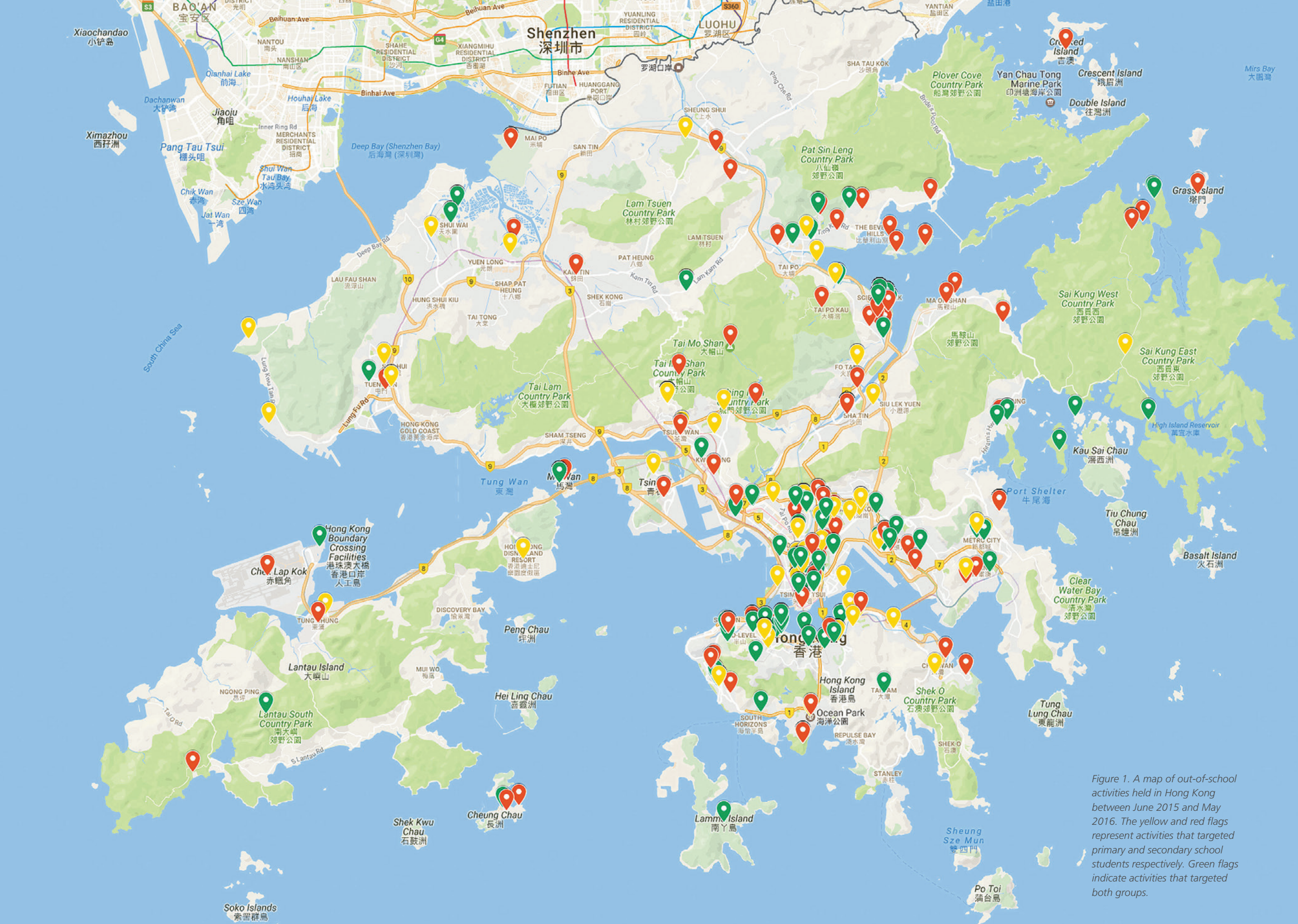


Figure 1. A map of out-of-school activities held in Hong Kong between June 2015 and May 2016. The yellow and red flags represent activities that targeted primary and secondary school students respectively. Green flags indicate activities that targeted both groups.

The Croucher Foundation is an independent private foundation established by the late Noel Croucher in 1979 to promote the standard of the natural sciences, technology and medicine in Hong Kong.

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Introduction

In Hong Kong, very little is known about out-of-school STEM learning programmes, or what the needs of their audience might be. These extracurricular STEM activities provided by different government-related organisations, non-governmental organisations (NGOs), tertiary institutions and private companies all play a part in evoking, sustaining and extending the interest of Hong Kong students in science.

In 2016, to explore the out-of-school STEM ecosystem in Hong Kong, the Croucher Foundation carried out a research study with the following objectives:

- To create a map detailing out-of-school STEM learning programmes held in Hong Kong between June 2015 and May 2016 for students aged from 6 to 18;
- To explore the different modes of teaching and learning used in these out-of-school STEM learning programmes; and
- To evaluate the effectiveness, possible gaps and limitations of these activities at the individual, programme and community levels.

The resulting mapping document, with its up-to-date online maps, is designed to provide a snapshot of all the out-of-school STEM activities that took place in Hong Kong in 2015/2016. The Croucher Foundation hopes that this mapping document will provide a useful point of reference for students, parents, teachers, STEM providers and education policy makers as they make plans for STEM activities in 2017.

To gain a more complete picture, encompassing both in-school and out-of-school STEM learning, we recommend reading the mapping document in conjunction with a report on STEM education published in January 2017 by the Academy of Sciences of Hong Kong (Lun et al. 2016).

In future years, as the mapping document is updated, we trust that it will become a valuable resource, documenting the continuing emergence of a robust and well-coordinated STEM ecosystem in Hong Kong, and a strengthened relationship between the school-based curriculum and activities taking place outside the classroom.

The Education Bureau (EDB) strives to promote Science, Technology, Engineering and Mathematics (STEM) education. Following the provision of additional resources for primary schools at the beginning of 2016, the EDB is prepared to provide each public sector secondary school with an additional one-off subsidy of \$200,000 to facilitate the implementation of school-based programmes related to STEM education.

Policy Address, Hong Kong SAR Government, 18 January 2017

Exploring Hong Kong’s out-of-school STEM ecosystem

To identify out-of-school STEM activities held in Hong Kong between June 2015 and May 2016 for students of ages 6 to 18, a team of five researchers carried out extensive desk research. Under this study, extracurricular out-of-school STEM programmes are defined as those activities which were voluntary and which carried no academic credit toward graduation. They include competitions, exhibitions, talks, courses, workshops, field trips and camps. An online survey was designed to find out more about these out-of-school STEM activities from the organisers. Organisers were interviewed in person to discuss their experience. In addition, local schools and STEM experts were invited to share with us their knowledge and experience in STEM education. *Figure 3* provides an outline of our research flow.

