A Design-Led Approach to STEM Education: Challenges and Opportunities in Hong Kong Secondary School Teachers' Responses to D-STEM

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Abstract
Science, Technology, Engineering, and Mathematics (STEM) education is now recognised as a key factor in the development of a country's workforce and economy. In Hong Kong, the design-led approach to STEM (D-STEM) facilitates the integration of creativity and technology and thereby encourages students to adopt collaborative and reflective processes and helps them develop the interdisciplinary skills necessary to solve real-world challenges. In fact, there are several difficulties facing by the secondary school teacher's in promoting D-STEM during execution in which there was limited research focusing on this issue in the past. Therefore, this paper aims to examine the challenges of the secondary school teachers in teaching and learning D-STEM and to investigate potentials opportunities accordingly via the use of a design-led approach as a solution in tackling problems. A mixed-methods approach was adopted for the study in both quantitative and qualitative measure in data collection. The findings showed that this intervention addressed the teachers' deep concerns about the management of STEM teaching and learning in schools by providing guidelines during the implementation of D-STEM classes, content based on advanced technology and materials, and a teaching toolkit with materials and activities. The participating teachers expressed a high degree of satisfaction with the programme and they believed that the interdisciplinary approach of D-STEM would provide opportunities for students to learn from each other's strengths. The findings reported here and those of the whole research will advance D-STEM education and serve as a guide for developing and implementing D-STEM curricula in Hong Kong.

Keywords: Design-Led STEM, Secondary Schools, Hong Kong, Teaching and Learning

Introduction

Science, Technology, Engineering, and Mathematics (STEM) education takes a multidisciplinary approach to school-based learning in which students find solutions to specified problems in authentic situations (Holmlund, Lesseig, & Slavit, 2018). D-STEM uses design as the media for problem-solving in STEM education to promote authenticity and student engagement in which creative and scientific disciplines naturally intersect (Trevallion, 2020; Henriksen et al., 2019). According to Toomey and Kapsali (2014), there are four principles of D-STEM practice: (a) design using advanced fabrication, (b) designing advanced material systems, (c) designing with advanced materials, and (d) designing products with advanced functionalities.

Despite an enormous funding in HK$500 million in STEM teaching and research from the government, lacking of clear teaching guidelines in STEM education still was a critical issue suffocate the promotion and development of STEM (Ho, 2021). The review of Lee, Chai, and Hong (2019) found that despite many studies being labelled as STEM-focused, most have in fact placed emphasis on one of the four aspects of STEM, usually science. There is an urgent need to realise this interdisciplinary and collaborative approach to ensure that local students meet the competitive demands of the future workforce (Lo, 2019). This study examined a design-led approach to STEM education that aims to integrate design thinking and practice in the delivery of STEM content.

In the absence of a standardised curriculum, schools have been given the autonomy to develop their own STEM content, and there has been a tendency for schools to skew towards science (Geng, Jong, & Chai, 2019; KO, 2018; Leung, 2018; Yeung et al., 2017; Yip & Chan, 2019; Yip, 2019). Besides, Hong Kong lacks clear guidelines for STEM learning and evaluation (Education Bureau of The Government of the Hong Kong Special Administrative Region, 2016). In 2019, the Federation of Education Workers interviewed 50 principals/ deputy principals, 172 STEM teachers, and 98 teachers taking part in STEM education (Oriental Daily, 2019). When asked about the difficulties encountered in teaching STEM, 51% of the respondents reported that they lacked suitable teaching materials and 29% that they had limited expert support and had failed to master the appropriate teaching approaches; only 29% of the respondents believed that the Education Bureau was providing adequate professional support to schools and around 60% disagreed that the Bureau provided clear guidelines and long-term plans for the implementation of STEM education. Many Hong Kong teachers do not have a science background and therefore find it very demanding to teach interdisciplinary STEM education effectively (Leung, 2018; Yeung et al., 2017). A number of studies have identified challenges to the implementation of STEM education in Hong Kong. A study by Geng et al. (2019), for example, indicated that STEM teachers have deep concerns about the management of STEM teaching and learning in schools, and Yip and Chan (2019) reported that science teachers had limited opportunities to improve their STEM teaching skills before they were required to conduct classes. To address these challenges, there is a need for a systematic, multi-stakeholder approach based on close cooperation between the government, education professionals, and design and technology enterprises (Ng, 2017). Education policymakers should formulate plans to resolve the issue of inadequate resourcing and provide clear guidance on how to implement STEM education. Guidance is vital because STEM teachers are drawn from different specialist backgrounds and most are used to working in a highly teacher-centred system. As Yip (2019) noted, teacher professional development in STEM education should consider factors such as the teacher’s background, teaching experience, and understanding of the STEM curriculum.

