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Analysis of STEM Activities in Primary Students' Science Projects in an Informal Learning Environment

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一个框架：分析STEM活动
什么样的活动？课外的。

Abstract This study adopted a researcher-generated framework to analyze STEM activities demonstrated in primary students' science projects in an annual extracurricular event held in Hong Kong. Ten students' project reports were randomly selected from each of the three groups of 24 outstanding, 45 merit, and 68 consolation awarded projects. Content analysis was conducted to code the activities in each project. The coded information was then changed into numerical data for quantitative analysis. The results showed that, in general, more engineering and science activities than technology and mathematics activities were adopted by the primary students in their projects. More projects with the Outstanding Award conducted STEM activities than those projects with Merit and Consolation Awards, and significant group differences existed in the science and mathematics activities. Besides, science activities significantly positively related to engineering and mathematics activities. Furthermore, STEM-related content knowledge of discipline core ideas and crosscutting concepts were reported. This study sheds light on the pattern of STEM activities in students' science projects, and has implications for promoting STEM integration in primary education.

阐明了
STEM活
动的特征

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Keywords Science education · Science projects · STEM integration

Introduction

It is increasingly recognized that the understanding and application of Science, Technology, Engineering, and Mathematics (STEM) play important roles in meeting "(1) societal needs for new technological and scientific advances, (2) economic needs for national security; and (3) personal needs to become a fulfilled, productive, knowledgeable citizen" (Zollman, 2012, p. 12). "A framework for K-12 science education: Practices, crosscutting concepts and core ideas" published by the National Research Council (2012) recommends that science education in grades K-12 in the USA should be integrated with engineering and technological practices. The trend to extend science education to include STEM education in the USA in the recent decade is also occurring in many other countries around the world (Marginson, Tytler, Freeman & Roberts, 2013). In Hong Kong, the development of STEM in education proposed in the 2015, 2016, and 2017 Policy Addresses include the following: "The Education Bureau will renew and enrich the curricula and learning activities of Science, Technology and Mathematics, and enhance the training of teachers, thereby allowing primary and secondary pupils to fully unleash their potential in innovation" (Item 152 in 2015), "The Government will step up efforts to promote STEM (Science, Technology, Engineering and Mathematics) education and encourage students to pursue the study of these subjects" (Item 89 in 2016), "the Education Bureau should strive to promote STEM education with the provision of additional resources for primary schools at the beginning of last year, and be prepared to provide each public sector secondary school with an additional one-off subsidy of $200,000 to promote the implementation of school-based programs related to STEM education (Para. 212 in 2017). There are different initiatives for promoting understanding of the future direction of STEM education in Hong Kong and exploring strategies to strengthen students' integrative learning and application skills.

International trends and What HK did recent years.

In the current local school curriculum, there are three interconnected components: (1) knowledge in Key Learning Areas, (2) Generic Skills, and (3) Values and Attitudes. STEM-related learning experience can be found in "Mathematics Education," "Science Education," and "Technology Education," which are three of the eight Key Learning Areas in the school curriculum. Moreover, STEM-related learning opportunities are also provided in the subject General Studies for Primary School Curriculum Guide (Curriculum Development Council (CDC), 2011), under the strand "Science and Technology in Everyday Life". It is proposed that Key Stage 1 students should be aware that science and technology are closely connected to activities in daily life, while students in Key Stage 2 should acquire the knowledge of concepts and applications of the design cycle, the skills to design and make artifacts with daily materials, and to work individually/collaboratively with peers to identify problems and design feasible solutions. In addition, the Generic Skills addressed in the curriculum are also fundamental to engaging students in STEM learning experiences, for example, information technology skills, numeracy skills, and problem solving skills.

Key Learning Areas

General Skills

However, there is little evidence from research studies reporting the status quo of local students' ability in STEM, as science and mathematics are now taught separately in Hong Kong primary schools. In order to have a better understanding of the current status of primary students' strengths and weaknesses in their interdisciplinary STEM knowledge and skills, a valuable source of information is from students' participation in science events, which is one of the STEM education initiatives currently adopted by Hong Kong schools. It is also an informal learning environment which are regarded as sources of early interest in science (Maltese & Tai, 2010) and nature of experiences responsible for the generation and maintenance of interest in STEM (Maltese, Melki & Wiebke, 2014). Denson, Hailey, Stallworth and Householder (2015) in their study found that STEM-based informal learning benefited students and was effective in recruiting, retaining, and encouraging students to pursue STEM careers.

Informal Learning:
Recruiting
Retaining
Encouraging

开发了一个相互依赖的STEM学习体验模型
－关注科学项目中的STEM活动

识别小学STEM活动的Pattern

Drawing on related literature and documents concerning STEM education, as well as the opportunity to access students' STEM-related work, this research consists of two major parts. The first mainly deals with the development of an interdisciplinary STEM learning experience framework which focuses on primary students' science, technological, engineering, and mathematical activities in science projects. The second part of the research is the use of this framework to identify the pattern of primary students' STEM activities in science projects. The significance of this study is that it systematically examines the STEM activities of primary students in their science projects based on a researcher-developed framework, so as to inform the possibilities of promoting STEM integration in primary education.

