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REGULAR ARTICLE

Designing STEM Education in Small Class Teaching Environments: The Hong Kong Experience

Weijun Liang[1] · **Dennis Fung**[1]

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Abstract This article begins with a historical overview of the STEM education policy and related classroom practices in Hong Kong. Against the backdrop that the Hong Kong education authority has been promoting STEM education over the past few years, there has been a pressing need for effective strategies of implementing STEM education in the context of reduced class size classrooms (i.e. small class teaching). With a view to addressing this need, this article strives to exemplify the incorporation of STEM education into small class teaching settings. Intended as a conceptual paper drawing on design approaches for STEM lessons and a small class teaching framework, the article demonstrates the relevance of STEM education to small class teaching. Two illustrative lesson design examples are provided to showcase how the design approaches and framework can be operationalised. In addition, the article also offers a thoughtful discussion concerning the potential challenges of delivering the two sample lessons as well as the coping strategies. It contributes to understanding of STEM education theories and provides a valuable reference for educational practitioners.

Keywords Design approaches · Hong Kong experience · Small class teaching · STEM education

✉ Weijun Liang
weijun15@connect.hku.hk

[1] Faculty of Education, The University of Hong Kong, Pokfulam, Hong Kong

Introduction

STEM (an acronym for Science, Technology, Engineering, and Mathematics) education has been gaining increasing popularity and become a buzzword in many education systems across the globe. Starting from 2015, Hong Kong, an international metropolis, has strived to promote STEM education with a view to fostering innovation and enhancing competitiveness. At the curriculum level, the Hong Kong education authority has updated and enriched the curricula of the Science, Technology and Mathematics Education Key Learning Areas (KLAs) (Curriculum Development Council [CDC], 2015). Integrated learning activities (e.g. Innovation Competitions and STEM Learning Day) for the highlighted KLAs have also been heavily promoted. At the teacher training level, the Hong Kong Government has offered substantial funding (i.e. more than HK$20 million) to strengthen the professional development of teachers and schools through STEM training workshops. School leaders, including school supervisors and heads, have also been invited to join a variety of training seminars to obtain a better understanding of the STEM education initiative. In general, STEM education has been envisaged as an innovative teaching and learning strategy that places a high value on interdisciplinary knowledge and constructivist learning (Hong et al., 2019; Lin et al., 2019). It often goes hand in hand with other educational reform initiatives such as small class teaching to promote quality teaching and learning.

Indeed, Hong Kong has been promoting small class teaching in public sector primary schools for over a decade. Whilst Hong Kong primary classrooms have long been portrayed as teacher-centred, curriculum reforms have endeavoured to shift that dominant pedagogy to a pupil-oriented approach (Mok & Morris, 2001; Yan & Brown, 2021). Against this backdrop, there has been a call for class size reduction to further promote pupil-centred learning. In Hong Kong, however, small class teaching was not officially launched until 2009, lagging behind many of Hong Kong's neighbouring countries and regions. Advocates of small class teaching suggest that its potential benefits include more time to cater for learner diversity, a greater variety of teaching and learning strategies, a closer teacher–student relationship (Hui et al., 2019), increased student participation and teacher–pupil interaction, more space for classroom activities, and fewer classroom management problems (Lai et al., 2016). However, little is known about how STEM education can be promoted in a way that maximises such benefits.

To address this knowledge gap, the article begins with a comprehensive review of the STEM education policy and Small Class Teaching initiative, followed by two examples of lesson design showcasing the incorporation of STEM education into small class teaching settings. Drawing on the framework of the six principles of small class teaching and two design approaches for STEM activities, this article analyses and discusses the design of two lessons in great depth whilst suggesting ways of capitalising on small classes to promote STEM education.

Review of the STEM Education Policy and Related Classroom Practices in Hong Kong

According to Bybee (2010), STEM is used as an acronym for Science, Technology, Engineering, and Mathematics and is originated by the National Science Foundation in the 1990s. Some scholars argue that only when the four disciplines of STEM are taught in an integrated manner, the education a student receives can be called STEM education (Brown et al., 2011). On the other hand, the term STEM has been employed "as a generic label for any event, policy, program, or practice that involves one or several of the STEM disciplines" (Bybee, 2010, p. 30).

In the Hong Kong context, STEM education mainly focuses on Science, Technology and Mathematics Education (CDC, 2015), with Engineering Education playing a peripheral role (Kutnick et al., 2018). In other words, STEM education encompasses three KLAs, namely the KLAs of Science, Technology and Mathematics Education, whereas Engineering Education is being promoted within the traditional STM curriculum areas. This suggests that Engineering Education does not enjoy the same status as other subject areas, and students' exposure to actual engineering topics is rather limited (Education Bureau [EDB], 2014). Since engineering-related subjects are mostly taught to senior secondary students, secondary students take more STM courses than STEM courses (Kutnick et al., 2018), and a similar situation characterises the Western school curriculum (Gunckel & Tolbert, 2018; Nugent et al., 2010).

Although STEM education has been implemented in the United States for decades, STEM education was not officially introduced to the Hong Kong education system until 2015 and is still in its infancy. The introduction of STEM education stems from the economic consideration of maintaining the international competitiveness of Hong Kong by cultivating talents that can keep abreast of the latest scientific and technological advancements (CDC, 2015). Accordingly, in the Chief Executive's 2015 Policy Address, it was proposed that STEM education would be launched at both curriculum and teacher training levels ("The, 2015 Policy Address", n.d.). It is noteworthy that the goal of STEM education in Hong Kong is not to develop all students into scientists and technicians, but to give full play to primary and secondary students' innovation potential and to foster their collaboration, creativity and problem-solving skills (CDC, 2015; EDB, 2016). To accomplish this goal, the CDC issued an official curriculum document entitled "Promotion of STEM Education—Unleashing Potential in Innovation" which put forward six strategies for the promotion of STEM education (CDC, 2015).