To encourage the synthesis of design and technological skills, the project reported in this article implemented practice-based workshops using creative experimentation as a "critical activity to interrogate the possibilities of materials" (Toomey & Kapsali, 2014). The teacher workshops featured in this study were part of a longer project implemented over a 15-month period from September 2020 to November 2021. This study investigated Hong Kong secondary school teacher's responses to D-STEM in relation to current teaching approaches to STEM, drawing on data collected through questionnaires and interviews conducted during workshops held for teachers who were delivering D-STEM education to over 480 students. The workshops were conducted by the authors, who are staff members of the Hong Kong Polytechnic University and the Royal College of Art. Design professionals from the Hong Kong design community provided expert reviews of the project. The project sample comprises 31 teachers from nine secondary schools.

The project aimed to address STEM-related challenges by integrating four main features: (a) The use of innovative technology relevant to everyday life as a medium to deliver the D-STEM approach; (b) Practice-based workshops that use hybrid practices to synthesise creativity and technology and thereby foster innovative real-world problem solving; (c) Cross-sector collaboration between academics from Hong Kong and the United Kingdom and the wider Hong Kong design community to co-nurture students and contribute to the teaching and learning experience; and (d) Workshops in studio-lab environments that encourage collaborative practice. The following research questions could be addressed in this study:

1. What experience do the participating teachers have of staff development for STEM?
2. How is STEM content delivered in participating teachers' secondary schools?
3. What impression do the participating teachers have of the D-STEM approach after attending the workshops?
4. What insights can be gained from the participating teachers regarding the feasibility of implementing D-STEM in their schools?

Theoretical Framework

Our practice-based workshops used the UK Design Council's Double Diamond framework for innovation (Design Council, 2019), which encourages both divergent and convergent thinking and combines exploration of the conceptual and practical aspects of a problem. According to (Gustafsson, 2019) and Dowlen (2012), the model applied in the programme had a positive effect on student's abilities to develop ideas, nurture a suitable environment for innovation, and introduce their ideas to the public. However, the author recommended that the programme be carried out over a longer period to achieve significant long-term benefits.

The Double Diamond model sets out a reiterative design process with four components (the "4Ds"):

1. **Discover**. Designers gain an understanding of the problem to be addressed via direct communication and experience, not by making assumptions.
2. **Define**. Deriving knowledge from the insights gained in the first step, designers define the challenge in a different way.
3. **Develop**. Designers seek multiple perspectives and actively explore potential solutions via experimentation.
4. **Deliver**. Different solutions are tested to eliminate unfeasible ideas and further improve viable solutions.

Method

A mixed-methods approach was adopted for the study in both quantitative and qualitative measure in data collection. To gather quantitative data, a questionnaire was designed on the teachers' demographic profiles and professional backgrounds. The questionnaire consisted of 11 questions and was administered online, with the teachers accessing the URL through a QR code provided in the introductory session of the project. The questions are listed in Appendix 1. In additional, to collect rich qualitative data about the current STEM teaching situation of each school, semi-structured interviews were conducted in each secondary school. Open-ended questions were used to encourage in-depth discussion that might yield insights into the situation of each school. The interviews were conducted face to face at the end of the workshop programme. All of the interviews lasted for between 30 and 60 minutes and took place at the workshop venue. The teachers were interviewed by one of the authors and a research assistant. Three interviews were conducted in English and six were conducted in Cantonese. Secondary school teachers in Hong Kong are required to hold either a Bachelor of Education, or a Bachelor's degree in any subject from a Hong Kong university (or equivalent) and a Postgraduate Diploma in Education (or equivalent). English was not the native language of the interviewed teachers but was the primary language for communication at their schools. The teachers had attained professional competence in English during their tertiary education. All of the interviews were recorded and transcribed, and the Cantonese interviews were translated into English to facilitate further analysis.