Connecting Science, Technology, Engineering, and Mathematics

Early STEM education was focused on isolated science, technology, engineering, and mathematics subjects rather than on an integrated approach to teaching and learning (Honey, Pearson & Schweingruber, 2014). Sanders (2009) pointed out that conventional STEM education faces the challenge of students losing interest in STEM learning. The most important modern conception of STEM is the notion of integration, that is, STEM is the integration of science, technology, engineering, and mathematics in order to solve real-world multi-disciplinary problems (Breiner, Harkness, Johnson & Koehler, 2012; Sanders, 2009, 2012). The National Governors Association (NGA) published a report entitled "Innovation America: Building a Science, Technology, Engineering and Math Agenda" in 2007, emphasizing that STEM literacy does not simply mean achieving literacy in these four strands or silos. Rather than that, a STEM classroom can consequently change students' learning from studying discrete bits of the knowledge and having rote procedures to investigating the interrelated facets of real-world problems (National Governors Association, 2007). Despite the emphasis on connections between science, technology, engineering, and mathematics, there is still lack of effective models in STEM integration (Roehrig, Moore, Wang & Park, 2012). Moreover, Breiner et al. (2012) claimed that most K-12 teachers do not teach STEM using integrated approach. In efforts of exploring the most effective integration mode, a meta-analysis involving 28 studies of integrated STEM reveals that integration of four subjects exhibit highest effect size among existing kind of integrations (Becker & Park, 2011), highlights the need to integrate all four subjects of science, technology, mathematics, and engineering.

Validation of integrated STEM in science education as best practice has been carried out for the past two decades. Some researchers have discussed the benefits of the convergences between science and technology; science and engineering; and between science and mathematics. Regarding the integration of science and engineering, Lewis

(2006) argued that design and inquiry are conceptual parallels because both are reasoning processes that target ill-structured and uncertain problems. An example pedagogy of science and engineering integration is Design-Based Science (DBS) promoted by Fortus, Krajcik, Dershimer, Marx and MamlokNaaman (2005), in which science is learned through designing artifacts. Mehalik, Doppelt and Schuun (2008) contrasted student's mastery of electricity concepts through traditional scripted inquiry versus a design-based systems approach. They found that the integration of the engineering design approach into science inquiry could help students better grasp scientific concepts.

Concerning the integration of science and mathematics, Yore (2011) claimed that mathematics and science have shared processes of searching for, describing, and explaining patterns. Charlesworth and Lind (2010) observed that mathematics process skills facilitate scientific problem solving, while So (2013) explored the application of mathematics in science inquiry in an extracurricular event, and found that students used measurement, numeracy skills of counting and calculation, and tables and graphs in their science inquiries, with most of their measurements found to be appropriate. Her study demonstrated that mathematics and science are connected.

For the integration of science and technology, Lee, Linn, Varma and Liu (2010) found that technology-enhanced science units could enhance students' understanding of complex scientific topics. Kim, Hannafin and Bryan (2007) proposed that technology has the potential to support science education because of its affordances such as efficient ways of data collection and analysis, vivid representation of information, and effective means of creating models and communicating results.

Other integration with three disciplines like *Math Out of the Box*™, which adapts post-secondary engineering units into K-5 mathematics and serves as a model for science, mathematics, and engineering integration (Diaz & King, 2007). There are also other studies involving three disciplines of mathematics, science, and technology; however, these studies shows a relatively smaller effect size compared to other forms of integration (Becker & Park, 2011).

Among the limited literature of S-T-E-M integration, there is exploratory program like *Secondary STEM Integration teacher-training module* trying to assist math and science teachers to better integrate engineering and technology (Wang & Nam, 2015). During the program, a qualitative study of several participating teachers reveals that technology may be the most difficult element when integrating STEM in teaching, and yet no mature integrated STEM pedagogy model was formed (Wang & Nam, 2015).

In the aforementioned studies, science educators have emphasized that the integrated approach facilitates students' science inquiry and enhances their understanding of scientific topics; however, research evidence of students' STEM work in science projects was not well reported.

Assessing STEM Activities

Both NRC (2012) and NGSS Lead States (2013) make clear that assessment tools, reflecting new modes of assessment designed to measure the envisioned STEM interdisciplinary learning, are essential. In the USA, it has been realized that new assessments will be needed as soon as states and districts begin the process of implementing the Next Generation Science Standards (NGSS) and change their approach to science education.

It is not, however, easy to assess STEM activities in learning processes (Honey et al., 2014). Usually, scholars and practitioners use content-focused assessment instruments to assess STEM learning. For example, Barrett, Moran and Woods (2014) proposed that in STEM outreach programs, content-focused assessment instruments specifically tailored for the content of the particular STEM activity could quickly and easily assess students' STEM content knowledge. However, STEM activities are not easily or fully assessed by such instruments. Honey et al. (2014, p. 112) proposed that "ideally, design of both the activities and assessments would occur simultaneously, accompanied by iterative cross-checking to ensure that learning activities are designed to promote the specified STEM knowledge and scientific and engineering practices and incorporate systematic assessments of progress in all the target areas".

Considering Honey et al.'s suggestion, it would be effective to assess STEM activities in the learning process with a framework which includes the indicators of STEM application of knowledge and practice. To the best of our knowledge, however, there seems to be a lack of such assessment frameworks. In order to generate a framework of assessing STEM activities which is appropriate for primary students in Asian contexts such as Hong Kong, a comprehensive review of the literature and references within the four disciplines was carried out to identify the core elements of the framework, as illustrated in the methodology session.

需要一个指标

Besides, there have been assessment methods focusing on disciplinary core ideas, and crosscutting concepts proposed by the "Developing Assessments for the Next Generation Science Standards" (NRC, 2014). There is another assessment framework developed by the Dayton Regional STEM Center (2011) which provides reflection and self-assessment on STEM education experience. In this STEM education quality framework, there are altogether ten STEM learning quality components which assess engaging students of diverse academic backgrounds; degree of integration; connections to non-STEM disciplines; integrity of academic content; the quality of the cognitive task; connections to STEM careers; individual accountability in a collaborative culture; nature of assessment; application of the engineering design process; and the quality of the technology integration. A scale of four levels ("Not evident," "Emerging," "Accomplished," and "Advanced") was used for the various STEM Learning Quality Components.

