Proceedings Paper:
Tsang, M.K.-Y. (2021) Science and Language connect the world - When STEM meets STSE with CLIL beyond a classroom context in Hong Kong. In: Lee, Y.-J. and Park, J., (eds.) Proceedings of the International Science Education Conference 2021, Singapore : 20/20 Vision for Science Education Research. ISEC - STEM Conference 2020, 22-24 Jun 2021, Singapore. Proceedings of the International Science Education Conference. National Institute of Education, Singapore, pp. 24-45. ISSN: 2630-5445.

2. Science and Language connect the world - When STEM meets STSE with CLIL beyond a classroom context in Hong Kong

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Abstract

Science literacy plays a crucial part in science education nowadays. However, it is confined to a need for assessments – few students are aware of the importance of science in the world. Worst still, even if students are literate in science, they do not know how to present themselves effectively through English. Consequently, a teaching and learning programme is tailored-made for students to increase their awareness of science to other disciplines through the science, technology, engineering and mathematics (STEM) approach (Bybee, 2010, 2013). Together with their awareness of the current environmental issues through science, technology, social, and environment (STSE) approach (Bencze et al., 2020) with language support through content and language integrated learning (CLIL) (Lin, 2016).

This action research adopted a design-based intervention design with a group of Secondary two (Grade 8) Science students (n = 5) with mixed ability in an EMI school in Hong Kong. Students in the intervention received additional language support of CLIL by a teacher-researcher for the background science knowledge. The teacher initiated students' thinking on sustainable development and endangered species by the STSE approach. After that, students were asked to design a device to help save the population of the endangered species by using the STEM approach. Through the research period, language support used in the intervention group will be gradually removed by careful scaffolding in order to increase learners' responsibility (Elliot, Frey and Fisher, 2019) to observe the learning progress of students. Teacher's observations and students' work were also used to understand the teacher and students' attitudes towards teaching and learning in various approaches during the study. Results, pedagogical and theoretical implications for STEM, STSE and CLIL are discussed.

Keywords: student science research, STSE, STEM

Introduction

Besides teaching students how to know science, it is more important to cultivate them to think science (Zoller and Nahum, 2012). Moreover, science is not a standalone subject; it has strong connections with mathematics and engineering subjects. Therefore, science, technology, engineering, and mathematics (STEM) education have become a popular topic for researchers and teachers to investigate how students learn science in a multidisciplinary approach (Bybee, 2010, 2013). However, recent studies (Rahman, 2021; Yuen *et al.*, 2021) are more inclined to robotics and programming. Few studies are replying to the social calls of environmental protection. Researchers have established science, technology, social and environmental education for a long time (Brown, 2012; Bybee, 2010, 2013; Stohlmann and Moore, 2012; Kelley and Knowles, 2016). Numerous successful studies show that environmental education is essential in science learning and teaching (Littledyke, 2008). Therefore, a learning and teaching programme with STEM and STSE elements was developed.

Other than thinking science, science communication has played an indispensable role in science learning and teaching. However, science educators and researchers had little focus on this issue for EFL learners except vocabulary building (Coxhead, 2018). Therefore, strong language support, such as that under CLIL approaches, is essential for Hong Kong students who are ESL/EFL learners while receiving sophisticated chemical knowledge using English as a medium of instruction (EMI). As a result, students can read and extract essential information from the text in reading materials and produce their work verbally and in written work using subject-specific vocabulary, general academic vocabulary and appropriate signalling words at a text level. It is hoped that this study can shed light on CLIL approaches in a science context in STEM and the STSE approach to give more insights to science scholars and teachers that language learning is crucial in science learning.

The research questions in this study include:

