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An Integrative Evaluation of STEM Policy in Secondary Education: Empirical Reflections, Conceptual Discussions and Policy Implications

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Abstract: Current academic research bodies on STEM education focus on five perspectives of student ability enhancement, teacher training, curriculum integration, pedagogy and curricular implementation in intra-national / cross-national comparative studies. Noteworthy, there has been no comprehensive policy analysis of STEM education in secondary school curricula in Hong Kong. For STEM is not formally documented into school curricula and students mostly join inter-school and international STEM project competitions. International literature reveals that conceptions of STEM education are still fuzzy. In this paper, a 2 X 3 matrix is utilized to evaluate the extent of implementing STEM education in mainstream secondary schools in Hong Kong, and to envisage contextual difficulties and obstacles against STEM education. This paper then leads conceptual discussions on integrated approaches, draw policy implications and recommend further research agendas.

Keywords: STEM education, policy analysis, ICT integration, teacher training, curriculum

1. Introduction

The concept of STEM education emerged in the United States in the 1990s in the hope of nurturing the talent in science and technology through STEM education, enhancing the scientific literacy of the nation, and maintaining a leading position in technology and the economy worldwide. Afterwards some Asian, Australasian and European countries followed the suit, STEM encompasses a multi-disciplinary integration of **S**cience, **T**echnology, **E**ngineering, and **M**athematics. However, such four individual disciplines are not simply superimposed, but are united to form an organic whole to better cultivate students' innovation and exploration and practical skills (Curriculum Development Council, 2015). In primary and secondary school curricula, STEM education is not a stand-alone subject in Hong Kong, but is implemented in cross-learning areas/subjects through the existing science, technology and mathematics education learning areas (The Government of Hong Kong Special Administrative Region, 2020). STEM education fosters student creativity and divergent thinking along with the foundational disciplines, inspires young people to generate new technologies and ideas, and encourages application of knowledge which are the needs of 21st century skills (Norris, 2021).

2. Literature Review

Heated research issues in STEM education include availability of various student scaffolding supports in STEM education (Qori, 2020), teachers' self-efficacy and concerns about STEM education (Geng, Jong & Chai, 2018), the design-thinking professional development of STEM teachers (Chiu, *et al.*, 2021; Wu, *H*u & *W*ang, 2019), students' interdisciplinary (withing the boundary or scope of existing subject disciplines) and transdisciplinary (transcending the boundary or scope of existing subject disciplines) skills in STEM education in school contexts (Drake *et al*., 2015; Wu, Cheng & Koszalka, 2021), parenting influence in students' career aspirations related to STEM (Lloyd *et al.*, 2022), how STEM cultural capital shapes students' STEM careers aspirations (Chen *et al*., 2022) and the emergence of creative problem-solving and systems-thinking skills in and through STEM programs in international and global perspectives (Wang, Shen & Chao, 2021).

Based on review of local and international research literature, the definition and conceptions of STEM education are still fuzzy. Existing forms of implementing STEM education in primary and secondary schools in worldwide can be divided into the three following domains:

1. *Formal curricula:* Integrating STEM elements or related e-learning platform into formal instructions in cross-curricular subjects or new STEM subjects *in schools* (e.g. Li *et al.*, 2019; Mystakidis & Christopoulos, 2022)
2. *Informal curricula:* Integrating STEM elements into school-based curriculum through informal project-based learning or other after-school activities *in schools* (e.g. Kelley & Knowles, 2016; Thingwiangthong *et al*., 2021)
3. *Extensional / instrumental uses (without curriculum development):* Implementing STEM education as a path or means to enhance students' interests, abilities and skills since STEM education is not formally documented into school curricula, such as merely recommending students to participate into inter-school or international competitions *outside schools* (e.g. Ziu & Lou, 2022)

At the same time, there are two senses of integration approaches during / beyond school hours:

A. *New / expandable learning contents:* Incorporating elements or ideas such as AI/Robotics, coding and computational thinking into STEM education or curriculum (e.g.Wang, Shen & Chao, 2021).
B. *Cross-level knowledge transfer:* Transferring advanced and high-level STEM knowledge at tertiary level into the existing curriculum in primary and secondary levels through simplification models or data visualization in using computer apps or through AR/MR/VR/XR environments (e.g. Krajcik & İbrahim, 2017; Ortiz-Revilla, Greca & Adúriz-Bravo, 2019).