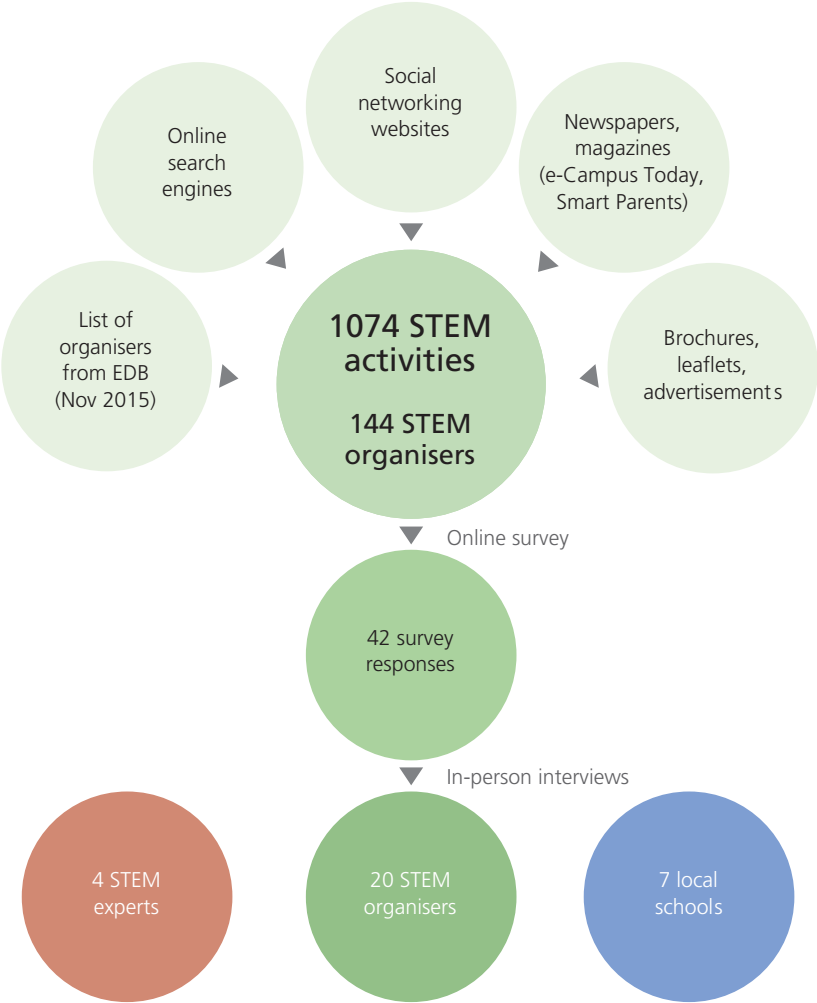


Figure 3. Research flow

Exploring Hong Kong's out-of-school STEM ecosystem

The list of STEM organisers published by the EDB in November 2015 was used as a reference as we searched for relevant government-related organisations, schools and NGOs. Online search engines and social networking websites were also used to find more STEM activities, especially those organised by private companies. In addition, newspapers and magazines with educational content published in Hong Kong between June 2015 and May 2016 were surveyed.

A total of 1074 out-of-school STEM activities and 144 organisers were identified. It is unlikely that this is an exhaustive list. Nonetheless it provides a useful snapshot of the out-of-school STEM ecosystem in Hong Kong.

144 organisers were invited to complete an online survey about their activities and experience, resulting in 42 complete responses. 20 of these organisers were interviewed including six government-related organisations and schools, seven NGOs, and seven private companies. Four STEM experts and representatives from seven local schools were also interviewed. The interviews strengthened our understanding of the immediate challenges and opportunities facing various stakeholders as they organise out-of-school STEM activities in Hong Kong.

Venues of out-of-school STEM activities

A digital map was generated using Google *My Maps* to show the venues of the 1074 STEM activities identified (*Figure 1*, inside front cover). For events with multiple locations, all the respective locations were mapped.

The activities took place all over Hong Kong, with main clusters around Sha Tin and Tai Po in the New Territories, Yau Tsim Mong district in Kowloon, as well as Central, Wan Chai and Western districts on Hong Kong Island.

Locations of STEM organisers

Figure 2 (inside back cover) shows the geographical distribution of the 144 organisers of the out-of-school STEM activities identified. For organisers with multiple branches, all the respective locations were mapped.

The organisers clustered within the business districts, particularly Yau Tsim Mong district in Kowloon, as well as Central and Wan Chai districts on Hong Kong Island.

Timing of the out-of-school STEM activities

Figure 4 provides an overall view of how the out-of-school STEM activities were distributed across the year (June 2015 to May 2016).

November 2015 represented a busy month in the out-of-school STEM calendar with a series of activities linked to the Hong Kong SAR Government’s InnoCarnival. Other than this peak, activities were quite evenly distributed throughout the year with dips in June and September linked to the examination season and the start of the academic year respectively.

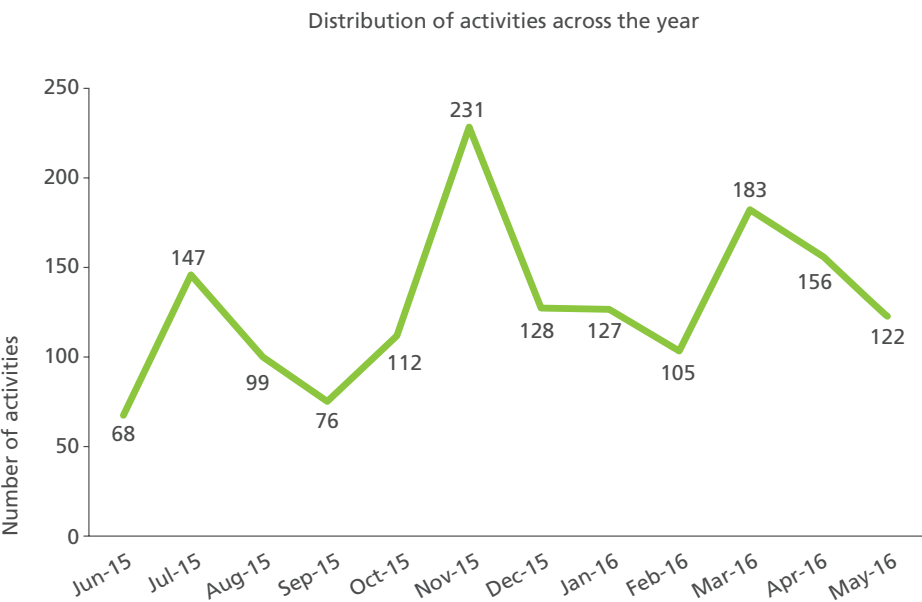


Figure 4. A graph showing the out-of-school STEM activities that occurred across the period of study, from June 2015 to May 2016.

Types of organisers and their extent of collaboration

The 144 organisers of the out-of-school STEM activities were categorised into government-related organisations and schools, NGOs and private companies (Figure 5a).

Out of the 1074 STEM activities identified, the majority were organised by a single party and very few were co-organised by more than one organisation. Figure 5b illustrates the number of collaborative links between different types of STEM organisers where they organised STEM activities together. Collaborations were more common between government-related organisations and schools and NGOs, while private companies often organised activities on their own. There were only two combinations of organisers in our dataset that involved the collaboration between all three types of organisers. They organised Science Alive and the 18th Innovations in Science and Environmental Studies competition respectively.

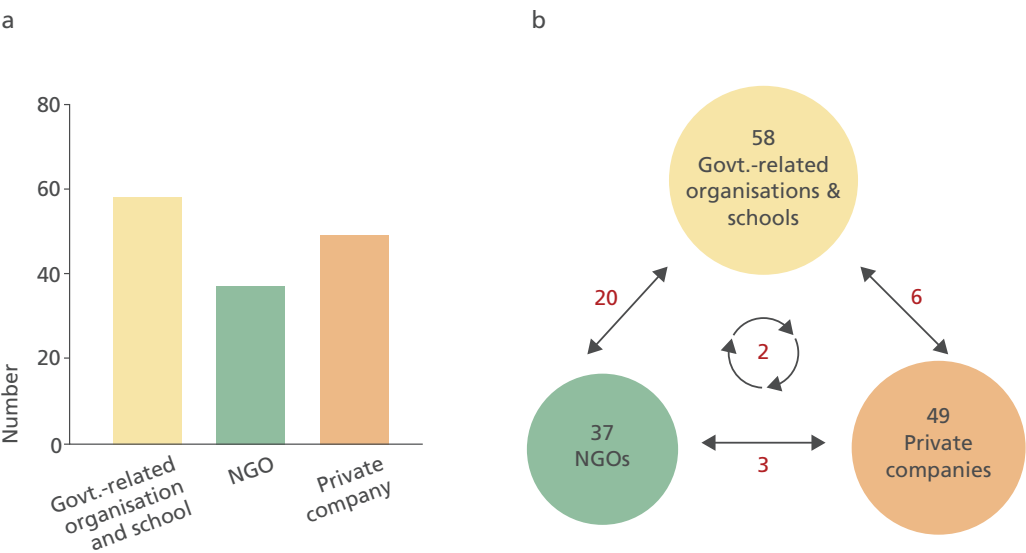


Figure 5. STEM organisers and their frequency of collaboration. (a) The distribution of different types of STEM organisers in our dataset. (b) A schematic diagram showing the extent of collaboration between the different types of organisers. The size of boxes corresponds to the number of each type of organisers while the width of the arrows indicates the frequency of collaboration. The number in red represents the collaborative links between different types of organisers.

Nature and types of STEM activities and their target participants

All the 1074 out-of-school STEM activities from our dataset were analysed according to their nature, type of activity and their target age group.

The nature of a STEM activity refers to whether it was science-, technology-, engineering- or mathematics-related. Most of the out-of-school STEM activities were science-related (Figure 6a). Some activities covered one or more areas of STEM (Figure 6b).

The out-of-school STEM activities were categorised into competitions, exhibitions, talks, workshops, courses, field trips and camps (Figure 6c). Courses and workshops were classified according to the number of sessions: courses involved two or more sessions, regardless of whether they occurred on the same day, whereas one-off activities were defined as workshops. Workshops involved hands-on experience but courses might or might not contain hands-on activities. Exhibitions included theatres and films, while talks included seminars delivered by STEM professionals. As illustrated in Figure 6c, the majority of the out-of-school STEM activities we identified were workshops and courses.