In terms of sampling, participants were recruited via email invitations sent to secondary schools in Hong Kong. The invitation email provided details of the research project, and upon confirmation of participation all of the schools were provided with a copy of the full programme. The sample for this study was originally made up of 38 teachers at 10 secondary schools. However, after providing initial consent, one school and its seven teachers opted out of the study, leaving a sample of 31 teachers working at nine schools. Each school was represented by three or four teachers. The research was approved by the Human Research Ethics Committee of the lead author's institution and all of the participants signed consent forms prior to the study. All data collected over the course of the study were treated as strictly confidential and stored securely. The participating schools were assigned codenames for the data analysis, and are referred to as School A, B, C, D, E, F, G, H, and J (with the letter "I" excluded due to potential confusion).

A thematic analysis was made of the interview data, using a semantic approach to identify the extracted codes within the explicit or surface meanings of the data in terms of themes and sub-themes (Braun & Clarke, 2006). The identified themes included school-based experience, workshop expectations, and workshop experience. The interview transcripts were analysed by two researchers working independently, with discussions held to resolve discrepancies.

The D-STEM Programme

The 15-month programme ran from September 2020 to November 2021 and consisted of practice-based workshops for teachers and students conducted by cross-sector collaborators. This study focused on the investigation of Hong Kong secondary school teachers' responses to D-STEM via the teachers' workshops.

The workshops offered a hands-on approach that permitted the participants to co-design and create simple prototypes using artificial intelligence (AI) and e-textiles. The provided materials had application opportunities in fashion, wearables, environmental management, and services. The rationale for using AI and e-textiles is that these are likely to have an increasingly significant impact on products and services.

The academic partners in this research project were The Hong Kong Polytechnic University and the Royal College of Art, with industry support from Fabrica, the Mills, and the Hong Kong Design Centre. The academic partners were responsible for developing the guidelines, content, activities and delivering the programme in the form of workshops, tutorials, and critiquing sessions. International staff trainers from the Royal College of Art conducted the workshop, tutorials, and critiquing via video conference, together with the project members in Hong Kong. Fabrica is an incubator for design and technology start-ups in Hong Kong and supported the research by participating in expert critiquing and sharing sessions and offering their prototyping lab as the workshop venue.

D-STEM Programme Activities

There were five phases to the overall programme: (1) context, (2) demonstration and coaching, (3) reflection, (4) implementation, and (5) review and dissemination. As this study focused on investigating teachers' reactions, the data were derived from activities that took place in Phases 1–3, which are summarised in Table 1.

Phase	Content
1: Context	Pre-workshop introduction: Introduction to project rundown, personnel and collaborators, D-STEM, materials, and technology to be used during workshops. Sharing session with collaborators about current D-STEM applications in industry and their value. Focus group with teachers.
2: Demonstration and coaching	Workshop 1 with teachers: Introduction to AI, intelligent textiles, and soft switches. Challenge and target group identification Storyboard. Exploration and experiments with technology and materials. Workshop 2 with teachers: Prototyping with materials. Presentation boards. Group presentation.
Phase 3: Reflection	Post-workshop focus group and user feedback questionnaire.

Table 1: *Summary of Activities in Phases 1–3*

Phase 4 involved organising workshops in which teachers guided their students by applying what they had learned in the earlier phases, and Phase 5 evaluated the whole programme and disseminated the findings.

Results and Discussion

Demographics and Teaching Experience

The results of the questionnaire survey are summarised in Table 2 and 3. Most of the participants (70.96%) were experienced in teaching who had 11 or more years of teaching experience, and the list of subjects they were teaching covers most of the core and elective subjects in the Hong Kong secondary school system, revealing that the responsibility for delivering STEM is broad-based and that schools appoint a range of staff members to the task.