不同学术背景学生的参与程度
整合程度
与非STEM科目的关联
学术内容的整合
认知任务的质量
与STEM职业的关联
合作文化中的个人责任感
技术整合质量

四个级别的量表

Methodology

Construction of the Framework for Assessing STEM Activities

The construction of the framework for assessing STEM activities started with a synthesis of the literature discipline by discipline. First, there was a selection of more comprehensive literature as the starting literature to start constructing the framework in that discipline. However, due to the enormous amount of detailed literature in the science discipline, there was no particular literature chosen as the starting literature; the indicators were compared and synthesized with other selected references in the same discipline. Symbolic and common practices from the discipline, related skills, and related problem solving methods were extracted, focusing on indicators closely related to primary students' disciplinary experience/practice.

In the present study, there was no intention to create a framework to cover all literacy criteria and/or goals of a particular discipline. Subjective wording like adverbs in the indicators were removed to ensure that the focus was on the primary students' practices. 单一目标 Indicators with multiple practices and conditional practices were modified, either separating the practices or removing the conditional part and focusing on the main idea of such practice. For example, "Design and use instrument to gather data" was changed to "Use instruments to gather data." Common and important indicators were categorized as items in the framework related to each discipline. The items were further categorized within disciplines for easier understanding. The same method was applied to all four disciplines. The framework was revised and modified during the process of analysis when the researchers found it not clear and when there was misunderstanding among the two raters during the content analysis. Table 1 summarizes the generated framework of assessing STEM activities.

Science Several studies or documents were used to substantiate and triangulate the indicators as starting literature, including AAAS (1993), CDC (2011), Chin (2003), Gott, Duggan and Ebrary (2003), Jeong, Songer, and Lee (2007), NAE and NRC (2014), NRC (2013), Toulmin and Groome (2007), University of the State of New York (2000), and Zollman (2012). Eventually, ten activities were identified as common and important. These activities were further categorized into three aspects, namely "initiating an investigation," "conducting the investigation," and "presenting the investigation" according to the process of science inquiry. In initiating an investigation, 3C10A students' activities of formulating and refining questions and setting up a hypothesis are assessed. In conducting the investigation, students' activities of identifying variables in a fair test or controlled experiment, analyzing data, describing the investigation process, and identifying the limitation of investigation are evaluated. In presenting the investigation, students' activities of drawing conclusions, formulating an argument, and suggesting further studies are measured.

Technology There is a wide range of literature which documents the standards of technological learning. The International Technology and Engineering Educators Association (2000) provided age-appropriate and comprehensive learning standards for technological learning. Another seven studies or documents, namely CDC (2011), Gagel (1997), Garmire and Pearson (2006), Hayden, O'Neill, Meyer, Carballada, Sanford and Cohen (2008), NAE and NRC (2014), the Pennsylvania Department of Education (2009), and Toulmin and Groome (2007), were reviewed to find the common activities in technological learning for primary students. In total, five activities 2C5A were identified. These activities were further classified into two categories, namely "use of technology" and "innovation and safe use." Use of technology includes the selection and use of appropriate technology to collect and analyze data. In the aspect of innovation and safe use, the safety issue of technology was addressed. Also, the emphasis on innovation and the modification of the natural environment to suit humans' needs was addressed as technological activities which often go beyond simple steps such as using tools and machines (Toulmin & Groome, 2007).

Engineering The document "Next Generation Science Standards: For States, By States." proposed by the National Research Council (2012) was selected to be the

Table 1 A framework for assessing STEM activities

Science	Technology	Engineering	Mathematics
S1: Initiating an investigation *S1.1*: **Formulate questions about natural phenomena (physics, biology, chemistry, and earth/space sciences)** (e.g., AAAS, 1993; NAE & NRC, 2014; Zollman, 2012) *S1.2*: **Refine and/or clarify questions so that they are subject to scientific investigation** (e.g., CDC, 2011; Hayden et al., 2008) *S1.3*: **Set up a hypothesis and conduct an experiment to test it** (e.g., CDC, 2011; NRC, 2013; Toulmin & Groome, 2007)	**T1: Use of technology** *T1.1*: **Select and use tools/products/materials to solve a problem** (e.g., Garmire & Pearson, 2006; ITEEA, 2000; The Pennsylvania Department of Education, 2009) *T1.2*: **Use instruments to gather data** (e.g., ITEA, 2000; NAE & NRC, 2014; Toulmin & Groome, 2007) *T1.3*: **Use computers and calculators in various applications** (e.g., Garmire & Pearson, 2006; ITEA, 2000; NAEP, 2006)	**E1: Defining the problem to be solved** *E1.1*: **Ask questions to define the problem to be solved** (e.g., NRC, 2012, 2013)	**M1: Collecting data** *M1.1*: **Measurement for experimental settings**(e.g., Ainley et al., 2012; So, 2013, 2016) *M1.2*: **Measurement for recording the progress or results of scientific experiments** (e.g., Ainley et al., 2012; So, 2013, 2016) *M1.3*: **Measure with appropriate tools and metric system** (e.g., So, 2013, 2016; NAEP, 2006)
S2: Conducting the investigation *S2.1*: **Identify variables and invariables in the fair test and/or controlled experiment** (e.g., Chin, 2003; Jeong et al., 2007) *S2.2*: **Describe the procedures used in the investigation** (e.g., CDC, 2011; Hayden et al., 2008) *S2.3*: **Analyze the results from the data collection/experiment** (e.g., Gott et al., 2003; NRC, 2013) *S2.4*: **Identify sources of error and the limitations of the data collected** (e.g., Chin, 2003; Jeong et al., 2007; NRC, 2013)	**T2: Innovation and safe use** *T2.1*: **Innovate/change/modify the natural environment to satisfy needs and wants** (e.g., Gagel, 1997; ITEA, 2000; Toulmin & Groome, 2007) *T2.2*: **Use tools/materials/machines in accordance with safety rules** (e.g., Garmire & Pearson, 2006; ITEA, 2000; NAE & NRC, 2014; Pennsylvania Department of Education, 2009)	**E2: Creating and testing the solution** *E2.1*: **Apply scientific and mathematical principles to practical ends to design a solution** (e.g., NRC, 2012, 2013) *E2.2*: **Develop and use a model to visualize a design** (e.g., NAE & NRC, 2014; NRC, 2012) *E2.3*: **Identify the constraints or flaws of the design or model** (e.g., NAE & NRC, 2014; NRC, 2012) *E2.4*: **Test the design to evaluate its performance** (e.g., NRC, 2012, 2013) *E2.5*: **Test two different models of the same proposed object, tool, or process to determine which better meets criteria for success** (e.g., NRC, 2012, 2013)	**M2: Processing data** *M2.1*: **Calculate averages for estimating central tendency** (e.g., So, 2013, 2016) *M2.2*: **Calculate percentage for communication** (e.g., So, 2013, 2016)