The target age groups of the 1074 out-of-school STEM activities were categorised into primary (Primary 1 to 6; age 6-12), junior secondary (Secondary 1 to 3; age 13-15) and senior secondary (Secondary 4 to 6; age 16-18) levels (Figure 6d). About half of the activities identified targeted multiple age groups (Figure 6e).

Figure 6. The nature and types of out-of-school STEM activities in our dataset and their target participants.

- (a) The distribution of the nature of STEM activities. There were 617 science-, 276 technology-, 234 engineering- and 188 mathematics-related activities. Some activities engaged participants in more than one area of STEM hence each area were counted separately.
- (b) A Venn diagram showing the number of STEM activities and the integration between different areas of STEM. The number of activities were indicated in each sector.
- (c) The distribution of the target age groups of the STEM activities. There were 777 activities that targeted primary students, 564 activities that targeted junior secondary students and 519 activities that targeted senior secondary students. Activities which targeted multiple age groups were counted separately.
- (d) The distribution of the target age groups of the STEM activities. There were 777 activities that targeted primary students, 564 activities that targeted junior secondary students and 519 activities that targeted senior secondary students. Activities which targeted multiple age groups were counted separately.
- (e) A Venn diagram illustrating the STEM activities that targeted one or more age groups. The number of activities were indicated in each sector.

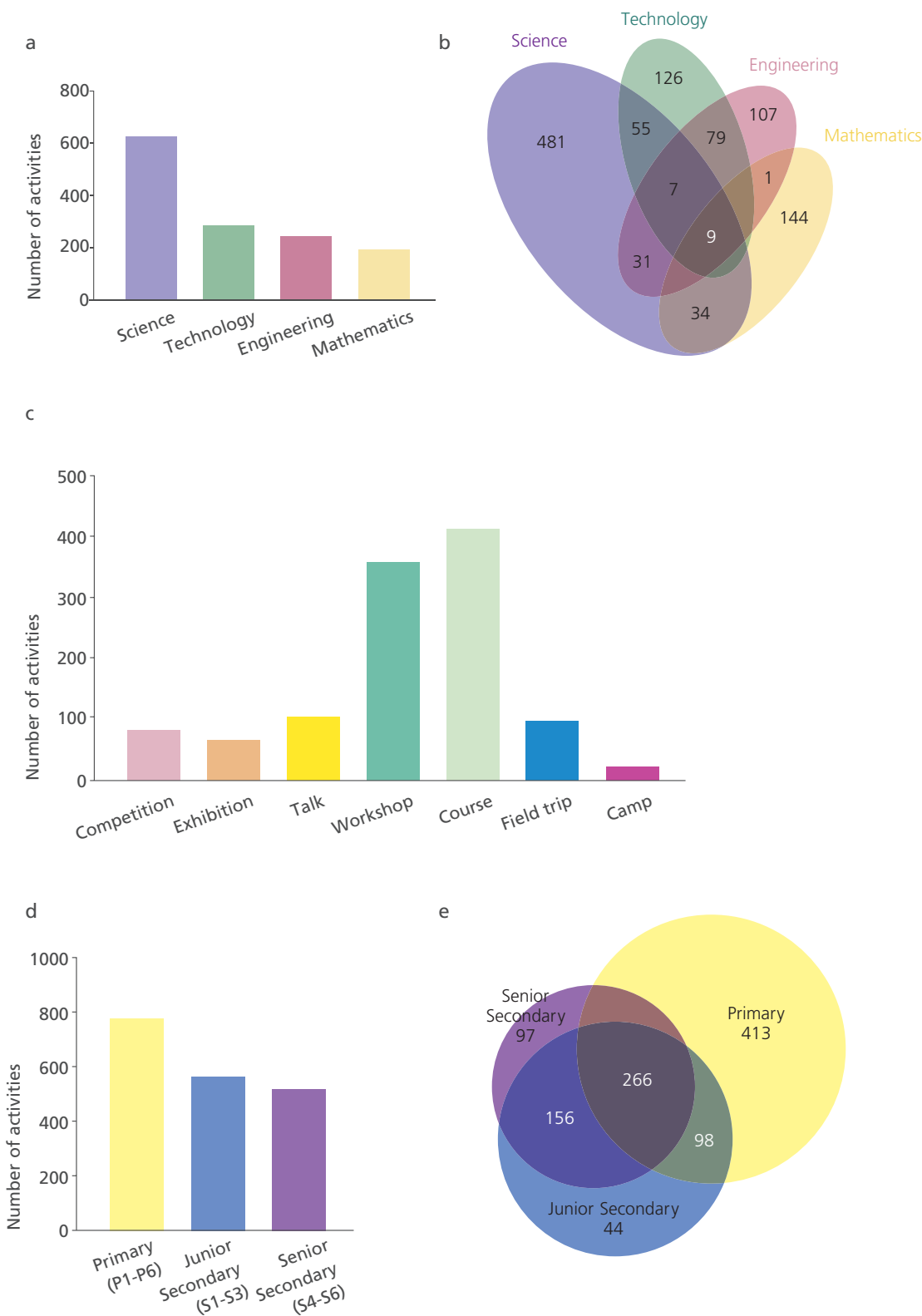


Figure 6. The nature and types of out-of-school STEM activities in our dataset and their target participants.

Exploring Hong Kong’s out-of-school STEM ecosystem

The dataset was explored further by looking at the type of activities that were organised for each area of STEM (Figure 7). Apart from science-related workshops and courses, mathematics-related courses were often organised and field trips also appeared to be a frequently organised science-related activity (Figure 7a).

There were many science-, technology- and engineering-related workshops but few for mathematics, an area where courses were often organised (Figure 7b). There were also very few exhibitions, field trips and camps, particularly for areas of technology, engineering and mathematics (Figure 7b).

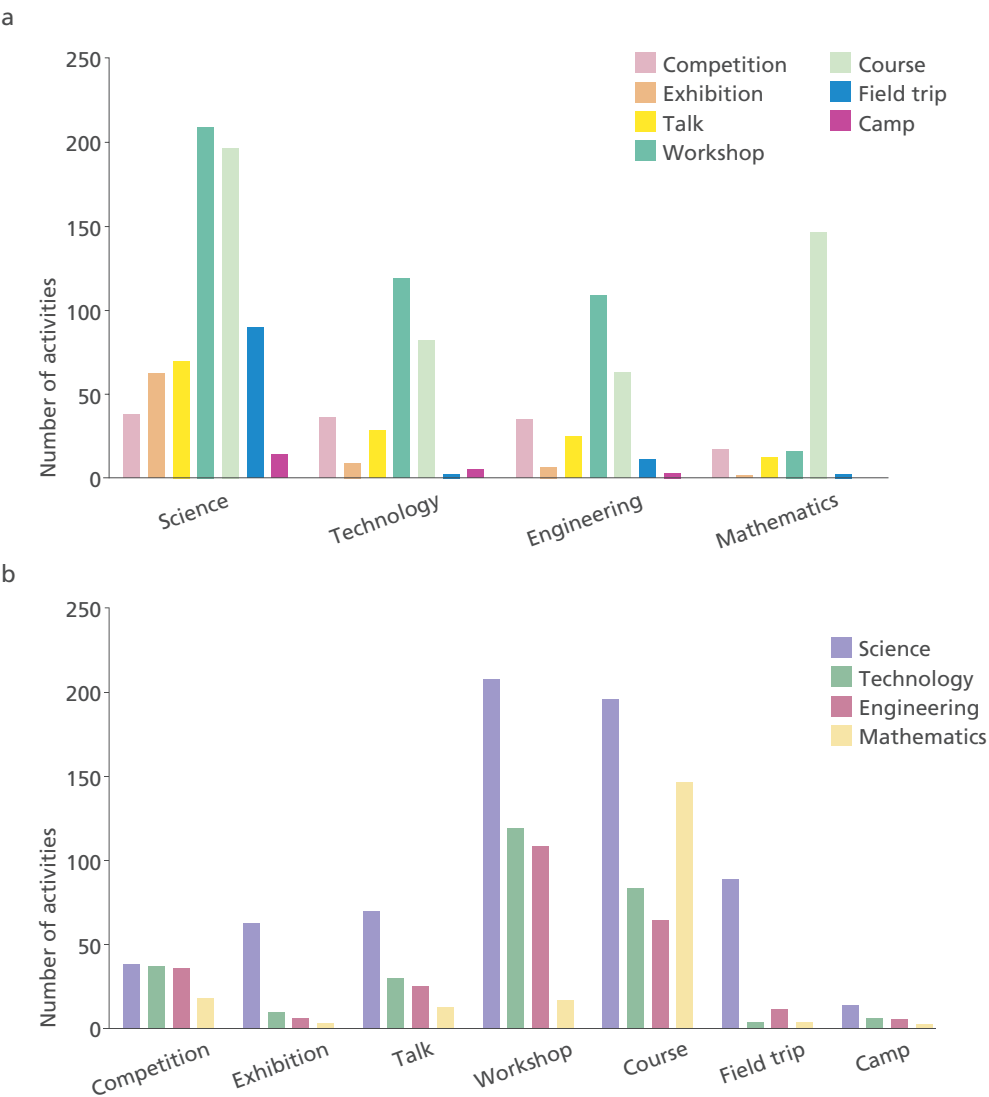


Figure 7. The relationship between the type and nature of STEM activities.
(a) The distribution of various types of activities according to each area of STEM.
(b) The distribution of each area of STEM according to the type of STEM activity.