At the classroom level, the STEM education policy can be translated into a promising teaching and learning strategy. First, as a teaching strategy, STEM education is characterised by its interdisciplinarity (English, 2016; Fan et al., 2020), meaning that teachers not only need to integrate cross-disciplinary knowledge of STEM subjects but also integrate such instructional factors as motivation, attitudes, and higher-order thinking skills into the creative use of extensive subject knowledge (Hong et al., 2019). Through STEM education, teachers can improve learners' problem-solving capacity and twenty-first century skills because integrated STEM instruction can engage learners in using interdisciplinary knowledge to undertake systematic scientific investigation (Mustafa et al., 2016). Teachers can also use STEM education as a pedagogical strategy to teach students how to apply STEM knowledge to solve real-life problems in an authentic context (Baharin et al., 2018).

Second, as a learning strategy, STEM education entails a student-centred learning environment in which students have ample opportunities to co-construct interdisciplinary knowledge (Walter et al., 2016). To that end, students should be enabled to acquire skills and knowledge for deep learning through hands-on learning experiences (Barak & Assal, 2018; Evans et al., 2014). They should also engage in project-based or design-oriented activities to obtain more collaborative learning experiences (Hong et al., 2019). Moreover, STEM education can be used as a strategy for promoting inquiry- and problem-based learning through which students' STEM capabilities can be developed (Fan et al., 2020; Murphy et al., 2019). Overall, students' engagement and interest in STEM subjects can be enhanced through such learning experiences (Baharin et al., 2018).

Regarding the learning and teaching effectiveness of STEM education in catering for learner diversity, the existing scholarship suggests that to make STEM education effective and inclusive for students with diverse needs, it is important to adopt instructional strategies and practices (e.g. project-based learning) that promote active learning of STEM content, processes, and skills (Peters-Burton et al., 2014). Of equal importance is to support underrepresented students' transitions to a STEM career by offering them bridging and tutoring programmes as well as extended school days or school years (Peters-Burton et al., 2014). In addition, personalisation of learning, problem-based learning, and rigorous learning are also believed to be critical components of inclusive STEM education (LaForce et al., 2016). Featuring these essential elements, inclusive STEM high schools may benefit students with diversified needs, particularly those from underrepresented groups (Means et al., 2017). For these groups, STEM research experiences and project-based instructional practices may help enhance their interests in STEM subjects. More recently, Wilson (2021) explored the effective STEM practices that could cater for learner diversity in a secondary school situated in a diverse community in Australia. The findings revealed the importance of engaging students in active learning, using multi-dimensional assessment that could allow students to display their STEM learning through non-traditional ways, and establishing a school culture that encourages innovative pedagogy (Wilson, 2021).

Small Class Teaching Initiative in Hong Kong

Notwithstanding the prevalence of small classes in many parts of the world such as the Greater China region, the United States and the United Kingdom (Galton et al., 2018), the Hong Kong Government has long opposed the reduction of class sizes on economic grounds (Ip & Lai, 2004) and by drawing on research results that cast doubt on the efficacy of small classes (Harfitt & Tsui, 2015). It was not until 2009 that the Small Class Teaching initiative was launched in Hong Kong by the EDB in response to the declining birth rate and primary student enrolments which slumped considerably by over 30% between the years 2000 and 2010 (Galton et al., 2015). To avoid school closure and teacher redundancy as a result of the decrease in student enrolments, starting from primary one (grade one) in the academic year of 2009–2010, the Government reduced the regular class size from 32–37 to 25 in public sector primary schools by phases. As of the academic year of 2013–2014, this initiative had been extended to primary five (grade five), and more than 70% of primary schools (i.e. around 334) had adopted small class teaching (Zhang & Tang, 2014).

Small class teaching does not simply involve the shrinkage of class size but requires a fundamental shift in teaching and learning approaches from traditional large class/whole class teaching. Whilst in large class teaching the teacher often maintains control by resorting to didactic teaching, with students engaging in rote learning and content memorisation in an examination-oriented, competitive, and independent environment (Fung, 2014; Fung et al., 2017; Lynch & Pappas, 2017), small class teaching has the potential to enable collaborative, interdependent learning and the provision of more teacher attention and caring to individual students (Blatchford, 2003). Another major difference between large classes and small classes lies in the classroom seating arrangement. Students in large classes tend to be seated at individual, teacher-focused desks (Fung et al., 2018), whereas when the class size is reduced, they can sit at movable tables and quickly form groups to engage in collaborative learning (Fung & Lui, 2016). In addition, more classroom space is also one noticeable feature distinguishing small class teaching from large class teaching. When class size is reduced, classroom space relatively increases, thereby allowing a wide range of classroom activities to take place (Ip & Lai, 2004).

Given the marked contrast between small classes and large classes, it is argued that the former provides favourable hardware for the pedagogical shift from didactic teaching to student-centred learning. However, to run this hardware, the use of new pedagogical strategies and principles as the software is pivotal. To capitalise on the small class environment, six pedagogical principles have been proposed as part of the key findings from Galton and Pell's (2009) large-scale study on small class teaching. The six principles are as follows: (1) clearly communicate learning objectives to students; (2) use extended questioning in whole class discussion; (3) encourage more pupil participation; (4) engage students in collaboration in pairs and groups; (5) use more informing feedback; and (6) promote assessment for learning.