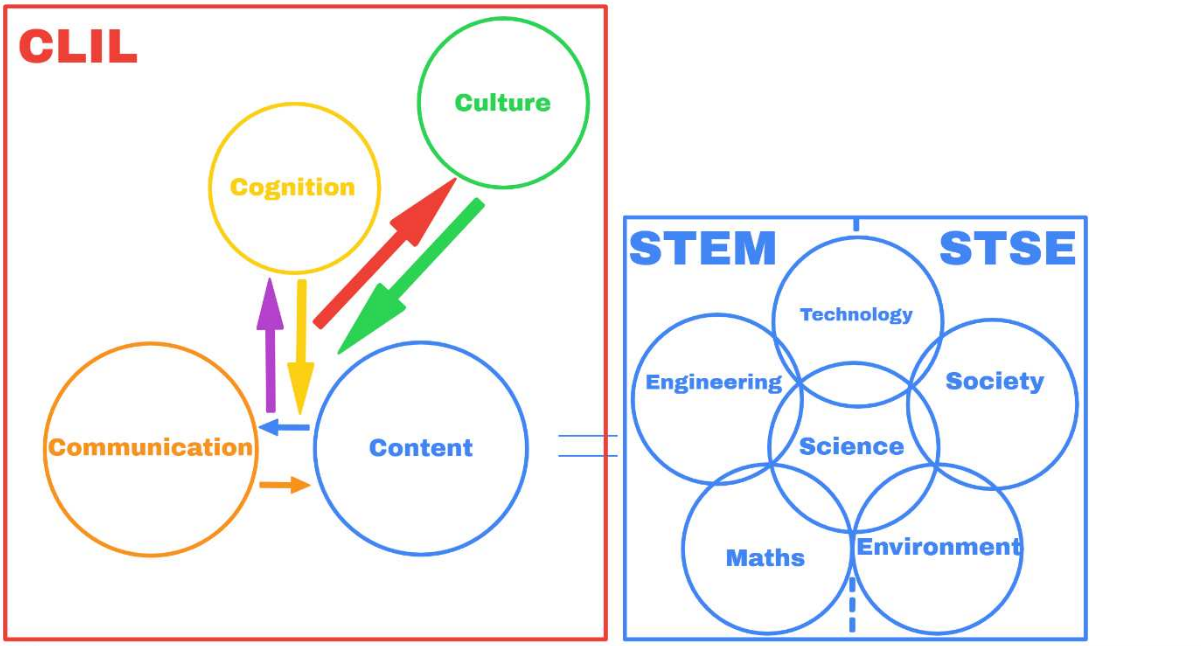
- the extent of the feasibility of integrating STSE, STEM and CLIL in an environmental education programme
- the extent of teaching and learning effectiveness of the programme in scientific, technological, engineering, mathematical, social, environmental, linguistic and cultural components.

Theoretical Framework

This theoretical framework is based on the 4C model of CLIL suggested by Professor Coyle (2010) with content, communication, cognition and culture. Throughout this study, students' receptive and productive skills in English were examined. In this study, the content includes science background (S), technological (T), social (S) and environmental (E) impact to the endangered species by the STSE approach. After discussing the undesirable impact to that endangered species, students applied science concepts they learnt (S), technology and computer literacy acquired (T), engineering principles (E) and concepts for mathematical manipulation (M) to build a prototype for improving the environment. Therefore, this study provides multi-dimensional learning opportunities for students. With plenty of scientific knowledge delivered, effective communication between teachers and students is crucial. As a result, careful planning for communication in lessons is necessary to foster effective teacher-student knowledge exchange. While students acquire sufficient basic science concepts with accurate language, they can analyse, evaluate and create science knowledge, which is the cognition process of the CLIL model. Ultimately, it is hoped to build students as responsible global citizens, which is the culture of the model.

Figure 1

Incorporation of the STEM, STSE and CLIL model in this study



Literature Review

The importance of STSE education

Environmental education is essential in value building, including being responsible, committed and care for nature (Bencze et al., 2020). However, if value-building is the principal teaching and learning objective, the background knowledge may not be sufficient. Therefore, environmental education should be promoted as value education embedded with essential knowledge. This teaching and learning programme involves students choosing an endangered species that they wanted to protect and conserve. Next, they learned about the endangered species' features (science) and how technological advancement threatened the species (technology). After that, they acquired knowledge about the societal (society) and ecological (environment) impact of the endangered species' decreasing population. Students showed their learning achievements of endangered species through written and oral presentations, which can evaluate the programme's teaching and learning effectiveness.

The importance of STEM education

STEM refers to science, technology, engineering and mathematics education (Bybee, 2013). Many educators misinterpreted it as science, technology, engineering and mathematics in a teaching and learning programme. However, the key to successful STEM education should be *integrating* scientific, technological, engineering, and mathematical elements in the programme. In this study, the extent of integration of the four elements in the programme was investigated.

Recent studies (Rahman, 2021; Yuen *et al.*, 2021) are more inclined to computer-based STEM programmes such as robotics and programming. It may help improve human living standards by increasing convenience to people. However, when it comes to environmental education, especially conservation biology, a technologically inclined STEM programme might not help. Therefore, in this study, more science concepts were embedded to form a concrete knowledge base to solve environmental problems.