Characteristic	*n* (%)
Sex	
Male	17 (54.84)
Female	14 (45.16)
Age (years)	
25–35	8 (25.81)
36–45	14 (45.16)
46–55	7 (22.58)
56–65	2 (6.45)
Teaching experience (years)	9 (29.03)
0–10	9 (29.03)
11–20	11 (35.48)
21–30	9 (29.03)
31+	2 (6.45)
Subjects	
Design and Technology	4 (8.33)
Home Economics	5 (10.42)
Information Technology	8 (16.67)
Mathematics	4 (8.33)
Science	7 (14.58)
Visual Arts	8 (16.67)
Others	12 (25)

Table 2: Characteristics of Participating Hong Kong Secondary School Teachers

Characteristic	*n* (%)
School type	
Boys (School A)	1 (11.11)
Girls (Schools B, G, H, and I)	4 (44.44)
Coeducational (Schools C, D, E, and F)	4 (44.44)
School region	
Kowloon	5 (55.56)
New Territories	4 (44.44)
Medium of education	
Cantonese	6 (66.67)
English	3 (33.33)

Table 3: Characteristics of Participating Hong Kong Secondary Schools

Thematic Analysis of the Interview Data

To address the four research questions, the results were analysed by the thematic approach, with the analysis divided into two main parts: an investigation of the current practices in STEM education (addressed in research question 1 and 2) and a study of teachers' expectations and experiences of D-STEM (addressed in research question 3 and 4). In terms of current practice of STEM education in Hong Kong secondary schools, there were six key themes identified in relation to current STEM education practices: (a) The integration of STEM in schools; (b) Staff Development for STEM education; (c) Internal Collaboration and School Support; (d) Project-based learning; (e) STEM teaching and learning environment; and (f) Challenges faced in delivering STEM. The interview data indicated that there are four main ways in which the secondary schools integrate STEM into their curriculum, as follows.

Simultaneous Delivery. It used a common project theme and subject-relevant content across core and elective subjects. School A integrated STEM in multiple key subjects: "We have Information and Communications Technology (ICT), visual art, design and technology; they complement each other and the complementary subjects sometimes involve Chinese, Information Technology (IT) and Mathematics." Each teacher delivers knowledge relevant to their specialist subject to contribute to the STEM programme.

Synchronised Delivery. Four schools (D, E, G, and J) adopted the synchronised approach of delivering STEM content using a common project across different subjects. A teacher from School D explained that relevant knowledge is taught to the students in the Mathematics lesson first, and then in the ICT lesson similar teaching steps are applied. The same goes for Design & Technology (D&T). D&T may help students go through the whole project by integrating what they have learnt. An ICT teacher from School E reported that "we extract content related to ICT from STEM and apply it in different classes and explore ways in which we can cooperate with other subjects. For example, to see which subject should start STEM and which should follow." Teachers from School G reported that they were teaching different subjects separately, normally with a project-based approach. School J had integrated STEM into different subjects: according to one teacher, part of it was in the science curriculum and another part was in IT, in which students learn about AI and robotics.

Extra-Curricular Delivery. STEM content can also be delivered through extra-curricular activities and competitions. School D had five STEM teams, one of which was focused on the Internet of Things (IOT).

Separate Delivery at Different Levels. School H tailored STEM content according to students' levels, with strategic emphasis on the foundational and application-oriented subjects appropriate for each level. As noted by a teacher from School H, "Mathematics teachers are in charge of Form 1 STEM education since the planned focus is on mathematics, while in Form 2 Science teachers deliver STEM." The multiple ways in which STEM content is delivered supports the findings derived from the literature review that schools in Hong Kong are afforded flexibility in the co-ordination, planning, and implementation of STEM content. This enables schools to adjust content according to the school schedule, availability of teaching expertise, and specific needs of their students.

Teachers' Overall Feedback

In terms of teachers' expectations and experiences of D-STEM, the interview data indicated that there are five main ways based on the teachers' feedback, as follows.

Teacher Development. The teachers all acknowledged that staff training for STEM education was a crucial bridge for knowledge transfer. A teacher from School D noted that "it is easier when the teacher gains knowledge and students can learn through us." Every participant reported having actively sought resources for staff training, with teachers from eight of the nine schools having previous experience of STEM-related training. A teacher from School C responded that "there are some workshops organised by the Education Bureau that focus on curriculum design and the integration of STEM into daily school life"; another noted that "since higher form students are preparing for public examinations, seminars from the Education Bureau also discuss the relationship between public examinations, assessment and STEM education." Teachers from School D had attended STEM workshops organised by local universities and local design organisations, such as the Unleash Programme of the Hong Kong

Design Centre. These teachers also reported that they had participated in STEM seminars on design thinking, in which the approach was to offer teacher training at the first stage and for knowledge transfer to students to follow.