Table 1 (continued)

Science	Technology	Engineering	Mathematics
S3: Presenting the investigation *S3.1*: **Draw conclusions related to the scientific phenomena** (e.g., Hayden et al., 2008; Toulmin & Groome, 2007) *S3.2*: **Formulate an argument about cause-and-effect relationships in the investigation** (e.g., Toulmin & Groome, 2007; Zollman, 2012) *S3.3*: **Suggest improvements and recommendations for further study** (e.g., Hayden et al., 2008; Toulmin & Groome, 2007; Zollman, 2012)		**E3: Refining the solution** *E3.1*: **Modify the model or design** (e.g., NRC, 2013; NAE & NRC, 2014) *E3.2:* **Analyze and choose an optimal solution to solve the problem** (e.g., NRC, 2012, 2013)	**M3: Representing data** *M3.1*: **Bar charts for visualizing central values** (e.g., Ainley et al., 2012; So, 2013, 2016; Hayden et al., 2008) *M3.2*: **Line charts for showing data trends** (e.g., Ainley et al., 2012; So, 2013, 2016; Hayden et al., 2008) *M3.3*: **Pie charts for displaying relative values** (e.g., Ainley et al., 2012; So, 2013, 2016; Hayden et al., 2008) *M3.4*: **Tables for arranging and grouping discrete data** (e.g., CDC, 2011; Hayden et al., 2008)

prototype for indicators of activities related to engineering in the framework because they are more comprehensive in suggesting standards of learning science and engineering in different grade levels. Another four studies or documents, namely CDC (2011), NAE and NRC (2014), NRC (2013), and Zollman (2012), were used to triangulate or complement the activities. NRC (2013) and Zollman (2012) complemented the NRC document in 2012. NRC (2013) complemented the framework with activities related to testing different models to determine which better meets the criteria for success; Zollman (2012) enriched the framework activity which encourages students to apply scientific and mathematical principles to tackle engineering problems. These complements are also supported by other reviewed literature in this discipline. 3C8A Eventually, eight activities were grouped into three aspects, namely "defining the problem to be solved," "creating and testing the solution" referring to developing models with constraints and testing, and "refining the solution" related to modification and choosing an optimal solution according to the engineering design process.

Mathematics The findings on mathematics activities in primary students' science inquiry in studies conducted by So (2013, 2016) were taken as the starting point for making indicators of the mathematics aspect of the framework because the findings of the study directly targeted primary students' mathematical activities in science projects. Another four studies or documents, namely Ainley et al. (2012), CDC (2011), Hayden et al. (2008), and NAEP (2006) were used to verify the common mathematical activities in science mentioned in the starting literature. Although calculation activities were not mentioned in other literature, these activities were regarded as important in science inquiry based on the findings of So (2013). She found that the use of numeracy in primary students' science inquiries mainly rested on counting for data collection, calculating averages, and calculating percentages. In total, nine activities were finally 3C9A identified. They were further categorized into three groups according to the use of mathematics in the process of science inquiry, including "collecting data," which refers to measurement in inquiry, "processing data," which refers to calculation, and "representing data," which refers to the use of charts and tables.

Research Questions

提出三个问题的目的：决定种类、整合、NRC三个目标、质量

Three research questions were explored in this study to determine the types of activities students conducted in their science projects; the integration of science, technology, engineering, and mathematics; STEM-related content knowledge of disciplinary core ideas and crosscutting concepts; and the STEM learning quality components of integrality of the academic content and degree of STEM integration.

(a) What types of STEM activities are employed by students in their extracurricular science projects? Are there any group differences in the various STEM aspects?
(b) Are aspects of STEM activities related with each other? If yes, what aspects and to what extent?
(c) To what extent are activities in students' science projects associated with STEM-related content knowledge?

Data Collection

The primary students' science project reports were chosen from 137 teams (with 4–5 members in a team) involving about 1000 primary students aged 10–12 who participated in the 2015 "Innovations in Science and Environment Studies" event in Hong Kong. Under the main theme of "Go Green at Home," pupils work collaboratively with their team members to promote a green lifestyle at home. The participating teams had to present the processes and results of their science projects and submit a written report which recorded their ideas, methodology, and results. The details of the event, including the assessment criteria, were made known to participating students and teachers. The criteria emphasized that pupils should inquire using scientific methods and principles to investigate and explain, or innovate to modify or suggest ways for improvement in their chosen topics.