With respect to the promotion of STEM to different age groups, our dataset showed that the organisers tend to target primary school students (Figure 8a). On average, there were similar number of activities covering science, technology and engineering targeting each age group, but particularly more mathematics-related activities for primary students than secondary students (Figure 8a).

There were more science-related activities for all age groups than other areas of STEM (Figure 8b).

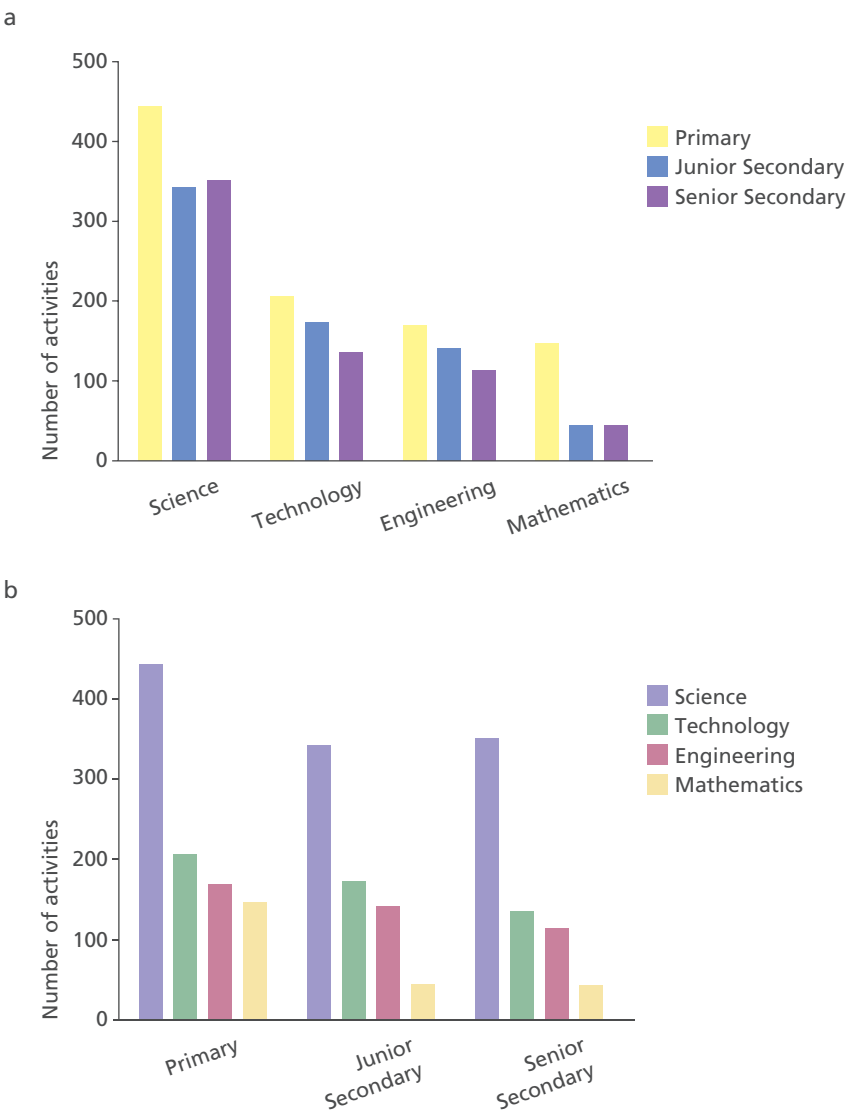


Figure 8. The relationship between the nature of the out-of-school STEM activities and their target age groups.
(a) The distribution of the target age groups according to the nature of STEM activities.
(b) The distribution of activities in each area of STEM according to their target age groups.

Majority of our online survey respondents had heard of ‘STEM’

Following data mining, a survey was designed and conducted online (Qualtrics, Provo, UT). Its objectives were to collect more detailed information about the out-of-school STEM activities held by different organisers and to find out about their experience. Survey invitations were sent to all the organisers in our dataset, after which 42 complete responses were received.

Among the 42 survey respondents, 36% were government-related organisations, tertiary institutions and schools, 33% were private companies and 31% were NGOs (Figure 9). The majority of them had heard of the term ‘STEM’ before completing the online survey (Figure 9).

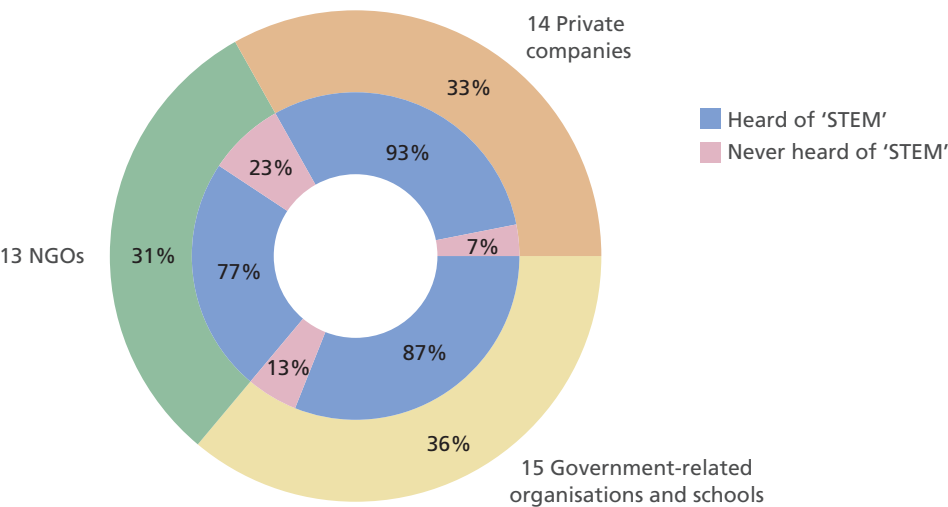


Figure 9. Summary of survey responses. The outer circle shows the type of organiser and the inner circle indicates whether the respondents had heard of the term ‘STEM’ before completing this online survey.

Participants of the out-of-school STEM activities organised by the 42 survey respondents mainly applied through their schools, or on their own (Figure 10). Some enrolled as a group or drop-in on the day of the activity.

Among all these activities, few involved lower primary students (6- to 8-year-olds) (Figure 11). There seemed to be a general decrease in participation in competitions, exhibitions, talks, workshops and courses as the participants got older. The opposite trend was observed for field trips, whereby more students participated as they got older. This might be attributed to the increasing number of field trips organised in support of the secondary school biology curriculum.

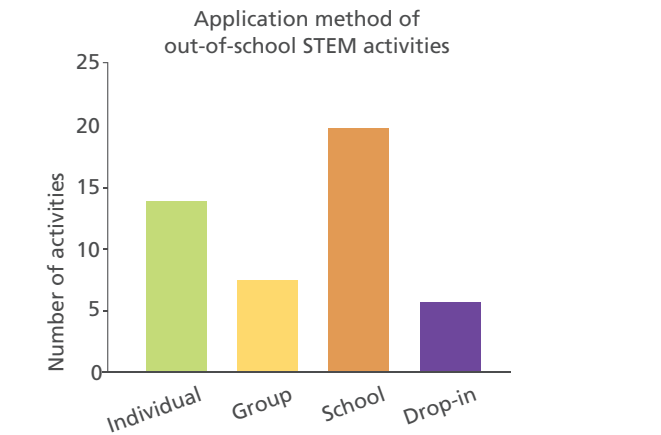


Figure 10. The application methods for the out-of-school STEM activities covered by the online survey.