The Linkage Between STEM Education and Small Class Teaching

In terms of the relevance of small class teaching to STEM education, the scholarship suggests that amongst the foregoing six principles, the principles of encouraging greater student participation and engaging students in collaborative group work dovetail nicely with the central tenets of Maker Education, which is closely associated with STEM learning. Specifically, Maker Education aims at providing students with opportunities for design and engineering practices (Martin, 2015), highlights learning through making (Halverson & Sheridan, 2014), and helps arouse students' interest in STEM subjects (Hsu et al., 2017). One of the underlying theories of Maker Education lies in active learning and constructivism in which high- and low-performing learners make joint efforts to achieve a shared goal (Martin, 2015; Vygotsky, 1978). Maker Education also emphasises collaborative learning and sharing by engaging students in helping one another to create artefacts and sharing their products with peers (Harvard Educational Review Editorial Board, 2014; Martin, 2015). In particular, in makerspaces which are considered a community of practice (Halverson & Sheridan, 2014), students are encouraged to support one another by engaging in collaborative learning (Oliver, 2016; Schrock, 2014).

Perhaps more importantly, small class teaching is considered conducive to STEM education, particularly with respect to the achievement of certain learning objectives. For example, whilst STEM education attaches great importance to problem-solving and critical-thinking skills and scientific inquiry, which promote higher-order thinking (Baharin et al., 2018), small class teaching environments provide favourable conditions for achieving such educational goals as the development of students' creative and innovation potential. A large body of research has demonstrated that collaborative learning facilitated by small class teaching can contribute to the cultivation of such higher-order thinking skills as critical thinking (e.g. Liang & Fung, 2021; Loes & Pascarella, 2017).

Regarding the significance of and rationale for linking STEM education with small class teaching, as the foregoing literature review demonstrates, small class teaching necessitates a fundamental paradigm shift from traditional large class/whole class teaching to more student-centred and constructivist learning approaches. Such a shift has been consistently promoted in Hong Kong, particularly since the launch of the small class teaching policy in 2009. At the same time, to promote STEM education as an innovative teaching and learning strategy, teachers in Hong Kong are encouraged to employ student-centred and constructivist learning approaches to teach interdisciplinary knowledge and higher-order thinking skills in an integrated manner, which is in alignment with the pedagogical shift underscored by small class teaching. Therefore, it seems meaningful to link STEM education with small class teaching. It is also meaningful to link inclusive STEM education with small class teaching. The reason is that whilst the literature (e.g. LaForce et al., 2016; Peters-Burton et al., 2014) suggests that the former emphasises the use of active learning, personalised learning as well as problem-based learning to cater for students' diverse needs, the latter provides favourable conditions for effective implementation of these teaching and learning approaches. Specifically, when the class size is reduced, teachers can direct more attention to individual students and engage them with diversified student-centred activities. Teachers can also take advantage of a small class environment by adopting multi-dimensional assessment which could empower students to demonstrate their STEM knowledge in their preferred modes (Wilson, 2021). As little scholarship to date has investigated the link between small class teaching and STEM education at the classroom level or documented the design of hands-on STEM learning activities (e.g. project-based or design-oriented activities) underpinned by student-centred and constructivist learning approaches, this article constitutes a worthwhile endeavour that sheds useful light on the design of STEM education in small class settings.

Using the Integration Approach to Design the "Floating-sinking Fish" Activity

In what follows, the article discusses two illustrative lessons showcasing how two design approaches can be used as a heuristic framework to design STEM activities in small classes. The two lessons were designed and delivered in two pilot primary schools in Hong Kong. In each school, each class consisted of around 25 students with prior experience of STEM courses. The students had mixed learning abilities and were generally from a middle socioeconomic background. Most of the participating teachers had undergone continuous professional development in STEM education, although they did not all hold a degree in a STEM-related subject. Because one of the two schools is located in a central district with some traffic lights in the vicinity, the teachers designed a STEM project based on such features of the surrounding neighbourhood to make it relevant to students' daily life.

The first approach to STEM lesson design is the *Integration approach*, namely selecting one KLA topic as the lesson base and incorporating relevant knowledge and skills from other KLAs (CDC, 2015). The lesson illustrating this approach is a STEM experiment called "floating-sinking fish" (see Fig. 1 for a sample of students' work). The topic "Amazing Water" from the "Water and Air" unit of the KLA *Science Education* is used as the base of the STEM activity, with relevant learning elements from the KLAs *Technology Education* and *Mathematics Education* playing a minor supporting role. Specifically, as the worksheet of the activity demonstrates (see Appendix I), *Science Education* involves the development of a skill set for scientific inquiry (e.g. observing, making hypotheses/ predictions, measuring, recording, making inferences, analysing and synthesising data) and the explanation of the relationship between an object's density and its sinking and floating. The "floating-sinking fish" activity comprises seven key stages which embody a standard scientific inquiry process. More specifically, the first stage encompasses two stimulating questions for students to brainstorm and explore: (1) What is the cause of an object's sinking and floating in the water? and (2) What are the factors that can change the floating and sinking of an object? At the second stage, based on the two foregoing questions, students then make hypotheses about the relationship between an object's density and its sinking and floating. For instance, they can hypothesise that objects with lower density than water will float on the surface whilst those with higher density will sink to the bottom. To test the hypotheses, proceeding to the third stage, students are then required to design an experiment by identifying experiment materials and drawing design diagrams. Indeed, this stage involves the learning elements of *Engineering Education* in the sense that it draws on the maker/making model which requires selecting materials to design and create "floating-sinking fish". The materials may include a plastic fish, a screw cap, two oily pens with different colours, a bucket, a plastic bottle, and a measuring cup. With these materials and design diagrams, in the ensuing stage, students start to conduct the experiment and collect data. The experimental steps should include the following: (1) use a measuring cup to obtain 800 ml of water, then pour the water into a plastic bottle and tighten the cap; (2) put a screw cap on the mouth of the plastic fish; (3) colour the plastic fish with an oily pen; and (4) place the fish in a bucket of water and carefully observe what proportion of the fish floats on the water surface. Students can adjust the amount of water in the fish by squeezing the fish until only a small proportion of the fish floats on the water surface. Subsequently, in the fifth stage, students test the hypotheses and observe the results. They can observe (1) whether the fish will float on the surface or sink to the bottom when it is placed inside the plastic bottle; (2) whether the fish will sink when they use their hands to press the bottle; (3) whether the fish will float when they relax their hands; and (4) in general, whether the fish can float and sink easily and smoothly. In the second last stage, students analyse the experimental results. In the final stage, students should be able to draw the following conclusion from the experiment: When the density of an object is higher than that of water, the object will sink, and when the density of the object is lower than that of water, the object will float.