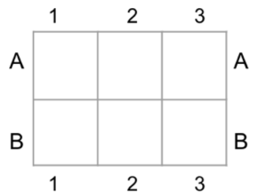

Figure 1. A 2 X 3 matrix of integrative evaluation of STEM curriculum

3. Research Design

3.1 Research Questions

In Hong Kong, previous policy analysis was limited to mere examination of policy documents, instructional design of teacher education programmes run by universities and annual teacher professional development programmes run by EDB (So, *et al.*, 2022). So far there has been no comprehensive analysis of how STEM or STEM-related policies implemented in secondary schools. Four research questions in this paper focus on:

1. How has the Hong Kong SAR government supported STEM education and how has she shaped STEM curriculum development in mainstream secondary schools?
2. How have STEM education policies been implemented in mainstream secondary schools in Hong Kong?
3. How has the implementation of STEM education in mainstream secondary schools in Hong Kong improved students' personal skills in teacher perceptions?
4. What are the contextual barriers against the development of STEM education when it has been implemented in mainstream secondary schools in Hong Kong?

3.2 Research Methodology and Methods

The research methods utilized in this study included an experienced mainstream secondary school teachers' e-survey (N=41), in-depth semi-structured interviews with some key informants who are educationalists and pioneers to promote and lead STEM education in Hong Kong and a documentary analysis of related important policy documents, school circulars and updated website information about STEM education in Hong Kong. In order to enhance its credibility, this study adopts cross-data, cross-method and cross-perspective triangulation (Denzin, 2009) to find some convergent data patterns.

4. Research Results

4.1 How the HKSAR Government Has Supported / Facilitated STEM education

A secondary data analysis of policy documents and EDB (2016, 2020) reports finds that the HKSAR government decentralizes her policy in STEM education by asking mainstream schools to apply for lifelong learning grants and other (non)recurrent school grants to buy STEM resources and encouraging some proactive schools to bid for school-based Quality Education Fund (QEF) projects to testify feasible directions of STEM education. For EDB must provide more flexible educational resources to cater for schools' diversified needs through school-based funding and granting supports, reflected in some interviews with the experienced ex-staff members of Curriculum Development Institute (CDI) of EDB. Noteworthy, the number of STEM projects in QEF was the greatest and the financial expenditure of QEF reached the peak in 2018-19, four times that in 2017-18 [without the public release of official EDB data in 2019-2022].

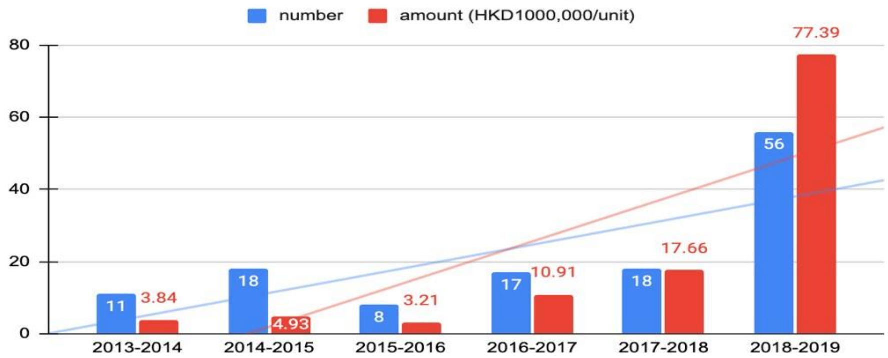

Figure 2. Number and Amount of STEM Projects of Secondary Schools Funded by QEF in 2013-2019

Figure 2 reveals that both sets of number of QE projects and funding data showed an overall upward trend, with the project amount increasing gradually at a faster rate starting from 2016-17 onwards. In contrast with a stable number of QEF projects in 2013-2018, the number of QEF projects increased rapidly to 56 in 2018-2019. It was only after 2015-2016 that QEF projects with STEM-related names and project descriptions gradually emerged due to the publicity of policy addresses. A content analysis of several large-scale yearly education expos and festivals also reveals that the number of demonstration booths and thematic talks related to STEM education or resources has had sharp rises from 2017-18 onwards. Figure 2 also shows vividly the overall increasing trend of the Hong Kong government's funding support for STEM-related projects through QEF from 2013 to 2019. This trend was in line with perceptions with those interviewees who have promoted STEM education in government, school and NGO sectors. In other words, the Hong Kong SAR government and some secondary schools in Hong Kong are paying more attention to STEM education in general. In particular, the rapid increase in STEM-supported fund following the inclusion of STEM education policies in the government policy addresses in 2015, 2016 and 2017 has had a positive effect and helped some secondary schools strengthen Mathematics and Science curricula through STEM education.