Internal Collaboration and School Support. STEM education integrates knowledge derived from different subjects, and collaboration among teachers is a necessary. All of the participating teachers indicated that their schools encouraged cross-disciplinary teacher collaboration and teachers including STEM education as part of their teaching duties. A teacher from School D expressed the view that teachers are not supposed to be expert in all disciplines, so they go and look for help and collaboration because STEM activities are not limited to one subject. A teacher from School G noted that before the introduction of STEM it was difficult for teachers to collaborate, because different teaching strategies were adopted in different disciplines, but STEM now provides opportunities for teachers to operate collaboratively. All schools are motivated to seek interdisciplinary collaboration, but the scale and, to some extent, success of this collaboration is determined by resources and timetables.

Project-Based Learning. Six of the nine schools in this study had integrated STEM into the curriculum through project-based learning. School A was running an interdisciplinary project for students, and a teacher from School H stated that "there are some parts of STEM taught or conducted in the Key Learning Areas (KLAs). We extract those parts and reconstruct them into a study or project." School G was asking students to do project-based work based on what they had learnt in several KLAs. School F had conducted two STEM projects with junior students based on project themes, such as the design of electric cars and hydraulic arms, which require the students to combine science, technology, and mathematics.

The STEM Teaching and Learning Environment. Due to the interdisciplinary nature of STEM, the content is often not delivered through traditional texts but instead makes use of special equipment and materials to facilitate research, experimentation, prototyping, and presentation. A traditional classroom in which most knowledge is transferred by textual and verbal explanation is clearly not the ideal environment for STEM teaching and learning. Three of the nine participating schools had a STEM room on their campus. The STEM room in School A was shared with the associated primary school. The teachers from School B described their STEM room as having been built in late 2019 and equipped with 16 high-specification computers to support 3D applications.

Preconceptions About STEM

Although schools and teachers welcome staff of different disciplines to cooperate on STEM, teachers of certain disciplines may have a preconception that their subjects are not relevant. Whereas educators regard only science, technology, engineering, and mathematics as relevant to STEM, the teachers from School D took a holistic approach and regarded all subjects as relevant to content delivery. For example, language teachers may feel that STEM is not relevant to their subjects, but language is communication and language teachers can help students to present their projects and write scripts.

Expectations and Experiences of D-STEM. The second part of the thematic analysis was focused on the teachers' expectations prior to the workshops and their experience of the workshops and subsequent application of what they had learned to the secondary school curriculum. The themes identified in relation to the teacher's expectations of the workshops were (a) guidelines and teaching resources; (b) collaborative learning and using STEM to solve real-world problems; (c) exposure to advanced technologies and materials; (d) practice-based workshops; and (e) studio-lab environments. While, the themes identified in relation to teachers' experiences of the workshops were (a) exposure to advanced technology, (b) provision of flexible ideas and guidelines; (c) use of practice to instil interest in STEM; and (d) opportunities to collaborate with cross-sector contributors.

Expectations Prior to D-STEM Workshops. The teachers' interview responses indicate that they expected the programme to provide insights and support in the following areas. With regard to the guidelines and teaching resources**,** schools G and J wanted concrete guidelines and specific teaching content that they could adapt for their students. The schools were attracted to the AI and e-textiles elements of the programme and wanted to gain knowledge in these specific areas. Although the teachers from School J had experience with textiles-related STEM content, they were only able to integrate the technology and design elements by directly applying LEDs on fabric, and thus were not able to deliver content involving more advanced materials and technology. The teachers also expressed a keen interest in a comprehensive programme with guidelines, content, and feedback and support from experts across different sectors. In the collaborative learning and using STEM to solve real-world problems, teachers from eight of the nine schools commented that applying STEM in the context of real-world problems faced by students was one of their motivations for engaging in the workshops. These teachers believed that the workshop's interdisciplinary approach would provide opportunities for students to learn from each other's strengths. In terms of exposure to advanced technologies and materials, teachers from five schools (A, B, C, D, and J) expressed their hope that the workshop would help them to introduce students to technologies, such as illuminative polymeric optical textiles and AI, for which resources are not readily available in their respective schools. In practice-based workshops, some of the teachers expressed a specific interest in the practical nature of the programme, especially given that previous STEM seminars or workshops had usually targeted public examinations or been otherwise achievement-oriented. A teacher from School A stated that "Students like to experience different workshops where they learn to create things. They gain confidence through the process of making." In their view, crafting and creating nurtures students' interests and thus encourages them to be more engaged with learning. Under the studio-lab environment, most of the participating teachers had no access to a specific STEM classroom as the STEM content was integrated into the core and elective subjects within the school curriculum. Teachers thus expressed their eagerness to explore how a studio-lab environment, with immediate access to equipment such as computers, 3-D printing, laser cutting, and sewing machines would enable students to experiment and create in a seamless manner.