With regard to *Mathematics Education*, this STEM experiment incorporates the knowledge and concept of volume and fraction. First, it prompts students to use a measuring cup to obtain the required volume of water. Second, it encourages students to think about how to equally divide a bottle of water into several proportions and gain a desired amount. To this end, the following challenging question can be posed to students: How can they fill three quarters of the bottle without using a measuring cup? They can then apply their knowledge of fraction to address this challenge. First, they pour the water from a big bottle into four empty bottles of the same size whilst ensuring that the water in the four bottles has the same height. If the height is inconsistent, they should adjust the height of water in each bottle until it is the same across four bottles. Then they pour the water of three of the bottles into the big bottle to get the desired volume of water, namely three quarters of the water previously stored in the big bottle. As for *Technology Education*, the relevant learning element is that teachers can use the online mathematics teaching resources (GeoGebra, https://www.geogebra.org) to show students measuring cups of different capacities and ways of reading different scales so as to help students measure a specified volume of water during the STEM activity.

Fig. 1 A sample of students' work called "floating-sinking fish"

In this STEM activity, the connection of the four disciplines of STEM lies in the relevance of other subject areas to the selected Science Education topic. Specifically, Engineering Education manifests itself in the design and making of the "floating-sinking fish", which provides the key experimental instrument for the Science Education topic regarding the relationship between an object's density and its sinking and floating. Mathematics Education focuses on the knowledge and concept of volume and fraction, both of which are required and highly relevant for students to fill the plastic bottle with an optimal volume of water (i.e. three quarters of the bottle) so as to achieve the most ideal experimental results during the STEM activity. Similarly, Technology Education is also relevant and connected to the selected Science Education topic because it uses the online mathematics teaching resources to show students measuring cups of different capacities and ways of reading different scales.

Lastly, the final section of the STEM activity provides students with a self-assessment opportunity through which they use a scale to evaluate their own performance before and after the activity. The evaluation encompasses three dimensions including knowledge, skills, and attitude. Whilst knowledge concerns the scientific principle of "floating-sinking fish" and the factors influencing objects' sinking and floating, skills include the ability to carefully observe things, to make hypotheses or predictions about scientific issues and to draw conclusions from experiments. In terms of attitude, it refers to interest in scientific inquiry and the capacity to collaborate well with peers to conduct group experiments. The self-assessment allows students to reflect on and share the difficulties and challenges their groups encounter during the entire scientific inquiry process and how they attempt to develop the solutions. To ensure the quality and reflectiveness of students' self-assessment experience, the following mechanism is proposed. After self-assessment and reflection, students need to share their learning gains and thoughts in groups of four. Each group should have a leader guiding the discussion on the quality of self-assessment. The groups should also engage in a process of peer evaluation in which teachers play the role of facilitator by providing contingent scaffolding to ensure that such evaluation cultivates a sense of reflective learning in students. It is believed that self-assessment followed by peer evaluation can lead students to collective improvement and a thorough understanding of their strengths and weaknesses in terms of knowledge, skills and attitude.

Using the Project Approach to Design the "Intelligent Traffic Lights" Project

Whilst the first example generally follows the *Integration approach*, the second example, namely, the "intelligent traffic lights" project (see Fig. 2 for a sample of students' work), follows the *Project approach* by initiating a project that involves learning elements from the KLAs of *Science Education*, *Technology Education* and *Mathematics Education*, with *Engineering Education* being promoted within the STM curriculum (CDC, 2015). The project is concerned with the making of intelligent traffic lights (see Appendix II for the worksheet for the project). To start with, students are presented with an everyday situation which has great relevance to them. Specifically, the situation or problem is that due to the lack of traffic lights in an intersection near the school, students inevitably cross the road with great danger. If students can design intelligent traffic lights to solve this problem, their safety can be ensured. This STEM project encompasses two tasks. The first task involves programming the traffic lights to make them perform a series of tasks, which constitutes the learning elements of *Technology Education*. In this task, teachers first briefly introduce BBC micro:bit which is a mini computer and requires programming in order to perform desired functions. To scaffold students' programming, teachers can offer a description of what the BBC micro:bit needs to do. For instance, it should make the traffic lights turn and keep red so that vehicles can drive past the junction. Subsequently, if the A button of the traffic lights (i.e. the A button in the BBC micro:bit) is pressed, the lights should turn green within three seconds, which will allow time for vehicles to stop and let pedestrians cross the road. Lastly, the BBC micro:bit should make the green light turn red in another three seconds so that vehicles can drive past the intersection after pedestrians cross the road. Step-by-step instruction can be provided to help students conduct programming using the online tool (http://makecode.microbit.org/#editor) to control the traffic lights. After students learn about the basics of programming, they can be challenged to a more advanced level which requires them to increase the duration of the red light.