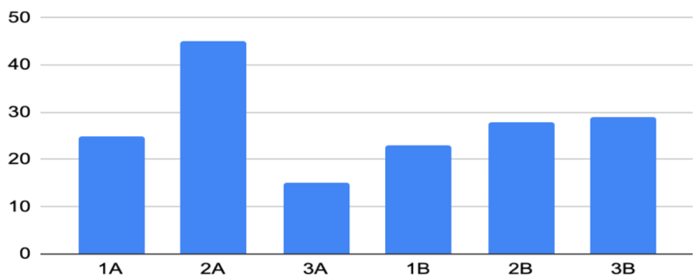

Figure 3. Number of QEF-funded STEM programs by types in secondary schools in 2013-2019

According to the data of the programs sponsored by QEF in the academic years 2013-2019, the number of STEM programs in those participating secondary schools corresponded closely to the curriculum integration approach in the matrix in figure 1 (except for some programs without detailed project descriptions). Notably, figure 3 reflects that QEF-funded projects focused more on 1 and 2 curriculum integration approaches (by comparing 1A + 1B, 2A + 2B with 3 A+ 3B figures) whereas most secondary schools used 2A as the main curriculum integration approach of STEM education through informal project-based learning or other after-school activities with some new / expandable learning topics like coding, computational thinking, AI & robotics, reported by those project descriptions.

4.2 Implementation of STEM Education in some mainstream secondary schools

According to the EDB's school inspection annual reports, quite a number of schools set up special committees to promote STEM education by coordinating tasks relating to the organization of activities, allocation of resources and professional development of teachers. Examples of these tasks included coordinating relevant subject panels to organize STEM education-related activities and deploying resources for the purchase of equipment to encourage students to participate in STEM activities. Schools with more comprehensive planning even strengthened cross-curricular or cross-subject collaboration, and systematically incorporated the elements of STEM education into the school curriculum and related activities. They also introduced external professional support and professional exchanges across schools to promote a collaborative culture of sharing among teachers in STEM education. Schools tended to design experiential learning STEM activities based on the learning of one subject, and then infiltrate the learning elements of other subjects.

In the 2019-20, more schools were implementing STEM education in the form of cross-curricular project studies. Many schools have also incorporated coding or programming elements into their curricula so that their students can apply programming to their home or resolve daily life problems. Besides, the EDB inspected schools have organized a variety of life-wide learning activities to promote STEM education, such as STEM Education Day / Week, robotics production and exhibition, etc. On the other hand, to enrich students' other learning experience, the schools also arranged advanced training programs for students who were more interested or capable of doing STEM education and recommended them to participate in some external local inter-school and international competitions. However, a transdisciplinary STEM subject or curricula was not commonly set up in those inspected schools through close interviews with some ex-chairmen of professional teacher associations in Mathematics and Computer Education and some experienced school teaches and ICT dept heads in the study. As a whole, STEM education in those primary and secondary schools was implemented through cross-learning areas or cross-/inter-disciplinary collaborations, mainly in the planning of life-wide learning activities, with lesser coordination and collaborations in the curriculum level, which mainly lie in the items 2A, 3A, 2B and 3B in the matrix.

In the e-survey, 63.4% of 41 teacher respondents in a purposive sample of mainstream secondary education sector (4.9% from government secondary, 80.5% from aided secondary and 14.6 % from Direct Subsidy Scheme schools) have been teaching for more than 16 years. A majority (66.70-83.30%) generally agreed or strongly agreed that the current STEM education policy in their secondary schools not only enhances students' interests in learning Mathematics and Science subjects, but also helps them foster their creativity and imagination, problem-solving skills, teamwork, leadership and communication skills, promoting their critical thinking, and advancing their future personal development in figure 4.