The science projects were judged by a team of adjudicators comprised of secondary school teachers, principals, educators, and curators who had a science background. In judging the quality of the science projects, the adjudicators made reference to the following criteria, namely (1) designing scientific inquiry, (2) demonstrating understanding of scientific ideas/principles, (3) demonstrating originality and creativity, and (4) illustrating practicality and applicability in daily life. Each team was judged by at least two adjudicators based on students' presentations and written reports with a preliminary rating. The finalized awards of outstanding, merit, and consolation were confirmed during the adjudicators meeting right after the judging process. Eventually, 24 projects were awarded outstanding, 45 projects merit and 68 consolation.

As the subgroup of outstanding projects available for analysis is much smaller than the other groups, disproportionate random sampling is used in order to get a larger sample size from the outstanding group for comparison, inference, and estimates with the other groups. Ten project reports were randomly chosen from each group of outstanding, merit, and consolation projects with a total of 30 projects analyzed (Table 2 shows the titles, ranking, and code number of the 30 projects). In order to eliminate biased results and to achieve a more reliable analysis, there were blind reviews by two raters (one was the research assistant for this project and the other was a doctoral student in science education).

Data Analysis

Two raters were involved in analyzing the project reports using a coding system with reference to the framework (Table 1) for identifying STEM activities in a deductive way. The aspects of each discipline were coded as S1, S2, and S3 for science; T1 and T2 for Technology; E1, E2, and E3 for Engineering, and M1, M2, and M3 for Mathematics. The items for each aspect were coded in a subordinate way. For example, in S1, there were three items which were coded as S1.1, S1.2, and S1.3. Fig. 1 shows examples of vignettes or pictures of some items like S2.2, T1.1, E2.2, and M3.4.

The pilot analysis that focused on interrater reliability was conducted with six reports (two selected randomly from each award group) by the two raters working independently on the coding. In order to explore the interrater reliability of the content analysis, the Kappa value was calculated; it was 0.63, which is believed to be acceptable (Lombard, Snyder-Duch & Bracken, 2002). After the interrater reliability check, the two raters discussed with the two authors the inconsistencies between their coding until an agreement was reached on the unanimous consensus and their understanding of the framework of assessing STEM activities. For instance, one rater was confused about the term “mathematical principles” used in item E2.1 and had a disagreement with the other rater. After sharing of ideas and comparing other examples from the literature, the two raters eventually reached a consensus. The remaining 24 project reports were then coded in the way agreed by the authors and raters.

The coded data were then changed into numerical data for quantitative analysis. The presence of each STEM activity recorded in each project report was transformed into “1” and absence of an item was transformed into “0” in the SPSS 21 system. Hence, the full score of each item is 1. The reliability of the framework of assessing STEM activities was calculated. A Cronbach’s alpha of 0.77 indicating satisfactory internal consistency was achieved, implying that it was reliable to use the framework to assess the primary students’ STEM activities in their science projects.

Descriptive analysis was used to describe the pattern of STEM activities at “aspect level” and “disciplinary level.” Aspect level focused on the achieving pattern in the aspects of different disciplines, like “processing data from mathematics” and “innovation and safe use” from technology. Discipline level focused on the extent of the activities achieved in a discipline by different science projects, to be more specific, the percentage of activities from the science discipline achieved by the projects. The mean for each project was calculated by dividing the sum of each aspect or discipline by the total number of items in each aspect or discipline. Accordingly, the group mean and total mean were calculated by averaging the means of the projects. One-way ANOVA analysis was used to testify whether the STEM activities demonstrated in the different award groups of the project reports differed. Correlation analysis was used to determine the correlation of activities from each STEM discipline and the degree of correlation.

The integrity of the academic content and the degree of integration of the 30 science projects were analyzed according to the description and example from each level in each component using the STEM Education Quality Framework (Dayton Regional STEM Center, 2011). A scale of four levels (“Not evident,” “Emerging,” “Accomplished,” and “Advanced”) was used for judging the degree of integrity of the academic content and the degree of integration. The results of the two analyses were converted to numerical data for quantitative analysis. In order to examine the relationship between the performances of the 30 science projects in these components, a Pearson Correlation Coefficient was calculated using the SPSS 21 software.

Findings

Types of STEM Activities in Students’ Science Projects

The analysis of the pattern of STEM activities was conducted at two levels: the aspect level and the disciplinary level. Different patterns of occurrence were found in the aspects among disciplines. Table 3 shows the occurrence of each aspect of

Table 2 Project titles, awards, and code

Awards	Project titles	Code
Outstanding:	Mystery of fruit preservation	A01
	The magical eco-enzyme?	A04
	Energy saving flush toilet	A51
	Turn food waste into organic	A58
	Efficient rocket stove	B11
	Energy saving cooking	B19
	Stove fueled re-heater	B37
	Eco-Cleanser	B42
	Food waste cleanser	B44
	Bone powder is good for farming	B61
Merit:	Multi-functional eco-enzyme	A07
	Cleanser from fruit peel	A09
	Turn food waste into fertilizer	A64
	Stacking water filter	A70
	Don't waste water from fish tanks	B13
	DIY towel wringer	B30
	Natural cleanser	B32
	Powerful eco-enzyme	B60
	Good ways to filter sewage	B68
	Soften old towels	B72
Consolation:	How to focus light beam?	A16
	3-in-1 environmental friendly system	A25
	Processing fish waste with plants	A40
	Is hydroelectricity possible at home?	A42
	Exploring ways of food preservation	A56
	Don't waste the fruit peel	A67
	Reuse water from drain to flush	B03
	Can we filter sewage with tea?	B15
	Multi-functional curtain	B27
	Make eco-enzyme form food waste	B45

the Science, Technology, Engineering, and Mathematics activities in the 30 science projects. The three science activities were equally commonly found, which is not surprising, in the science projects. For the two aspects of technology, the "use of technology" was more commonly found than "Innovation and safe use." Among the three aspects of engineering, "refining the solution" was comparatively less used than "defining the problem to be solved" and "creating and testing the solution." The "collecting data" in Mathematics was much more than processing and representing data, which reflected the lack of use of these mathematics activities.