Experience of D-STEM Workshops. The programme gave the teachers access to technology and materials that would enable them to help students build on their existing knowledge in developing prototypes with advanced capabilities. With the D-STEM programme's introduction to e-textiles, the teachers felt confident about pushing the boundaries of students' knowledge. They noted that the use of e-textiles, such as polymeric optical fibre, obviates the need to launder each component of a garment after use. In terms of provision of flexible ideas and guidelines, teachers from four schools (D, G, H, and J) stated that they would adapt the D-STEM programme for their students. Teachers from Schools G and H noted that the guidelines and content of the programme had given them material that they could "tailor a little bit to fit [their] students" and that would help them integrate design and STEM into the formal curriculum. The teachers from School A, which is a special education boys' school, noted that their students lacked confidence in their abilities in STEM, which predisposed them "to pursue vocational training after S3, because they think they are not capable of attaining their Diploma of Secondary Education." However, these teachers believed that the design-oriented and project-based approach of the workshops could be adapted to the students' interests, allowing them to build confidence in their ability to pursue university education by "seeing the similarity (in work processes) between secondary school and university in terms of the workshop project." The teachers felt that the workshop could help to develop students' problem-solving skills and improve their chances of getting into university. Teachers from School J, an all-girls school, felt that the delivery of D-STEM with e-textiles and AI would enable students to identify applications of the knowledge in aspects of daily life, such as the living environment and fashion. The teachers clearly appreciated the hands-on activities offered at the multidisciplinary workshops. When used in the classroom, these practical activities provide opportunities for students to work together to craft and create. Engagement with this process has the potential to trigger students' passion for STEM and affect their future career paths. With regard to the opportunities to collaborate with cross-sector contributors, three schools (C, H, and J) stated that they valued the opportunity to collaborate with international and local academics and with the local design community. The teachers felt that it would be helpful for students to have early exposure to different sectors to obtain a detailed and realistic understanding of the creative industries beyond the scope of the Visual Arts and Design and Technology subjects offered in school. This collaboration of International staff trainers from the Royal College of Art created a teaching and learning community with a wide range of perspectives and maximised the opportunities for teachers and students to explore, experiment with, and apply their newly acquired D-STEM knowledge. They believed that these insights would help them to strengthen the STEM curriculum in their schools and better prepare their students for tertiary education and work.

Limitations of the Study

One of the limitations of the study is that this was a one-off programme involving teachers and students from a limited number of secondary schools. For the continued evolution of STEM education, a study of the programme conducted with a larger group of secondary school teachers and students would be beneficial. Further studies could also take a more scholarly approach to exploring the influential factors of teacher training for STEM education. A larger study could also expand the scope of the present study by tracking the effectiveness of the teacher training and the effects on student performance over a longer period, with the impact evaluated from the perspective of teachers and students based on their achievements in the programme. A limitation of the interviews conducted in this study is that Cantonese is the main language for communication in most Hong Kong secondary schools, and the interviews were conducted in Cantonese and translated into English for analysis. Cantonese is mother tongue, Chinese and English are mediums of instruction for secondary schools.

Conclusions

This study examined secondary school teachers' responses to a design-led approach to STEM in Hong Kong. Our programme addressed teachers' concerns by providing guidelines, content based on advanced technology and materials, and a teaching toolkit with materials and activities. The project took a discovery-based approach to learning, in which engagement in the experimentation, design, and application of technology precedes analysis and the internalisation of underlying concepts and principles.

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