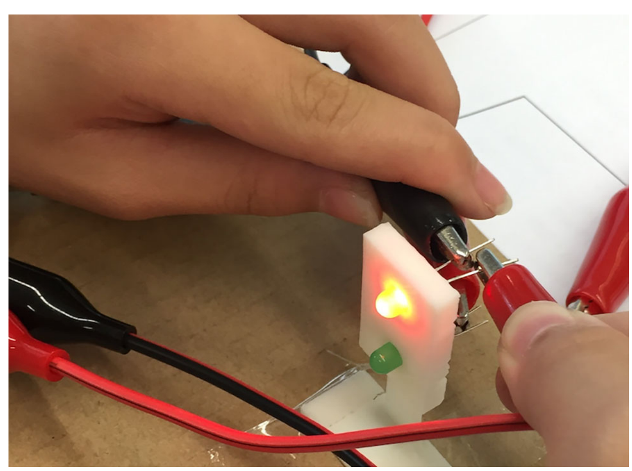


Fig. 2 A sample of students' work called "intelligent traffic lights"

The second task requires students to make traffic lights, which reflects the learning elements of *Engineering Education*. Students can make use of the following materials including the BBC micro:bit along with a battery case, red and green LED lights, traffic light holders, wire, metal stickers, and cardboards. Then students should be required to draw a design diagram for the intelligent traffic lights to ensure that the red and green LED lights have a closed circuit. Indeed, the concept of closed circuit constitutes the learning elements of *Science Education*. Apart from Science Education, this STEM activity can also involve *Mathematics Education* if students are required to measure the width of the road and calculate pedestrians' pace so that they can suggest reasonable crossing time. This is indeed necessary because the crossing time for pedestrians is only three seconds in the project, which seems too short.

In this STEM project, the four disciplines of STEM are connected in the sense that each stage of the project requires an integrated use of knowledge of different disciplines. In the first stage, students need to use the BBC micro:bit to conduct programming for the traffic lights, which forms part of Technology Education. Subsequently, they need to apply their mathematical knowledge in measuring the width of the road and calculate pedestrians' pace so as to work out reasonable crossing time, which is indicative of Mathematics Education. In the next stage, they should assemble the traffic lights, which is what Engineering Education concerns. Lastly, they need to understand the concept of a closed circuit in order to successfully connect the circuit components of the traffic lights, and this involves the learning elements of Science Education. As a brief summary, Table 1 below compares and contrasts the design of the two STEM lessons in terms of their goals, design approaches, STEM elements, advantages, and disadvantages.

STEM Education in a Small Class Teaching Environment

Central to this article is its illustration of how STEM lessons can be designed in small classes. If the two above-mentioned STEM lessons were to make the best of a small class teaching environment, theoretically they should be implemented with reference to Galton's (2010) framework of the six principles of small class teaching. According to the framework, when teaching small classes, teachers should consider three important dimensions including curriculum, pedagogy, and assessment. They should ensure that the curriculum sets clear and achievable learning goals and can employ such pedagogical strategies as using extended questioning, promoting active pupil participation, organising pair/group work, and providing informing feedback. In terms of assessment, they ought to use more assessment for learning than assessment of learning. This framework provides a holistic understanding of the inter-relationships amongst curriculum, pedagogy, and assessment. In the following paragraphs, the article elaborates how the six principles of small class teaching can be operationalised in the two STEM lessons presented above.

First, in articulating the learning objectives, teachers need to not only describe the activities but also clarify their purposes (Galton, 2010). For instance, the learning objective of the "floating-sinking fish" activity can be to design and make a model to display how fish sink and float and to understand what makes fish sink and float through scientific inquiry. The learning goal of the "intelligent traffic lights" project can be to make traffic lights and to solve the safety problem for pedestrians.

Second, teachers should use extended questioning in class discussion. In other words, they should encourage and elicit more and detailed responses from students by using

Table 1 STEM lessons using the two design approaches

STEM lesson	Floating-sinking fish	Intelligent traffic lights
Goal	Make inventions	Solve everyday life problems
Design Approach	The Integration Approach: select one topic of KLAs as the base and incorporate relevant knowledge and skills from other KLAs	The Project Approach: use a project that integrates pertinent learning elements from different KLAs
Science Education	Cultivation of skills for scientific inquiry	The concept of closed circuit
	Relationship between an object's density and its sinking and floating	
Technology Education	Online mathematics teaching resources (GeoGebra)	The use of BBC micro:bit for programming education
Engineering Education	Design and make "floating-sinking fish"	The making of traffic lights
Mathematics Education	The knowledge and concept of volume and fraction	Measure the width of the road and calculate pedestrians' pace so as to work out reasonable crossing time
Advantage	Low cost of experiment materials	Hands-on and minds-on
	Emphasis on enhancing students' scientific inquiry skills	Relevant to students' everyday lives
Disadvantage	Relatively less cognitively demanding	High cost of experiment materials

such encouraging remarks as "Excellent. Can you say more?" and "Would anyone like to add more?" (Galton, 2010). Meanwhile, teachers should provide more wait time for students' extended responses (Galton, 2010). In the "intelligent traffic lights" project, at the beginning of the class, teachers can raise the question about how students can design traffic lights to address the safety issue in the crossroad and activate their thinking by inviting elaborated responses.

Third, to promote pupil participation, teachers ought to consider whether the context of a task is meaningful, relevant and motivating to students. Prior to the commencement of a task, they should allow students to brainstorm ideas of a relevant topic (Galton, 2010). For instance, in the case of "floating-sinking fish", two stimulating questions are available for students' brainstorming and exploration: (1) What is the cause of an object's sinking and floating in the water? and (2) What are the factors that can change the floating and sinking of an object? In the "intelligent traffic lights" project, students are supposed to be very familiar with the context of the task and find it meaningful and motivating to address a safety problem closely related to them.

Fourth, it is indispensable to enhance cooperation among pupils. To this end, teachers should make sure that the pair and group work assigned to students is academically challenging (Galton, 2010) and that students receive sufficient training in using ground rules to govern their cooperation (Fung & Howe, 2014). An often neglected but indispensable element is a debriefing session in which students discuss and reflect on how well they work as a pair/group and how they can improve next time (Galton, 2010). Take the "intelligent traffic lights" project for example: the task of conducting programming for micro:bit is novel and challenging to pupils who need to work in groups and follow some classroom rules to achieve a shared goal. At the end of the project, they need to conduct self-assessment which functions in a way similar to a debriefing session.