Science projects showing the process of test (*S2.2*: *Describing the procedures used in the investigation*)


②開始試驗，并對實驗數據進行紀錄采摘。

表二：設定不同出水量熱水器水溫變化情況表 單位：℃時間：10分鐘

出水量	2ML/S	4ML/S	6ML/S	8ML/S	10ML/S	12ML/S	14ML/S
水温	59	56	54	52.5	50	47	43.5

The tools used in the science project were listed in the report with words and photos (*T1.1*: *Select and use tools/products/materials to solve a problem*)

測試材料及用具

材料方面:
大白/黑紙(大約 A2size)x2

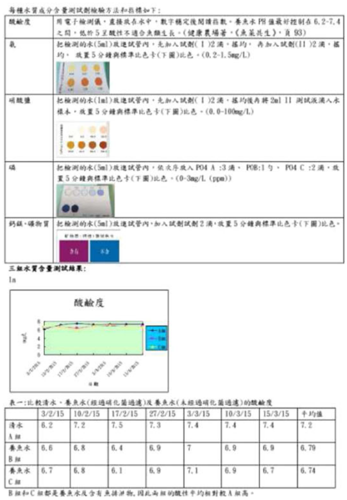
用具方面:
圓規、量角器、鉛筆、計算機
(繪畫燈罩紙樣時使用)

剪刀、膠紙
(製作燈罩時使用)

電筒(附 D 型電池 x2)、
手提電話(附測光應用程式—家用測光表)
(測試時使用)

Model construction for tests (*E2.2*: *Develop and use a model to visualize a design*)

Results and data were represented in varies representational means (*M3.4*: *Tables for arranging and grouping discrete data*)


表一:比較清水、養魚水(經過硝化菌過濾)及養魚水(未經過硝化菌過濾)的酸鹼度

	3/2/15	10/2/15	17/2/15	27/2/15	3/3/15	10/3/15	15/3/15	平均值
清水 A組	6.2	7.2	7.5	7.3	7.4	7.4	7.4	7.2
養魚水 B組	6.6	6.8	6.4	6.9	7	6.9	6.9	6.79
養魚水 C組	6.7	6.8	6.1	6.9	7.1	6.9	6.7	6.74

Fig. 1 Captures from science project reports

The Group Differences of Science Projects in Various STEM Aspects

Table 4 with the means of each of the Science, Technology, Engineering, and Mathematics activities shows that there were more Engineering and Science than Technology and Mathematics activities identified in the students' science project reports.

Table 3 Occurrence of each aspect of Science, Technology, Engineering, and Mathematics activities in 30 science projects

		Outstanding Mean	Merit Mean	Consolation Mean	Total Mean	SD
S	S1: Initiating an investigation	0.77	0.77	0.53	0.69	0.21
	S2: Conducting the investigation	0.93	0.88	0.68	0.83	0.21
	S3: Presenting the investigation	0.80	0.80	0.53	0.71	0.23
T	T1: Use of technology	0.77	0.70	0.73	0.73	0.16
	T2: Innovation and safe use	0.35	0.35	0.35	0.35	0.23
E	E1: Defining the problem to be solved	0.90	1.00	1.00	0.97	0.18
	E2: Creating and testing the solution	0.92	0.90	0.70	0.84	0.24
	E3: Refining the solution	0.60	0.40	0.55	0.52	0.33
M	M1: Collecting data	0.93	0.83	0.60	0.79	0.27
	M2: Processing data	0.50	0.30	0.00	0.27	0.34
	M3: Representing data	0.40	0.33	0.23	0.32	0.18

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Outstanding and Merit groups conducted far more science and mathematical activities than the Consolation group, but there was a similar medium occurrence of Technology and high occurrence of Engineering activities among the three groups.

In order to understand whether group differences existed in the STEM activities in a statistical sense, one-way ANOVA analysis was used. Table 5 shows that there are significant group differences in both science activities and mathematical activities ($p < .001$), confirming that there were far more science and mathematics activities in outstanding and merit projects than consolation projects. However, the difference among the three groups in the technology activities and engineering activities is not distinctive.

Integration of STEM Activities in Science Projects

STEM is not a simple combination of science, technology, engineering, and mathematics, but rather an integration of the four disciplines. Hence, the exploration of the relationship among the four aspects would delineate students' STEM activities in their science projects. Table 6 shows the correlations among the occurrence of the activities related to the four aspects of Science, Technology, Engineering, and

Table 4 Occurrence of Science, Technology, Engineering, and Mathematics activities in 30 science projects

	Outstanding Mean	SD	Merit Mean	SD	Consolation Mean	SD	Total Mean	SD
Science	0.84	0.08	0.82	0.12	0.59	0.17	0.75	0.17
Technology	0.60	0.16	0.56	0.13	0.58	0.15	0.58	0.14
Engineering	0.84	0.17	0.79	0.16	0.70	0.26	0.78	0.20
Mathematics	0.60	0.21	0.49	0.12	0.30	0.12	0.46	0.20

Table 5 Comparison of Science, Technology, Engineering, and Mathematics activities in three award groups of science projects

		Sum of squares	*df*	Mean square	*F*
S	Between groups	0.39	2	0.19	11.11***
	Within groups	0.47	27	0.02	
	Total	0.86	29		
T	Between groups	0.01	2	0.00	.19
	Within groups	0.58	27	0.02	
	Total	0.59	29		
E	Between groups	0.10	2	0.04	1.19
	Within groups	1.10	27	0.04	
	Total	1.20	29		
M	Between groups	0.46	2	0.23	9.51***
	Within groups	0.65	27	0.02	
	Total	1.11	29		

***$p < .001$

Mathematics activities in 30 science projects. Science activities were found to be significantly related with mathematics activities ($r = 0.62$, $p < .01$**) and engineering activities ($r = 0.38$, $p < .05$*). Mathematics activities were not related with engineering activities, and technological activities were found not to be correlated with the other three.