This teaching and learning programme involves learning a scientific approach to build a shelter to conserve an endangered species (science). Before students had found appropriate materials for the shelter, they searched for necessary information for shelter building (technology). After that, they make a shelter prototype (engineering) with careful calculations (mathematics). All four elements of STEM education were present, the effectiveness of the programme was investigated.

Improving students' English proficiency in science through the CLIL approach

Content and Language Integrated Learning was defined as' a dual-focused educational approach in which an additional language is used to learn and teach of both content and language' (Coyle, Hood and Marsh, 2010). When participants were Grade 8 students with mixed English ability of ESL and EFL learners, English support through CLIL was necessary. When they learnt the environmental impacts of endangered species through the STSE approach and built a prototype to help conserve endangered species through the STEM approach, the CLIL approach is essential to bridge the participants into the target language.

Code-switching between Chinese and English

At the beginning of the programme, some EFL learners searched Chinese (L1) information for the endangered species. Instead of asking the students to find the information again in English (L2), it was a golden opportunity to introduce subject-specific English words to increase their vocabulary. After that, they tended to search information bilingually to have various angles for their endangered species research. This scaffold was removed in the latter part of the programme as the EFL students were more accustomed to learning science in English as the only medium of instruction.

Figure 2

The ‘Rainbow Diagram’ (Lin, 2016) illustrating code-switching as the transition between L1 and L2 academic languages

Promoting literate talk

Some subject-specific vocabulary can be explained from students' schemata as they had learned English words in English lessons used for daily scenarios. For instance, when a teacher-researcher explained the meaning of 'biodiversity':

'When we look at the word "biodiversity", we can chop it down into two parts – "bio" and "diversity". Do you still remember the word 'biology'? It is the study of ... Yes! Plants and animals. Diversity means "how many", the number of, the amount of. Therefore, biodiversity means the number of plants and animals in the world.'

The teacher-researcher started introducing the term biodiversity by chunking the words into two parts, "bio" and "diversity". For the first part, the teacher-researcher recalled the word they learned in science lessons (biology). Then, the teacher-researcher used words they have learnt in English lessons (plants and animals). Similar practice went on for the second part. The teacher-researcher used words they have learnt in English lessons' how many', then he paraphrased as 'the number of' and 'the amount of'. Overall, he used a wide range of daily oral language and oral academic language vocabulary to target written academic language.

Figure 3

The 'Rainbow Diagram' (Lin, 2016) illustrating literate talk as transition of L2 language registers

Using multimodalities

Multimodalities refer to audio-visuals, images, diagrams, concept maps, graphic organizers, demonstrations, role-play, actions and gestures (Lin, 2016). When students do not understand words from other words, multimodalities can help students to understand the concepts other than words. For instance, when students learnt the biodiversity of organisms, videos were used to introduce some complex and abstract concepts. With explanation using daily oral English and elaboration using plenty of photos, students could understand the term 'biodiversity' easily. When students learn the life cycle of an endangered species, diagrams familiar to students were shown to students with further explanations. These multimodals serve as the bridge between students' prior knowledge in daily experience and the knowledge to be learnt in English.

Figure 4

The 'Rainbow Diagram' (Lin, 2016) illustrating using multimodalities (red arrow)

Research gap to be filled

There are few studies concerning environmental education from the STEM approach. Moreover, there are few studies concerning hand-on activities from the STSE approach. When there are more hands-on activities for environmental education, there can be more practical solutions for environmental problems from individuals. With sufficient language support, the current study evaluates students' learning effectiveness in acquiring science knowledge in a classroom using English with language support through CLIL in a STEM and STSE classroom.

Methodology

Research design

Compared with other research designs, action research is a plausible method in this context to promote a naturalistic enquiry to knowledge co-construction between teachers and students (Burns, 2009). This study was practical action research involving problem-solving of an environmental issue – conserving an endangered species. Therefore, practical action research was carried out to discover the meaning of participants' behaviour in the research with the outcomes depends on the participants. A brief scheme of work is shown below.