Fifth, it is recommended that teachers should use more informing feedback instead of corrective feedback (Galton, 2010). This means that teachers' feedback should help pupils to identify and self-correct their own mistakes rather than simply pointing out their mistakes and offering the right responses. For instance, in carrying out the "floating-sinking fish" activity, when students record the observational results of the experiment, they may find that the fish cannot sink and float easily and smoothly. Under this circumstance, teachers can provide the following informing feedback: "That's a good try, but what problems do you think the fish may have?" and "How did you make the fish?"

Sixth, it is significant for teachers to promote assessment for learning which uses formative assessment to evaluate students' learning progress and to provide individualised instruction to cater for students' diverse needs. In addition, the classroom organisation should have enough flexibility in letting students with similar needs to learn together. More significantly, formative assessment should take the forms of both oral and written assessments (Galton, 2010). In the example of "intelligent traffic lights", it is very likely that when pupils are challenged to increase the duration of the red light, they may encounter great difficulties and make mistakes. Under this circumstance, teachers can use formative assessment by asking individual pupils questions to check their understanding of the concept of programming, thereby adjusting their instructional techniques and scaffolding provided. In addition, at this point, teachers can insert a self-assessment section for students to think about what they perform well or struggle with. Based on students' in-process evaluations of learning progress, teachers can then enhance their instruction and student learning.

Discussion and Implications

Whilst the potential of the two STEM lessons can be maximised by upholding the six principles of small class teaching, both practical and pedagogical challenges may affect lesson delivery. For instance, the practical challenges of the "floating-sinking fish" lesson may include a lack of laboratory technicians to buy the requisite experiment materials in Hong Kong primary schools, which could reduce teachers' willingness to conduct the experiment with students. It is thus strongly recommended that Hong Kong primary schools follow their secondary school counterparts in employing technicians to support teachers in their preparation of STEM experiments and activities, thereby easing the latter's workload. For the "intelligent traffic lights" lesson, because it involves Maker Education, which is not part of the formal curriculum, schools need to allocate a proportion of lesson time to it within an already tight school schedule, which can cause timetabling issues. Moreover, in order to prepare this kind of lesson well, teachers need to invest additional time in learning about programming (or coding) and updating their professional knowledge. Special attention should therefore be paid to both curriculum time and teachers' availability for professional development in designing this type of STEM lesson.

Pedagogically speaking, it is noteworthy that in Hong Kong, engineering-related subjects are taught primarily to senior secondary students. Therefore, secondary students in general take more STM courses than STEM courses

(Kutnick et al., 2018). Exacerbating the problem is that even when engineering is taught within the STEM curriculum, teachers may not be equipped with sufficient expertise and resources or effective pedagogical strategies (Cavlazoglu & Stuessy, 2017; Lee et al., 2019; Nathan et al., 2010). The majority of teachers in Hong Kong are generally not well prepared for STEM education, meaning they have a wide range of concerns (Geng et al., 2019). Therefore, both teacher and student knowledge of engineering and readiness for STEM education and Maker Education are in urgent need of enhancement, which may pose formidable challenges to delivery of the two STEM lessons discussed herein. To address these challenges, it is suggested that more professional training programmes in STEM education in general and engineering education in particular should be provided to school leaders and teachers. If sufficient training in these areas is provided, then school leaders and teachers can be expected to enhance their expertise and self-efficacy in the planning and delivery of STEM programmes. As a result, the potential of STEM education as a teaching and learning strategy is likely to be fully realised, leading to truly integrated STEM instruction and a student-centric learning paradigm.

Another potential pedagogical challenge is that whilst small class teaching calls for a paradigm shift from teacher-centred to student-oriented teaching, STEM education requires the teaching of basic knowledge of science, which is often delivered through traditional or whole class didactic teaching. When delivering the two STEM lessons in small classes, teachers may therefore feel confused about how to strike a healthy balance between using whole class teaching to present the fundamentals of science and promoting collaborative group work to enhance students' hands-on skills.

Finally, because both STEM lessons emphasise the connections amongst the four STEM disciplines, without sufficient interdisciplinary understanding, teachers may be easily misled by the STEM acronym to feel that an integrated STEM lesson is a lesson that simply involves elements of each STEM-related subject (Kelley & Knowles, 2016; Ryu et al., 2019). They may fail to recognise the interrelationships amongst the STEM subjects, and thus deliver the two lessons in an ineffective manner. As Lin et al. (2019) suggest, interdisciplinary STEM learning occurs only when the four STEM disciplines are taught in an integrated manner. Therefore, it is crucial for teachers to develop an interdisciplinary understanding of STEM.

This article has broad implications for scholars, educational practitioners, policymakers and other stakeholders in the STEM education community. First, the article enriches the design approaches for STEM activities recommended by the Hong Kong education authority by adding learning elements of Engineering Education and infusing engineering into the STM curriculum, which suggests that the two approaches discussed are rather flexible and that variants may be plausible. For instance, it is possible within the Integration approach to select two topics and learning elements from two KLAs as the lesson base and then integrate learning elements from another KLA and Engineering Education. Scholars in the field of STEM education may thus find some food for thought from this article regarding the theoretical frameworks for planning STEM activities. Second, each of the two STEM lessons embodies a different design approach. Learning from the two lesson designs, educational practitioners may garner a more concrete understanding of the two design approaches and make effective use of them in their future planning and designing of STEM-related tasks. Third, since there has been a lack of scholarship discussing ways of capitalising on small classes to implement STEM education, this article constitutes a pioneering attempt to provide educational practitioners with insights into integrating the framework of the six principles into the STEM activity process. It is hoped that with the abovementioned examples of applying the principles in the STEM activities, STEM instructors are inspired to be creative in finding alternative ways of integrating STEM education into small class teaching. In other words, the examples provided are not meant to be exclusive, but to serve as a starting point for figuring out varying ways of following the six principles in STEM education. Fourth, for policy makers, they may find this article a useful reference for enhancing the linkage between small class teaching and STEM education at the policy level. It is suggested that they should offer more guidelines and blueprints in relation to effective strategies for promoting STEM education in the context of small class teaching. Last but not least, the article may have great relevance to other countries and regions which also have a dual focus of STEM education and small class teaching. For instance, the Hong Kong experience is likely to be useful to mainland China, Taiwan, Japan, and South Korea.