Two examples are listed as follows to show the significant correlation between science and mathematics as well as between science and engineering in the science

Table 6 Relations among the activities related to each aspect of Science, Technology, Engineering, and Mathematics in 30 science projects

		S	T	E	M
S	Pearson correlation	1	0.042	0.383*	0.621**
	Sig. (2-tailed)		0.824	0.037	0.000
	N	30	30	30	30
T	Pearson correlation	0.042	1	0.107	0.041
	Sig. (2-tailed)	0.824		0.573	0.829
	N	30	30	30	30
E	Pearson correlation	0.383*	0.107	1	0.228
	Sig. (2-tailed)	0.037	0.573		0.225
	N	30	30	30	30
M	Pearson correlation	0.621**	0.041	0.228	1
	Sig. (2-tailed)	0.000	0.829	0.225	
	N	30	30	30	30

*Correlation is significant at the 0.05 level (two-tailed); **correlation is significant at the 0.01 level (two-tailed) projects. One example is a project investigating the detergency of a homemade food waste enzyme cleanser, and the other is a project studying the combustion efficiency of a designed stove.

In the project of the homemade food waste enzyme cleanser (The magical eco-enzyme? Project A04), detergency was tested by measuring the transmittance and reflectivity of towels which were stained in advance and then washed using the cleanser. During this process, relevant knowledge and integrated skills were applied. This included scientific knowledge that a light colored surface has higher transmittance and reflectivity than a dark colored surface, skills including the setting up of a repeated fair test to examine the detergency of the scientific phenomenon (S2.1), and mathematical skills in the testing process, from measuring the portion of the test solution as the experimental setting (S1.1) to measuring the transmittance and reflectivity of the washed towels using an appropriate instrument (photometer) and unit (Lux) as test results (M1.2, M1.3), as well as processing data by calculating averages (M2.1) and representing the data in the form of tables (M3.4) and bar charts (M3.1) to compare and interpret the results (S2.3). This learning process shows the integration of science and mathematics by converting scientific knowledge into a method of testing with the use of mathematical skills. Such integration provided solid support for the test the students designed, and made the interpretation of the test results convincing.

In the project of combustion efficiency (Efficient rocket stove, Project B11) with the intention of solving the problem of low efficiency of fuelwood combustion, the idea was acquired from the Internet and a homemade stove was constructed with the objective of testing its efficiency. The main scientific principles used were the chimney effect, which increases the burning temperature, the re-burning effect which diminishes the smoke, and the construction of the stove with a special structure to allow such effects to work. It was observed that in a problem solving situation, scientific principles were applied in the produced model (S1.1, E2.3). Testing the design with a fair test (S2.1, E2.4), modifying the design (E3.1), and choosing an optimal setting to solve the problem (E3.2) were also identified. Moreover, the engineering elements in the science project with the discovery of a problem (E1.1) and attempting to design a solution to the problem were observed. In the testing process, flaws in the design were identified (E2.3). For instance, the original design was to put infill in the stove to prevent heat loss, but the result was not as expected. This was considered by the students as the limitation of their solution, and an optimal way was then suggested to solve the problem after the tests. This integration demonstrated the students' ability to use principles and test methods in science, such as setting up a fair test and controlling variables in an engineering design process.

STEM-Related Content Knowledge

The disciplinary core ideas and crosscutting concepts of the 30 science projects were analyzed. For disciplinary core ideas, they all focused on "Physical Sciences" from the NRC's framework (2012). In detail, only 6 of the 13 sub-categories of the Physical Sciences core ideas were recorded in the science project reports. "Chemical Reactions" under "Matter and Its Interactions" was the most frequent one with 15 (7 Outstanding, 5 Merits, and 3 Consolation) reports featuring that idea. Four projects featured the core idea "Stability and Instability in Physical Systems," for example some investigated the aquaponics system. Four focused on "Structure and Properties of Matter." "Forces and

Motion," "Conservation of Energy and Energy Transfer," and "Relationship between Energy and Forces" were also featured with two project reports respectively.

It was found that science projects may present more than one crosscutting concept in their learning (NRC, 2014); in the current study, these 30 projects demonstrated one to three crosscutting concept(s) from six out of seven crosscutting concepts mentioned by the NRC. The most frequently applied crosscutting concepts are "Patterns" and "Cause and effect: Mechanism and explanation", 11 (7 Outstanding, 4 Merits, and no Consolation) projects showed such a combination. The majority (10 Outstanding, 10 Merits, and 9 Consolation) of projects being studied applied two crosscutting concepts in their work; and two Consolation projects were recorded applying only one.