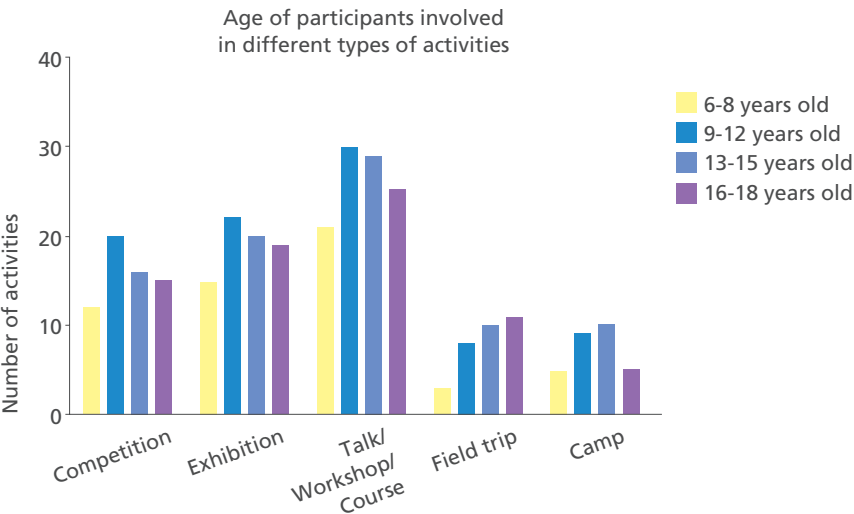


Figure 11. Ages of participants in different types of out-of-school STEM activities according to the survey respondents.

Figure 12 summarises the average number of participants for the out-of-school STEM activities organised by the 42 survey respondents. Competitions and exhibitions generally accommodated much larger numbers of participants whereas talks, workshops, courses, field trips and camps had smaller groups of participants.

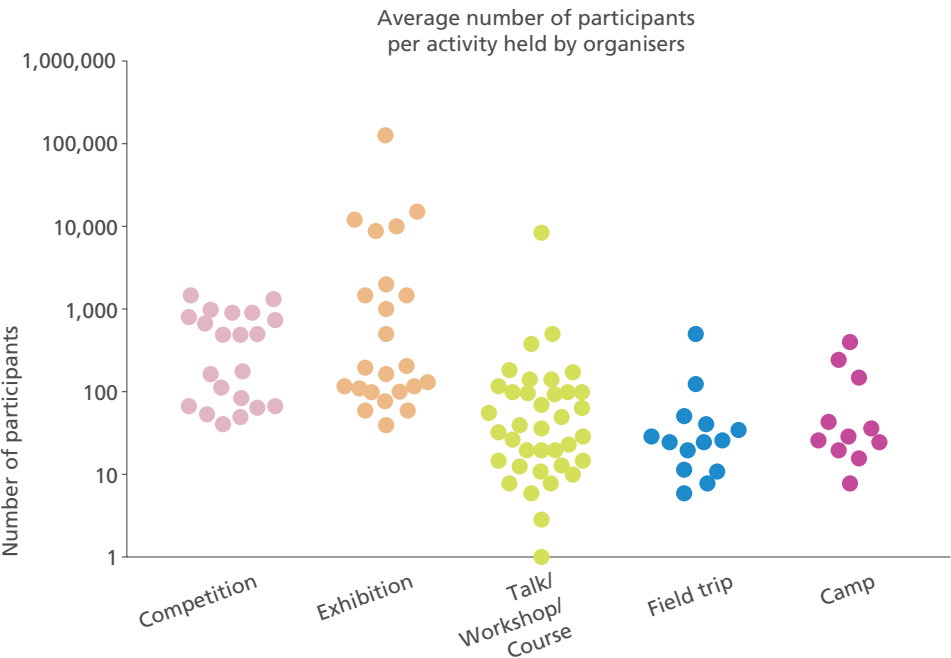


Figure 12. The average number of participants in each type of activity according to the survey respondents. Each dot represents an individual event. The logarithmic scale was used to show the number of participants.

Immediate issues and challenges faced by survey respondents

when organising STEM-related activities

- Financial resources
 - Funding
 - Equipment
- Human capital
 - Teacher training
 - Administrative support
 - Content design
- Venue and time
 - Class size
 - Scheduling: time clash
- Communication and promotion
 - Communication with schools, parents and students
 - Promotion and media coverage

when conducting STEM-related activities

- Financial resources
 - Funding
 - Equipment
- Human capital
 - Teacher training
 - Teaching materials
- Content delivery
 - Wide age range
 - Students of diverse backgrounds and interests
- Insufficient time and support
 - Pre-activity briefing
 - Post-activity debriefing

The organisers discussed their difficulties further when interviewed. Their thoughts have been summarised in the upcoming chapter.

The out-of-school STEM ecosystem from the organisers' perspective

Amongst the 42 online survey respondents, 20 organisers discussed further with us their experience through an in-person interview. The interviewees comprised representatives from seven NGOs, six government-related organisations or tertiary institutions, and seven private companies.

Course design

In general, the out-of-school STEM activities were designed with reference to

- the Hong Kong school curriculum
- the UK curriculum
- Benchmarks for Science Literacy developed by the American Association for the Advancement of Science

Elements of STEM education

When asked about their views on the essential elements of STEM education, the organisers put emphasis on hands-on experience. Such hands-on experience engages students and arouses their interest in STEM, better illustrates complicated concepts, and trains students to be more independent. They pointed out that schools were often unable to provide sufficient hands-on learning opportunities for students.

The organisers often mentioned the idea of problem-based learning which creates an encouraging environment to promote STEM education. Through scientific investigation, problem-based learning encourages creativity, inspires students to initiate their own learning, trains their logical and systematic thinking, and minimises the distance between science and daily life.

Out-of-school STEM activities complement the school curriculum

All the interviewees agreed that out-of-school STEM activities, to a large extent, complement in-school education. The organisers of out-of-school STEM activities are more specialised and familiar with the topics, and are able to provide the required equipment and teaching resources. They also have more flexibility in course design as they are not bounded by any curriculum, so more hands-on elements can be included.

Nevertheless, in-school education is still important as it provides the foundation knowledge of STEM. Schools teach basic knowledge while students can deepen and integrate knowledge outside school.

The organisers also pointed out that good competitions always involve two "R"s: reward and reputation. Schools prefer international competitions or local competitions organised by renowned organisations. While schools may not pay so much attention to monetary rewards, they hope that the prizes would be meaningful for their students.

Limitations of out-of-school STEM activities

Many organisers were concerned about the limitations of traditional teaching methods in schools and students' inadequate exposure to science and other STEM-related disciplines. In response to this perceived gap, they organised a wide array of STEM activities with the goal of nurturing STEM-literate individuals and strengthening the future workforce in Hong Kong. Organisers discussed some of the challenges and problems they faced in promoting STEM in Hong Kong:

Insufficient human resources

Most of the organisers interviewed reflected that they lacked human resources to organise workshops and programmes for young people. Organisers noted that, both in-school and out-of-school, teachers in Hong Kong are still used to traditional teaching methods. They noted that teachers seldom get training on how to engage students in STEM through hands-on learning. One organiser noted that there are currently fewer than 20 qualified Design and Technology (D&T) teachers in Hong Kong. It appears that secondary schools have recruited Information and Communication Technology (ICT) teachers rather than Design and Technology teachers. To recruit highly capable instructors and teachers able to arouse and deepen students' STEM interest and knowledge was considered to be a significant challenge.

Recruiting instructors with science backgrounds was also considered to be challenging since these recruits often did not have expertise and/or professional qualifications in education and required specialist training.

Insufficient financial support

Investments and funding are important financial resources for tertiary institutions and NGOs in organising on-going programmes and large-scale events for local students. However, even though the public's awareness of STEM has been growing since the EDB's promotion of STEM in 2015, the organisers reflected that it has been difficult to obtain funding. This difficulty even applied to well-established NGOs and well-recognised competitions that had been organised for over a decade.

The out-of-school STEM ecosystem from the organisers' perspective

Lack of suitable equipment and venue

Education in technology and engineering are particularly challenging when compared to science and mathematics as it often requires expensive equipment and tools in order to offer students hands-on experience. Organisers often faced difficulties in finding suitable and affordable equipment for their activities.