Conclusion

This article begins with a review of the STEM education policy and the Small Class Teaching initiative in Hong Kong, followed by two examples of lesson design illustrating how STEM education can be designed in a reduced class size setting. Both the potential practical and pedagogical challenges of delivering the two STEM lessons are discussed, and coping strategies proposed. One of the article's significant contributions lies in its strong theoretical foundation in drawing upon two design approaches to STEM education and the six-principle framework for small class teaching. The article also helps fill the knowledge gap concerning the connection between STEM education and small class teaching by discussing both the theoretical underpinnings and design of two exemplary STEM lessons in the context of small classes. Lastly, it is argued that the article has important implications for scholars, educational practitioners, policymakers and other stakeholders putting concerted efforts into promoting STEM education.

Appendix I

The Worksheet of the "Floating-sinking Fish" Activity

常識科 STEM 工作紙

「浮沉魚」科探活動

（一） Science（科學教育）

科學技能 (活動前):

觀察	假設 / 預測	分類	量度	記錄	推論	分析和綜合數據	設計公平測試	其他

A. 探究問題：

1. 物體在水中能夠浮沉的原因是什麼？

____

____

2. 有哪些能夠改變物體浮與沉的因素？

____

____

老師提示：單元一《水和空氣》主題：奇妙的水（P. 4）

科學原理

1. 認識浮沉魚的科學原理
2. 認識物體的密度與其浮沉的關係

1

B. 擬定假設:

(例子: 假設密度低的物體將會浮於水面)

(例子: 假設密度高的物體將會沉於水底)

C. 設計實驗:

材料:

設計圖:

（二）Engineering（工程教育）

老師提示：Maker/Making/Model 選用材料設計及製作浮沉魚

基本材料及步驟：

材料和工具

1. 豉油魚 1 條 	2. 螺絲帽 1 粒 
3. 油性筆 2 支 (不同顏色) 	4. 水桶一個 
5. 塑料瓶 1 個 （瓶內注水 800 毫升） 	6. 量杯一個 

設計圖:

3

D. 進行實驗及收集數據:

步驟:

____

____

____

____

1) 使用量杯量度 800 毫升水，然後把水倒進塑料瓶， 扭好瓶蓋；
2) 將豉油魚的嘴用螺絲帽套住；
3) 將豉油魚魚身用顏色筆（例如油性筆） 塗色；
4) 將浮沉魚放置於盛有水的水桶，仔細觀察浮沉魚浮出水面高度，可通過擠壓魚身調整魚內水量，直至浮沉魚只露出水面少許，如果露出水面太多，會影響實驗效果 。

E. 測試及觀察結果:

1) 當浮沉魚被放置於塑料瓶內，浮沉魚會（浮於水面/沉於水底）。
2) 當我們用手施壓於瓶身時，浮沉魚（下沉/沒有下沉）。
3) 當我們把手放鬆時，浮沉魚（上浮/沒有上浮）。
4) 總體而言，浮沉魚（會/不會）浮沉自如。

F. 分析結果:

因為水有壓力，所以當我們對差不多盛滿水的塑料瓶的瓶身施壓時， 浮沉魚會受到增大了的水壓， 更多水會通過魚嘴流入魚內， 魚的質量會因此增加，魚的密度會變得大於水，結果會往下沉。

放鬆手時，水壓__________，之前被壓進浮沉魚內的水便從魚嘴流出來，浮沉魚的質量會因此__________，魚的密度__________水，並因而__________。

總結：當物體的密度大於水，物體就會沉下去；當物體的密度小於水，物體就會浮上來。

4

G. 結論:

____

____

(當物體的密度大於水，物體就會沉下去；當物體的密度小於水，物體就會浮上來。)

科學技能**(活動後):** :