Regarding the STEM education quality framework, the results showed a similar pattern for "Integrity of the Academic Content" and "Degree of STEM Integration." Most of the science projects were analyzed as "Accomplished" in the integrity of academic content, only one outstanding project achieved "Advance," while five consolation reports were considered as "Not evident" in the integrity part as there was a lack of a fair test and/or control of the variables causing the inquiries to be unscientific. For the degree of STEM integration, all outstanding and merit reports achieved "Advance" integration, while the consolation reports varied from "Advance" to "Accomplished" and "Emerging" integration, with five of them recorded "Advance" in this analysis; four recorded "Accomplished," and one recorded "Emerging." From the Pearson correlation coefficient, these two components, integrity and degree of integration, were found to be significantly related ($r = 0.91$, $p = .000^{**}$), suggesting that accurately portrayed academic content is fundamental to integration.

Discussion

Unbalanced STEM Activities in Science Projects

This study examined STEM activities conducted in primary students' science projects in an extracurricular event. The results show that the students conducted more engineering and science activities than technological and mathematical activities in their science projects. It is a self-evident truth that there were a great number of science activities conducted by students in science projects. Lewis (2006) argued that design and inquiry are conceptual parallels because both are reasoning processes which target ill-structured and uncertain problems. That might explain why the students conducted more engineering activities in their science projects.

The analysis reported students' ability in the different aspects of STEM activities, and found that there is room for improvement and a more STEM approach to conducting science projects. Specifically, for the science aspect, there were fewer initiating activities by the students, especially with the setting up of a hypothesis. This indicates that the students' science was more likely to be initiated by others, possibly their teachers or parents, or by making reference to others' work. Regarding the engineering aspect, difficulties in conducting the activities of refining the solution were identified. It is postulated that the students might have overlooked the fact that the design process is cyclical and there is a need for continuous improvement. In terms of the technology aspect, a limited number of activities concerning innovation and safe use were conducted. This infers that students might lack the abilities of innovating technology to satisfy their use, and they seemed not to have an awareness of the safety issues regarding using technology. As for the mathematics aspect, the students in the present study were less likely to use mathematics expertise to process and represent data. This finding is consistent with that of So's (2013) previous study in which primary students faced difficulties analyzing and calculating numerical data and interpreting graphs and tables.

Group differences in the STEM activities were also found. The Outstanding group conducted more STEM activities than the merit and consolation groups, and significant group differences existed in the science and mathematics activities. There are two possible explanations as to why the outstanding groups significantly excelled in the science and mathematics activities. First, this might be related to the criteria of the contest judgment, as it largely focused on science knowledge and practice. Second, although mathematics knowledge and practice were not considered explicitly in the judgment, science learning is inherently related to mathematics learning (DePaul Science Working Group, 2013), and the mathematical way of presentation may influence the judges' judgment of the quality of the science projects.

Association of STEM Activities and Content Knowledge

Science activities were significantly positively related to engineering and mathematics activities in the students' science projects. The connection between science, engineering, and mathematics was established in the students' projects. This result shows that the integrative approach with a connection of science, engineering, and mathematics was established in science education. Differing from the studies which focused on the integration of two subjects (e.g. Charlesworth & Lind, 2010; Lee et al., 2010; Mehalik et al., 2008; So, 2013), this study proves the potential of integrating more than two subjects in science projects.

Hew and Brush (2007) listed six types of barriers to technology integration in K-12 schools, namely resources, institution, subject culture, attitudes and beliefs, knowledge and skills, and assessment. The finding that science was not significantly related with technology in this study confirms that the integration of technology into primary students' science learning is both insufficient and difficult. Although suggesting that technology should be incorporated into science education is not new, it is still a challenge that advancing STEM education should respond to (Bybee, 2010, 2013; Williams, 2011).

The 30 project reports demonstrated diverse and multiple disciplinary core ideas and crosscutting concepts, and the performance in "Integrity of the Academic Content" and "Degree of STEM Integration" was also satisfactory, meaning that the students were anchoring knowledge correctly and integrating what they had learnt. One possible explanation could be that the event with an environmental theme of "Go green at home" allows the pupils to innovate on issues that come from daily life rather than the content of any particular subject. They can utilize skills and knowledge from different subjects that they have learnt, thus creating an opportunity for them to integrate different disciplines in a single learning experience. This may suggest promoting informal learning so as to strengthen students' ability to solve real-life problems.

Despite the positive findings reported, there are always limitations to research studies which require further work. First, the assessment framework of STEM activities needs to be tested in different STEM learning situations such as formal learning. Second, students might receive different types of support or guidance from their parents or teachers during their science projects. Hence, there is no attempt to generalize the findings of this study. Third, students' science reports were the only data source in this study, other methods such as follow-up interviews would be useful to explore the possible reasons for the pattern of STEM activities and the integration of STEM.

Conclusions and Implications

The researcher-generated framework making reference to a comprehensive range of literature related to each of the disciplines to identify the possible indicators worked well for the present study to identify the STEM activities conducted by primary students in their science projects. The extracurricular event with science projects reported in this study provided evidence of great opportunities for primary students to experience STEM in solving a problem relating to their environment. It is well supported by Chiu, Price, and Ovrahim (2015, p. 12) that "constructivist approaches, problem-based learning, and making connections to the real world often characterize effective STEM education when implemented using inquiry-based strategies.".

The low frequency of technology adoption and the lack of significant connection to the science activities suggested an enhanced integration of technology in science education. As recommended by Barab and Luehmann (2003), technology coupled with appropriate scaffolding from teachers and other experts could support inquiry-based learning. Much effort from the teachers and other experts to offer necessary help and provide access to technology to students' science inquiry work should be emphasized.

To conclude, the identification of relevant activities from a STEM perspective in this study not only provided better understanding of students' enactment of science projects and the assessment of students' performance of STEM integration in science projects, it also offered baseline information and suggestions for further research and instructional efforts in the planning and implementation of the future development of quality STEM education at the primary school level.

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