Figure 5

Scheme of work in this study

Stage of study	Content	The teaching and learning approach used	Assessment	Duration
1	Sustainable development	CLIL	Poster design	30 minutes
2	Endangered species	STSE, CLIL	Poster design and oral presentation	3 hours
3	How can we help to conserve endangered species	STEM, CLIL	Eco-house design and oral presentation	4 hours

Before participants learnt how to conserve living organisms, they needed to know the importance of protecting them. Otherwise, this study would undesirably become a knowledge-draining activity after they were convinced that environmental protection is of paramount concern. They needed to find an endangered animal or a plant for investigation. In this study, students chose to study bees for further investigations. They studied the features and the life cycle of bees, which is the science part of the STSE approach. Next, they researched how the decline in the bee population affects society and the environment. After participants knew the negative impact of the population decline of bees, they were required to build an eco-house to support the bee population. At that time, the STSE approach was completed, and the STEM approach was conducted. Participants needed to conduct internet research on how to attract bees to settle down its eco-house. Next, they need to find suitable materials for building an eco-house. After that, they calculated the numerical parameters for a suitable living environment for bees. Finally, they built the house, cutting down the materials they found with their results after calculations.

Research setting and Participants

Participants (n=5) were drawn from Grade 8 (13 years old) students studying Science with mixed ability in a secondary school in Hong Kong. Other than students, one science teacher was also involved as a teacher-researcher to co-construct knowledge with students through STSE, STEM, CLIL learning, and teaching strategies.

Methods of data collection and analysis

Observations

Observations were employed to increase the amount of research data quantitatively by recording events and programme context in detail, ultimately providing a more holistic picture for the study.

Regarding the type of observations, the programme was planned, and the observation focus was known before the study. Moreover, the researcher aimed to test the hypothesis: ‘STSE, STEM and CLIL approaches are helpful to non-native English students to learn environmental education effectively’. Furthermore, the observer was also a teacher-researcher in the lesson, taking an active role in observation. The observations recorded in this study were structured, with full participation. Throughout the 8-week study, lessons were audiotaped, transcribed and analysed to answer one research question – to evaluate the teaching and learning effectiveness of the programme in scientific, technological, engineering, mathematical, social, environmental, linguistic, cognitive and cultural components.

Students' works

Students' works were collected to enrich research data qualitatively, ultimately providing a more comprehensive picture for the study. Throughout the study of eight weeks, students worked on two posters – one emphasising the importance of sustainable development and another one focusing on the rationale of conserving bees by the STSE approach. After that, students created an eco-house to conserve bees by the STEM approach. Throughout the programme, language input and output of students' works were supported by the CLIL approach. Students' works were analysed to answer one research question: what students have achieved in scientific, technological, engineering, mathematical, social, environmental, linguistic, cognitive, and cultural components.

Research Questions

1. the extent of the feasibility of integrating STSE, STEM and CLIL in an environmental education programme
2. the extent of teaching and learning effectiveness of the programme in scientific, technological, engineering, mathematical, social, environmental, linguistic and cultural components.

Ethical Considerations

Informed consent was received from the students, parents, and principal to guarantee students' privacy and their rights in the study period. A power relationship existed between the researcher and the participants, as the researcher was the participants' teacher. Therefore, the research process was democratised, and the power relationship was minimised as they were free to participate in the research aspects of the study and had the right to opt out at any time. These measures were implemented to allow a smooth investigation and make participants feel at ease and comfortable.

Results

Students were required to produce two posters, one for stressing the importance of sustainable development and another for reporting what they have done in this learning project. After that, students needed to present what they have done based on their second poster in an oral presentation. The followings report the effectiveness of every component in the STSE, STEM and CLIL approaches.

After students had known the importance of sustainable development, they were asked to one endangered species to study, and they agreed to investigate bees. Next, students were required to report information on the structure of a bee in its life cycle and how the adaptive features help bees to survive. Students initially reported much information about the structures of a bee without synthesising the valuable information in the poster. Therefore, the teacher-researcher intervened by teaching students how to find out crucial information from the data source. After that, students managed to synthesise information and reported that the hard shells of eggs, hard pupa, wings, and stings helped protect themselves. Other than that, they reported that the community living of bees also helped to protect bees from each other. However, due to excessive human activities and technological advancement, bees were on the verge of extinction, leading to irreversible social and ecological impacts.

Figure 6

Participants' Poster design to summarize their ideas on the bees' extinction

After they had known that the bees would become extinct, they searched for ways to help bees. They discovered that there were some solitary bees which do not have a nest. Therefore, they started to build a nest as the eco-house for the solitary bees. That was the 'bee hotel'. When students built the bee hotel for solitary bees, it was essential to know about the dimensions of the house. Therefore, they searched bees' sizes from the internet and managed to design and create a bee hotel that suits their needs.