Additionally, many organisers were concerned about finding appropriate venues for conducting their activities. They often approached NGOs and schools to borrow venues for large-scale competitions and workshops to avoid high rental costs. However, those venues were often unable to accommodate all the participants, especially for large-scale international STEM competitions held in Hong Kong. In addition, some organisers could not conduct certain hands-on experiments that involve the use of toxic substances or fire due to regulations governing the use of their venues. This imposed some restriction on the course content and design.

Lack of support from schools

A supportive school is an excellent facilitator in promoting STEM education. Most out-of-school STEM activities require students to apply via their schools (*Figure 10*). Teachers, parents and students may prioritise in-school and academic-related activities and perceive extracurricular activities as leisure activities. According to organisers, teachers were often busy with teaching and administrative duties, and not so willing to spend time and effort promoting these extracurricular activities.

Organisers also found it hard to promote STEM to secondary school students as their schedules were often occupied with tutorials and extra classes. Certain workshops and experiments, like biotechnology and microbiology laboratory work, require much longer lesson time and students have not been able to participate. In order to cater to the secondary school students' needs, organisers often had no choice but to reduce course content.

For competitions, participants' sense of achievement is driven by reputation and reward. However, students may find some international competitions, such as the World Robot Olympiad, too challenging and are unwilling to spend time on these activities. In addition, organisers believed that some teachers might inadvertently undermine students by expressing a view that certain groups of students, especially those in lower band schools, were not capable of joining or winning competitions.

Lack of parental support

Out-of-school STEM programmes and workshops help young people develop higher-order thinking, problem solving skills and unleash their potential in innovation. However, these intrinsic skills take time to acquire and are not easy to measure. Hence, parents may not be aware of the relevance and value of STEM education. According to organisers, some parents in Hong Kong held the misconception that STEM has little connection with daily life and/or significance in relation to the career path of their child.

Inadequate media coverage

Media is an important channel for local students to be exposed to STEM topics. The organisers recalled that media outlets often reported their activities after the events were completed, which therefore, did not help to boost the number of participants significantly. More media coverage of STEM activities would facilitate the promotion of STEM education in Hong Kong.

The out-of-school STEM ecosystem from the schools' perspective

In order to evaluate the out-of-school STEM ecosystem in Hong Kong from multiple perspectives, we invited local schools to share with us their opinions. Representatives from two primary and five secondary schools were interviewed in-person. These discussions enabled us to understand the successes and limitations of in-school STEM activities, students' participation in out-of-school STEM activities, and how these activities were perceived.

Keys to a successful STEM Activity

The interviewees shared their experience in organising successful STEM activities and explained the reasons for their success. They also shared some common views on important elements of STEM activities.

First of all, they emphasised the introduction and use of the scientific method in STEM activities, including setting hypotheses, making observations, designing and conducting experiments, and drawing conclusions. Independent and self-directed project-based activities were also effective ways to promote STEM. The STEM activities should involve hands-on experience which help consolidate their theoretical knowledge.

In order to arouse the interest of students in STEM, they chose topics closely related to daily life and encouraged students to apply their knowledge. Some of them collaborated with NGOs or private companies.

Some schools placed emphasis on training students according to their abilities and interests. These schools provided STEM activities for all students then conducted extra programmes for those who are talented or passionate about a certain STEM subject.

Interviewees believed that STEM education could help students develop problem-solving skills and stimulate their creativity. They noted that STEM education was not only about acquiring knowledge but also about communication and presentation skills.

Schools noted that the effectiveness of STEM activities should not and could not be evaluated by the school or public exam results.

Keys to effectively promoting STEM education

The schools mentioned that parental support was important for effective promotion of STEM education in Hong Kong. They noted that students should be taught STEM as early as possible. However, they also noticed that some parents did not understand the benefits of learning STEM or mistakenly thought that STEM activities would hinder students' academic studies.

All interviewees noted that teacher training was crucial and essential.

Limitations of in-school STEM activities

Representatives from the primary schools interviewed expressed that most General Studies teachers do not have a science background so they may not be able to explain the STEM concepts and theories to students clearly.

Besides, it was noted that primary schools lack resources for STEM activities, for example, to hire a laboratory technician, so the preparation for experiments adds to the teachers' heavy workload.

Representatives from secondary schools commented that their teachers have limited time to organise STEM activities. Similarly, senior secondary students are too busy and do not have time to join STEM activities. Moreover, some teachers do not have the specific knowledge on certain STEM subjects, such as aquaponics, robotics and coding.

Schools expressed uncertainty about how they should spend the funding they received to promote STEM and the equipment they should buy to make STEM education effective. They found it difficult to get suitable and affordable equipment for their STEM activities. For instance, some schools could not offer a biotechnology elective for students as they lack the equipment for DNA fingerprinting and gel electrophoresis. It was also not easy for schools to invite successful STEM experts to give talks in schools.

In relation to extracurricular STEM activities, it was noted that some students and parents think that these activities would hinder students' academic studies and affect results in school exams.

Strengths and limitations of out-of-school STEM activities

Schools noted that out-of-school STEM activities could complement in-school programmes and were an important feature of the overall ecosystem. They noted that external organisers had the human capital and suitable equipment for more effective STEM teaching. Some organisers of talks, workshops and courses were highly-qualified and could teach students specialist subjects, like coding, robotics and forensic science. They were often more familiar with the latest technology than school teachers.

With respect to competitions, schools noted that students were more interested in taking part in out-of-school STEM competitions, rather than workshops or courses. Students gained a sense of satisfaction and accomplishment by entering competitions. Some competitions were task-based or involved creating innovative products. These could encourage students to think critically and creatively.

However, schools observed that some out-of-school STEM activities were too expensive. Some activities remained the same year after year and did not evolve. Schools noted that in some cases students only learnt to follow instructions, for example to produce computer code, without any training in logical and systematic thinking. Some organisers put a lot of resources on training but ignored the importance of arousing the interest of students.

It was noted that some competitions that offer hands-on experience require long-term preparation and that students might not be able to spend enough time for good results.

Schools considered that there was insufficient collaboration between STEM activity organisers and related businesses and industries. It was important for students to learn about STEM-related career paths before they would choose to study STEM in their senior years.

In summary, data mining from various online and printed sources provided a snapshot of the out-of-school STEM ecosystem in Hong Kong for the twelve-month period from 1 June 2015 to 31 May 2016. The study covered the nature, type, and target age groups of these out-of-school STEM activities, as well as the extent of collaboration between different organisers. Digital maps generated from the dataset showed the geographical distribution of these activities and their organisers.

To obtain views from different stakeholders, an online survey and in-person interviews were conducted to learn about the challenges they faced in organising out-of-school STEM activities and their views of the current out-of-school STEM ecosystem in Hong Kong.

The following sections aim to provide a comprehensive overview of the findings of this study, with the hope of better implementation of STEM education in Hong Kong.

Essential elements of STEM education

Arousing young people's interest

The first step of STEM education should be to inspire and motivate students to learn. In contrast to conventional education where students may be spoon-fed, STEM learners are encouraged to observe interesting phenomena and take the lead in learning, while teachers act as facilitators to guide them in uncovering the secrets behind the phenomena. This triggers students' curiosity and makes them more motivated in learning independently.

Exploration, investigation and application

STEM education trains students to think logically and systematically through active learning, scientific investigation as well as hands-on experience. Engaged with relevant contexts and data, students are encouraged to apply their knowledge and use various research methods to explain phenomena or solve challenging problems independently. From setting the investigation objectives to drawing conclusions from their results, students' critical thinking skills are strengthened. Opportunities for students to apply their knowledge as well as hands-on experience also help develop their problem-solving skills.

Creativity and innovation

Effective learning does not only involve the retention of knowledge, but also the ability to make sense of and use the knowledge (Krathwohl 2002). The multiple modes of learning in STEM activities equip students with higher-order thinking skills and stimulate their creativity. These skills are important when they advance into STEM topics that they are passionate about, or innovate products to solve some of the most pressing issues in today's society.

Collaboration and exchange of knowledge

Opportunities for working with businesses and organisations should be offered to highly motivated and gifted students, for them to utilise their knowledge and skills to create innovative products. The evaluation process should not only require them to demonstrate their expertise in different fields, but also demand sophisticated communication skills in order to cooperate with different parties. Collaboration between businesses and/or industries encourage students to exchange ideas and information, and consolidate their knowledge from different areas of STEM.