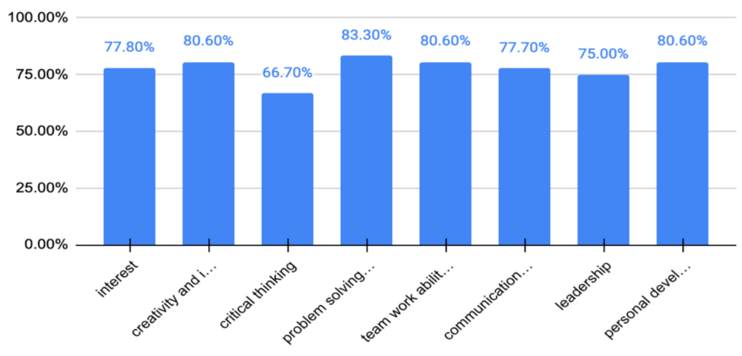

Figure 4. Teachers' opinions about how STEM education policies help improve student abilities

Meantime, 72.9% of survey respondents indicated that their working schools have increased funding in the related subjects after the STEM education policy was implemented. 77.5 % respondents showed that extracurricular STEM activities in their schools have enriched student learning in related subjects and 75 % stated that their teaching times have been extended in the related subjects after the STEM education policy was implemented. In those mainstream secondary schools, they usually use extracurricular activities to promote STEM education.

4.3 How implementation of STEM education improves students' personal skills in teacher perceptions

Most e-survey and interview respondents described their rich supervision experiences in helping their students join inter-school STEM competitions or in preparation for local and international competitions. This phenomenon often reflects student enthusiasm for participation, creativity, collaboration, communication, and their hands-on skills and leadership, and even data visualization / simplification process and visual or visual presentation skills. This suffices to show that many secondary school students are improving STEM skills by engaging themselves in internal or external competitions beyond school hours. In addition, the rest of the activities mentioned by the respondents such as making robots, manipulating robots, designing rocket cars, smart city design, and so forth indicate that some secondary schools in Hong Kong have incorporated high-tech elements such as AI/Robotics into STEM teaching, which also embodies a form of reinvention of STEM curricula in 2A, 2B and 3A, 3B integration approaches.

4.4 Contextual Barriers and Obstacles Against the Development of STEM education

In-depth semi-structured interviews with those key informants found that besides local and international inter-school competitions, STEM education has been implemented mostly into junior secondary curricula using school-based afterschool activities or some STEM elements have been integrated into computer literacy or computer studies subjects, facing open-examination-driven upper secondary curricula. Finally, those surveyed frontline experienced secondary school teacher respondents revealed lack of instep teacher training programs in enhancing students' STEM skills (which was converged by some interview data), teachers' urge for increasing the publicity of STEM education to gain societal recognition, and their need for development of more school-based STEM curricula in some pilot schools as STEM education has not been fully integrated into their current curricula in their perceptions during the research time. Besides the need for conceptualizing STEM learning in terms of scientific inquiry, technological application, engineering design, and mathematical processing, there is also a need to conceptualize ingredients of teacher training program in STEM education.

5. Conclusions and Implications

5.1 Conclusions

This paper provides a data-supported integrative 2 X 3 matrix using parameters of formal curricula, informal curricula, extensional / instrumental uses, new / expandable learning contents and cross-level knowledge transfer. In fact, such evaluative matrix is a measurement indicator for STEM education policy to further strengthen or improve secondary (especially science and mathematics) curricula in Hong Kong and cross-national perspectives. Within this matrix, the HKSAR government supports schools to explore their own development paths through the bottom-up approach in financial support, such as the Quality Education Fund and other (non-)recurrent school grants.

5.2 Implications

Further research agendas in STEM education in Hong Kong should focus on:

- Learning models or theory for students or student agency to adopt deeply integrated (e.g. transdisciplinary) approaches in STEM education, instead of teacher or school facilitation
- Teacher professional development and pedagogical models for taking deeply integrated approaches
- School or teacher leadership models for initiating and sustaining reforms for adopting deeply integrated approaches (or transforming from interdisciplinary to transdisciplinary approaches in particular) in STEM education (c. f. Liao, 2016)
- Nourishing collaborative learning communities-of-practices among schools, teachers and students for sustainable development or growth of deeply integrated approaches in STEM education

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