觀察	假設 / 預測	分類	量度	記錄	推論	分析和綜合數據	設計公平測試	其他
✓	✓		✓	✓	✓	✓		

（三） Maths（數學教育）

知識：1. 認識體積的概念

2. 認識分數的概念

技能：1. 學會使用量杯量度規定的水量并注入容器

2. 懂得把一瓶水平均分成若干份，并得到想要的分量

問題：在不使用量杯的情況下，怎樣裝滿四分之三的水瓶？

步驟：____

____

____

____

老師提示：

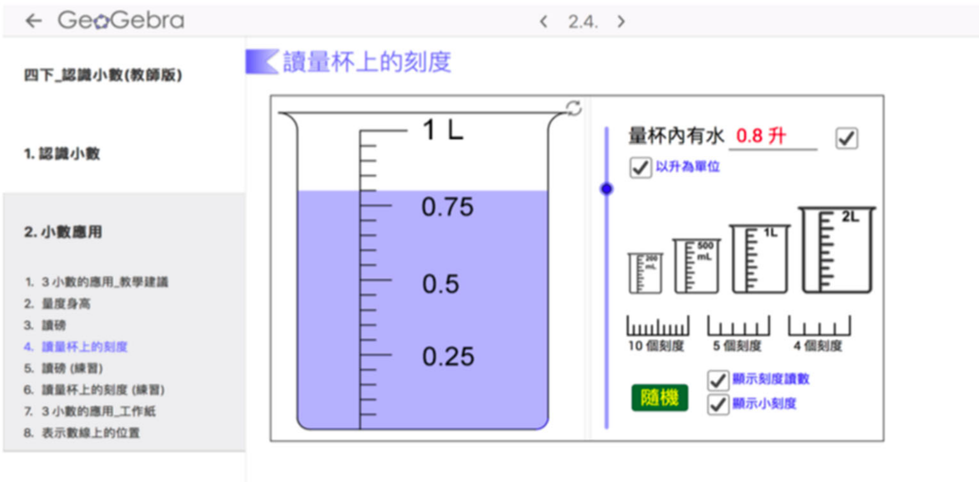
1. 把一瓶裝滿水的水瓶的水均勻倒進四個大小一樣的空瓶里，注意觀察四個瓶里水的高度是否一致；
2. 如不一致，調整各個瓶里水的高度，直至各瓶水高度一致；
3. 把其中三個瓶的水注入原先裝滿水的水瓶，得到四分之三的水量。

5

（四）Technology（科技教育）

知識：認識不同容量量杯及不同刻度讀數

資訊科技元素：教師運用網絡數學教學資源（GeoGebra）向學生展示不同容量量杯及不同刻度讀數方法，幫助學生在活動時用量杯量度指定的水容量



鏈接：https://www.geogebra.org/m/vwPDHPGX#material/KXYNDWDn

自評

範疇	評估項目	活動前表現（優良 ---- 欠佳）	活動后表現（優良 ---- 欠佳）
知識	1. 對浮沉魚的科學原理的認識。	4 3 2 1	4 3 2 1
	2. 對影響物體浮沉因素的認識。	4 3 2 1	4 3 2 1
技能	3. 能做到仔細觀察事物。	4 3 2 1	4 3 2 1
	4. 能對科學問題進行假設或預測。	4 3 2 1	4 3 2 1
	5. 能通過實驗得到結論。	4 3 2 1	4 3 2 1
態度	6. 對科學探究有興趣。	4 3 2 1	4 3 2 1
	7. 能與同學愉快合作進行小組實驗。	4 3 2 1	4 3 2 1

反思與分享

在整個浮沉魚科學探究活動中，我們組遇到以下困難與挑戰，并嘗試這樣解決：

____

____

____

Background Information

There is an intersection near the school gate. Unfortunately, due to the lack of traffic lights in the intersection, students cross the road with great danger. If students can design intelligent traffic lights to solve this problem, their safety can be ensured.

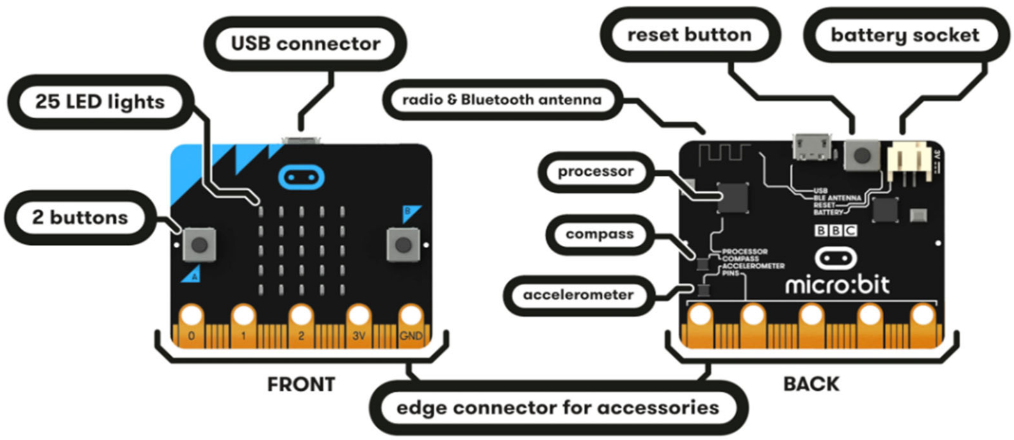
The Tasks

You need to complete two tasks in order to make the intelligent traffic lights. The first task involves programming the traffic lights to make them perform a series of tasks. The second task is to connect all circuit components properly to make the traffic lights work.

Appendix II

The Worksheet of the "Intelligent Traffic Lights" Project

Introduction of BBC Micro:bit



(Source: https://microbit.org/hk/guide/features/)

BBC micro:bit is a mini computer and requires programming in order to perform desired functions.

Programming

Before conducting programming for the traffic lights, you can think about and write down what BBC micro:bit needs to do. For instance, it should make the traffic lights turn and keep red so that vehicles can drive past the intersection. Then if the A button of the traffic lights (i.e. the A button in the BBC micro:bit) is pressed, they should turn green in three seconds, which will allow time for vehicles to stop and let pedestrians cross the road. Lastly, BBC micro:bit should make the green light turn red in another three seconds so that after pedestrians cross the road, vehicles can drive past the intersection.

You can use the online tool (http://makecode.microbit.org/#editor) for programming.

Challenge Yourself!

Could you adjust the traffic lights to deal with the following situation?

> Some impatient people keep pressing the green light button in order to go across the road as soon as possible. But this would keep the green light on for a long time and cause traffic jam. Could you revise the programme to increase the duration of the red light so that vehicles have enough time to pass?

Making the Traffic Lights

Some materials required:
BBC micro:bit along with a battery case, red and green LED lights, traffic light holders, wire, metal stickers, cardboards.

Before you connect the circuit components, you need to draw a design diagram for the intelligent traffic lights to ensure that the red and green LED lights have a closed circuit.

After completing the diagram, you should start assembling the traffic lights and test whether they function properly.

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