Strengthening the STEM ecosystem to enhance students' STEM learning experience

The STEM learning ecosystem includes home, school, after-school and summer programmes and STEM-focused institutions. All of these environments together provide numerous learning opportunities for students. STEM activities organised within these settings can engage students and develop related knowledge and skills under each discipline of STEM during their adolescence and early adulthood (Traphagen and Traill 2014). Learning science is a complex and multi-faceted process, through which students should learn not only conceptual knowledge, but also the epistemologies of science and how science is enacted in everyday settings (Bell and National Research Council (U.S.). Committee on Learning Science in Informal Environments. 2009).

Apart from formal school education, students are exposed to numerous opportunities to learn STEM in a wide variety of settings. Out-of-school STEM activities are less verbal, more tactile and more connected to everyday settings than in-school programmes (Bevan, Michalchik et al. 2010). They are not bound by the curriculum, thus providing more opportunities for first-hand experience in science-related topics (Bevan, Michalchik et al. 2010). The out-of-school environment also has the competitive advantage of being able to take on new roles and stance that are less possible under the current education curriculum, for instance, students have more time and space to experiment with science. This is particularly encouraging for students who do not perform so well in school and those who think they are not competent or interested in science (Bevan, Michalchik et al. 2010).

Engaging students from a young age

Research from the Partnership for 21st Century Skills initiative and other important government and private agencies have shown the importance of engaging students in STEM education from a young age as it is more effective for them to learn STEM in early grades (DeJarnette 2012).

To begin with, early exposure to STEM influences students' perceptions and disposition in a positive way (Bagiati, Yoon et al. 2010; Bybee and Fuchs 2006). Hands-on and inquiry-based activities capture their interest in different STEM disciplines, which may spark their desire to pursue a career in any of these fields.

In addition, problem-based learning and training of critical thinking in students' early education assist them in understanding more abstract concepts in science and mathematics. Such learning approaches develop their confidence and self-efficacy when they pursue more advanced STEM courses in the later school years, and better equip them with skills required for further studies at institutions of higher learning (DeJarnette 2012). Besides, integrative approaches in STEM education could be implemented with more flexibility at the elementary level as when compared to secondary and college levels without much school structural limitation and standardised testing (Judson and Sawada 2000; Zubrowski 2002).

Although there are benefits for learning STEM from a younger age, this study revealed that junior primary students had a relatively low participation rate in out-of-school STEM activities when compared to senior primary and secondary students (*Figure 11*). *Figure 6d* and *Figure 8a* illustrated that primary students was the most popular target group but junior primary students (6- to 8-year-olds) had the fewest participants compared to other age groups.

In light of the low participation rate of junior primary students, more promotion of STEM education is needed to raise parents' awareness about the importance of STEM and encourage them to let their children participate in more extracurricular STEM activities. Out-of-school STEM activities should reach out to more primary students through more active collaboration between primary schools and external organisers.

Provide more regular courses for Technology and Engineering

Effective learning requires time, effort and continuous exposure. Students need time to develop and organise ideas in order to understand and transfer relevant knowledge to other contexts. In fact, students may have to carry the ideas and concepts beyond a single school year before they can connect and organise the knowledge around important concepts in a systematic way (Bransford, Brown et al. 1999). Nonetheless, many approaches to the design of extracurricular STEM activities in Hong Kong do not facilitate in-depth study as there is little time for students to develop important, organised ideas.

For instance, the number of courses organised for technology and engineering was significantly fewer than that of one-off workshops (*Figure 7a*). Courses engage students in learning STEM over a period of time, which is essential for consolidating their knowledge and enhancing their long-term memory. On the contrary, workshops, defined as one-off activities in our study, aim at introducing and exposing students to STEM-related topics; hence, the coverage of the topics were rather superficial. Information and knowledge learnt from one-off workshops often remain in short-term memory if there is no further reinforcement and consolidation of the information.

To help students develop the competencies for future learning and a possible career in STEM, activities which involve in-depth study across a longer period of time, rather than superficial coverage of facts, should be promoted. Even though students may be inspired by participating in workshops, their interest in STEM need to be sustained through regular courses in order to gain more advanced and in-depth knowledge (Lam, Doverspike et al. 2008).

Integration of Science, Technology, Engineering and Mathematics

There were more out-of-school STEM activities integrating technology with engineering than other combinations. These are two separate but closely related disciplines as technology brings the theory and conceptual design of engineering to life. Therefore, these were the two most frequently integrated disciplines. Science is a very broad field so activities related to technology, engineering and mathematics were often integrated with science respectively (*Figure 6b*).

Only 0.8% of the activities integrating all four areas of STEM (*Figure 6b*). However, an integrative approach to STEM education can improve students' learning and achievement along with their interests in STEM (Becker and Park 2011).

One form of STEM integration introduced in the USA is the concept of interdisciplinary integration (Vasquez, Sneider et al. 2013). Other forms of STEM integration include disciplinary, multidisciplinary and transdisciplinary integration. In interdisciplinary integration, students learn across two or more disciplines of STEM after gaining some fundamental concepts and knowledge in each area. This allows students to deepen their knowledge by linking up concepts from different areas.

Collaboration between different stakeholders

To enhance STEM learning, collaboration between different stakeholders is also important. There is currently insufficient collaboration between different stakeholders (*Figure 5b*). For instance, many private companies adapt their teaching materials from the curriculum of other countries, but these resources may not be applicable to or effective in the local context. Thus, local schools, tertiary institutions and publishers should work together to design more comprehensive teaching resources for teaching and learning of STEM in Hong Kong.

In order to integrate all four disciplines of STEM, it is important for the experts to communicate and collaborate across the disciplines. There is expertise in each area of STEM in tertiary institutions in Hong Kong but these research academics often specialise in a particular field and seldom collaborate across other fields. They should communicate and work with experts from other areas in order to integrate STEM effectively.

Challenges in promoting STEM education in Hong Kong

Curiosity-driven education and independent critical thinking

It is widely believed that students in Hong Kong have adapted to a system in which teachers teach them everything they need to know, with a focus on rote memorisation and lack of in-depth conceptual understanding. In this view, students passively receive information taught by their teachers most of the time and rarely ask questions.

Curiosity-driven education aims to develop students' logical thinking and problem-solving skills. This learning approach usually involves a series of challenging questions where students are required to investigate by themselves without too many descriptive instructions from teachers (Lord and Orkwiszewski 2006). In this way, teachers act as facilitators to guide students to think and explore more. On the other hand, students can have a more enduring understanding of the knowledge gained (Wiggins and McTighe 2005). However, the current education system in Hong Kong appears to lack such learning approach (Lun et al. 2016). This hinders the promotion of STEM education since teachers are also highly adapted to conventional teaching methods and are unwilling to change their teaching style.

Exam-oriented education system

Another deep-rooted problem often associated with the current education system in Hong Kong is its focus on examinations. Examinations can be an effective way to measure learning and teaching efficacy because there are always standard answers (Kirkpatrick and Zang 2011). Thus, it offers a relatively objective assessment of students, avoiding potential bias by markers. Nonetheless, examinations may not be a good way to assess students' genuine abilities, such as creativity. Some students with poor academic performance but talented in STEM subject areas may not be identified as gifted STEM learners.

In addition, students and parents may be concerned more about public examination results than extracurricular STEM activities. Since public examinations help select students of better academic achievement for tertiary education, parents and students prioritise academic-related activities, such as tutorial classes, over STEM activities (Lun et al. 2016). This thus makes it difficult for many organisers to promote STEM activities.

Lack of community support

STEM organisers noted that some parents believe that out-of-school STEM activities hinder students’ academic studies. Parents may not view STEM as important for students’ learning, hence, they do not encourage their children to participate in STEM-related activities. While some parents ask students to join many different kinds of activities to boost their “Other Learning Experience” profile, according to STEM organisers, they usually prefer activities related to sports, music or academic subjects. In doing so, parents may underestimate the importance of STEM literacy. Understandably, students themselves may prioritise school examinations over STEM learning.

Apart from the parents and students, teachers also play an important part. Ideally, a STEM teacher would have sufficient knowledge of all four disciplines and would be trained to arouse students’ interest in and engage them in self-initiated inquiry-based STEM projects. However, education courses in tertiary institutions in Hong Kong focus on the traditional science subjects and do not yet have an integrated approach to training STEM teachers, resulting in a lack of passionate, well-trained and knowledgeable local STEM teachers.