Figure 7

The bee hotel as a prototype of bees' shelter

From the observations of the project team, some solitary bees stayed for some time for a short rest, but they did not regard it as a living place. Students noticed that they just considered the length and width of the hotel, but they neglected its depth. Because of the insufficient depth of the bee hotel, solitary bees did not stay long. Therefore, they are currently investigating to build a modified version based on the prototype to make the hotel more suitable for bees to live in.

Language played an essential role throughout the whole project. The teacher-researcher bridged students' schemata of their mother language to target academic vocabulary. Next, the teacher-researcher constructed knowledge jointly with students by exchanging students' daily English language to target academic vocabulary. After that, the teacher-researcher co-constructed knowledge with students from multimodalities to target academic vocabulary. While the teacher-researcher gradually removed language scaffolds, students were asked to write more and more, from point-form posters to paragraph-length presentation scripts. The teacher-researcher did the final stage of the study to give oral and written feedback only, without much language support. This gradual release of learners' responsibility, suggested by Elliot, Frey and Fisher (2019), ran smoothly throughout the programme. Overall, students were engaged in every teaching and learning activity. The teacher-researchers observed that they were particularly interested in making the bee hotel, especially drilling the holes with the calculated diameter. Moreover, they were highly concerned about the number of bee visitors coming to the bee hotel; especially one student was asking the teacher-researcher how we can seduce more bees to come', hoping that they could stay longer to save them from extinction. These shows not only the high engagement of participants but also their increasing environmental awareness.

Discussions

Compatibility of STEM, STSE and CLIL

This study showed that the STEM, STSE and CLIL approach not only existed but also integrated fully in this programme. From the teacher's observations and students' works, Participants learnt the features of bees and how their adaptive features help them survive. Also, how the advancement of technology adversely affects society and the environment was thoroughly discussed. Moreover, there is a smooth transition from STSE to STEM when the teacher-researcher asked participants to work on a prototype to conserve bees. They improved their information literacy in an internet search for scientific facts for providing a comfortable living place for bees. Furthermore, they designed and created a bee hotel prototype as an eco-house for bees with careful mathematical manipulations. Besides, this study showed that students could produce relevant subject-specific vocabulary, general academic vocabulary in the poster presentation and signalling words to link their ideas in oral presentation text. Other than that, participants showed high cognitive ability in analysing, creating and evaluating the bee hotel by applying the scientific, technological, engineering and mathematical concepts they learnt. Most importantly, students were more and more environmentally aware of conserving bees from their responses in the programmes. These responses from the participants show that teacher-researcher successfully co-constructed knowledge based on various teaching and learning objectives, and students appreciated the value of the programme about species conservation. While students were strong at acquiring what they should learn, they were generally weak in how they should. In other words, they lacked the skills to accomplish teaching and learning tasks. For example, they had limited knowledge to extract information from data, and they tended to work independently instead of working most of the time collaboratively. Such practices hindered the teaching and learning effectiveness of the programme and their further studies. Consequently, in the next run, more skill-based activities should be introduced before concept teaching and learning.

Limitations

The sampling size (n=5) of the participants was not significant, which may affect the generalizability of the results. Moreover, the programme was run only once, which may affect the trustworthiness of the results. Nevertheless, the teacher’s observation and students’ work were highly triangulated, showing that the results were trustworthy and highly credible.

Conclusions and Implications

In this study, the STSE, STEM and CLIL approaches were successfully implemented in an environmental education programme, leading to high teaching and learning effectiveness in scientific, technological, engineering, mathematical, social, environmental, linguistic, cognitive and cultural components was high. Moreover, students achieved all teaching and learning objectives in cognitive and affective domains. However, more emphasis and support about learning skills should be introduced to students to further increase the teaching and learning effectiveness of the programme and participants. In the next run, it is hoped that the sampling size can be more significant to increase the reproducibility and trustworthiness of the programme.

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Acknowledgements

I would like to thank Professor Chi-syan LIN from the National University of Tainan and Miss Jennifer Yun-chai CHEN from National Sun Yat-sen University to recommend joining this study project in APEC Cyber Academy in Taiwan. Without their generous and wholehearted support, this study project would not accomplish with great success.