Although from 2015 the Hong Kong SAR Government provided schools with funding specifically aimed at enhancing STEM education, schools appeared to be uncertain whether they would have enough resources to run their STEM programmes in the long term. Schools noted that it was difficult, within the Hong Kong examination system as currently structured, to measure learning outcomes and therefore to evaluate the effectiveness of STEM programmes. According to schools, this may be one reason why the funding emphasis of the Hong Kong SAR Government until now has been on one-off grants rather than long-term strategic funding for integrated STEM education.

Science, Technology, Engineering and Mathematics are inseparable from our life and have tremendously changed the way we live, think and communicate. Across the world, STEM practitioners including scientists, engineers, and technology entrepreneurs are helping to solve the most fundamental problems we face today. STEM education not only sparks off great inventions and developments, but also contributes to a diverse and stable workforce. It is therefore important for the future of Hong Kong.



Figure 13. The four stages for the promotion of STEM education.

Future perspectives

Arouse interest

The foundation of STEM education begins in early years so more STEM activities should be introduced to students in their early years (Moomaw 2013). In the United States, there has been an increasing interest in formulating clear outcomes and standards for preschool programmes given the growing recognition of the role of stimulation in early brain development (Katz 2010).

Parents should be more aware of the importance and benefits of learning STEM. Since parents have a tremendous influence, the exposure of young children to any kinds of knowledge highly depends on their parents (Merrill and Daugherty 2010). Thus, there should be more STEM activities not just for the students but also their whole family.

STEM education should be made available for all students, regardless of ability or age, especially at the first and most important stage of arousing their interests.

Exploration, investigation and application

Self-directed investigation is a good way to promote STEM. With e-learning, students can learn at any time of the day (Welsh, Wanberg et al. 2003).

Instead of merely learning from textbooks, students should explore and learn to apply their knowledge to their daily life. Hands-on experience strengthens their understanding of the knowledge and prepares them for the next stage of creating new products.

Another important element in STEM education is to nurture students' problem-solving and critical thinking skills, which can also benefit their learning in other subjects. Solving problems in STEM activities enable students to be independent and solve problems in their daily life on their own in the future.

The qualification of teachers is a main factor when considering the launch of STEM education in Hong Kong. Teachers should be trained in terms of their knowledge of the classroom learning environment, teaching experience, and their further professional development (Beatty, National Research Council (U.S.). Committee on Highly Successful Schools or Programs for K-12 STEM Education. et al. 2011). Both training and continuing professional development are important since they need broad knowledge in STEM to lead students in investigative projects. (Williams 2008).

To facilitate exploration, investigation and application of STEM, stakeholders would require not only human capital, but also resources, funding, equipment, and appropriate venues.

Creativity and innovation

Students should have more opportunities in both in-school and out-of-school settings for design and innovation, in order to strengthen and apply their STEM knowledge.

Students should learn about the successful cases in pursuing a STEM-related career (Tai, Qi Liu et al. 2006). More support from businesses and industries would encourage students to choose STEM-related subjects in their senior years and motivate them to create new products.

Special attention should be given to talented and gifted students in STEM at this stage for them to utilise their abilities and further strengthen their interests and knowledge.

Collaboration and exchange of knowledge

STEM learning should be integrative (Rennie, Venville et al. 2012). For instance, more integrative approaches can be introduced, such as integrating mathematics modelling or scientific methods with design-based activities involving technology and engineering (Sanders 2012). Collaborations among different stakeholders, including the government, educators, businesses, industries, the community, and the media, should be encouraged to coordinate the development of STEM education (Kennedy and Odell 2014).

Next steps

The study reveals a rich and vibrant ecosystem for out-of-school STEM education in Hong Kong with over 1,000 discrete activities covering a very wide range of scientific disciplines. Students have excellent access to online resources and can easily keep up-to-date with the latest news and developments in STEM. Hong Kong has a tradition of manufacturing and is geographically close to some of the world's most advanced research and manufacturing facilities. Compared with their peers in the region and internationally, Hong Kong students achieve excellent academic results in STEM-related subjects (Lun et al. 2016). The Hong Kong SAR Government has allocated significant resources, and in January 2017 reiterated its commitment to the development of STEM education in Hong Kong.

The Croucher Foundation trusts that this snapshot of the out-of-school STEM learning ecosystem, with its associated digital maps, will be a useful resource for students, parents, teachers, STEM providers and education policy makers in Hong Kong. Future versions of the mapping document will enable us to chart the STEM ecosystem as it evolves and, through the concerted effort of the STEM education community, as it strengthens over time.

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Hong Kong Wetland Park
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Workshop Dynamics Limited
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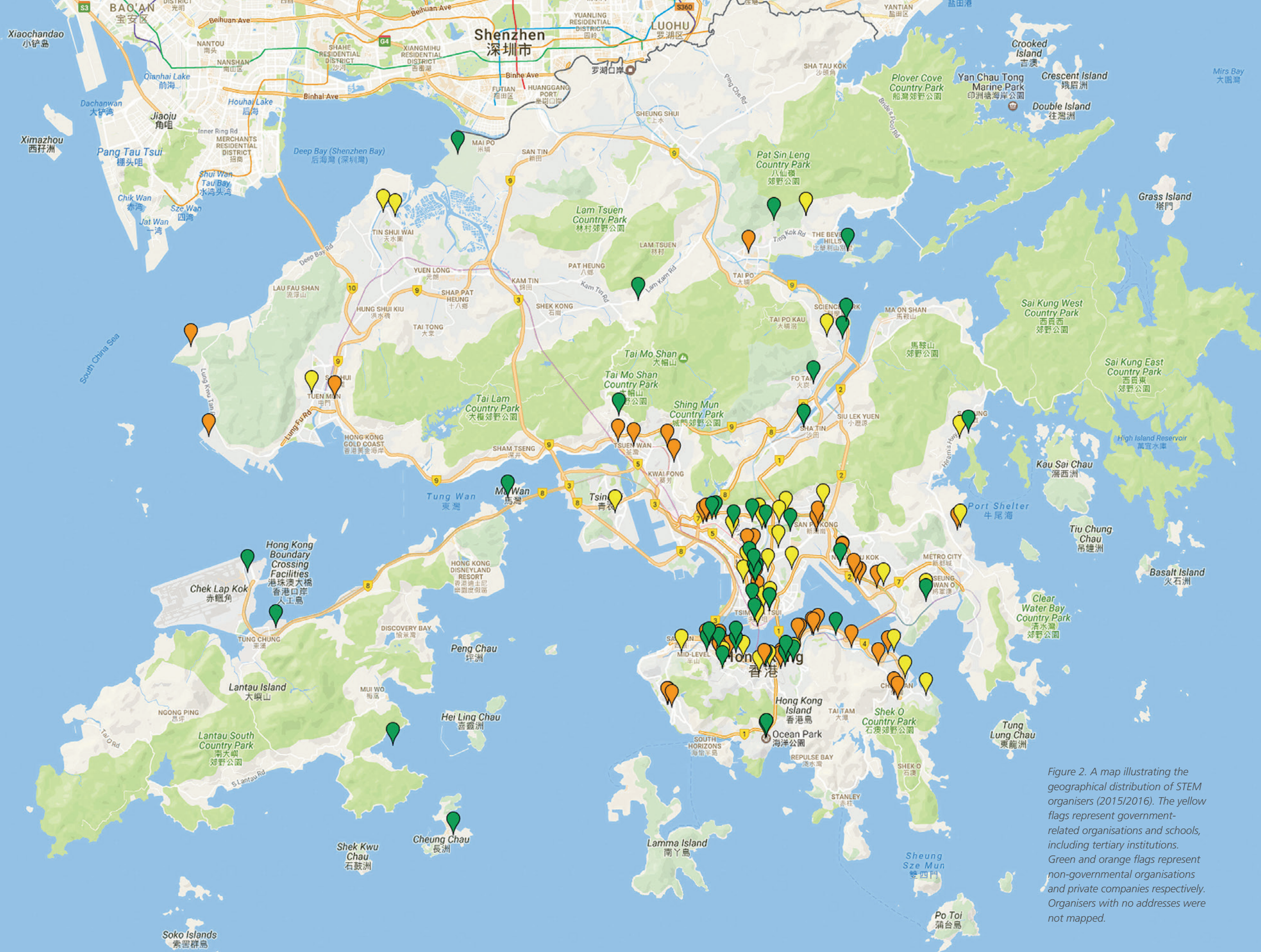


Figure 2. A map illustrating the geographical distribution of STEM organisers (2015/2016). The yellow flags represent government-related organisations and schools, including tertiary institutions. Green and orange flags represent non-governmental organisations and private companies respectively. Organisers with no addresses were not mapped.

