How does flipped classroom foster STEM education: Cases studies of two innovative teaching and learning approaches?

by

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Statement of Originality

I, FUNG, Chak Him, hereby declare that I am the sole author of the thesis and the material presented in this thesis is my original work. I further declare that I have followed the University's policies and regulations on Academic Honesty, Copyright and Plagiarism in writing the thesis and no material in this thesis has been submitted for a degree in this or other universities.

Abstract

STEM, which refers to the acronym of the integration of Science, technology, engineering, and mathematics (STEM), was first introduced by the National Science Foundation in response to the global challenges around the world. Due to its significance, it soon becomes very popular and thus STEM education is now a hot issue among many countries. However, teaching STEM is not an easy task. According to current studies, lack of appropriate pedagogies is one of the main factors to be blamed. Establishing linkages between knowledge and real-world problems as well as the linkages among subject disciplines are very challenging. In response to the above, this thesis aims at investigating the mechanism of how flipped classroom could enhance STEM education in two innovative approaches named as Flipping - Practical - Discussion (FPD) and the flipped learning by teaching. As new attempts, qualitative studies were conducted to investigate the possibility, feasibility and possible outcomes of such integrations.

As indicated by the results, flipped classroom was compatible with practical work and discussion as well as learning by teaching approach. FPD and flipped learning by teaching were not only theoretically but also practically effective in fostering students' learning in STEM. Further investigations revealed that the use of flipped classroom may retain and strengthen the existing advantages of the practical work and discussion as well as learning by teaching. It also suggested that the use of video, which was considered as a weakness of the use of simple flipped classroom approach, was an essential ingredient in boosting the effects of practical work, discussion and learning by teaching in the FPD and the flipped learning by teaching. Eventually, FPD and flipped learning by teaching could result in a bigger gain than using those elements (eg. Video, practical work, discussion and learning by teaching) independently.

Perhaps one of the greatest importance of this dissertation is that flipped classroom could be an effective mean to unleash the potential of those traditional elements in STEM education. By integrating flipped classroom, practical work, discussion and learning by teaching would become more effective in fostering students' learning in STEM education. It also suggests the possibility of the integration of flipped classroom with other traditional teaching and learning approaches for better STEM education. Eventually, it leads to a new era of new innovative approaches for STEM education enriched by flipped classroom.

Keywords: STEM education, Flipped classroom, Flipping - Practical – Discussion approach, flipped learning by teaching

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List of Abbreviations

STEM	Science, technology, engineering, and mathematics
NAE	National Academy of Engineering
NRC	National Research Council
FPD	Flipping - Practical - Discussion
NSF	National Science Foundation
LdL	Learning-by-teaching pedagogy

Chapter 1. Overview of this dissertation

1.1. What is STEM and why do we need STEM education?

STEM is a hot issue in education. The history of STEM could be dated back to the 2000s when it was first initiated by the National Science Foundation in react to the rising of global competition (Chesky and Wolfmeyer, 2015; Sanders, 2009). As first, it was just a term representing the four disciplines. Nowadays, STEM refers to acronym of the integration of Science, technology, engineering, and mathematics (STEM) (Sanders, 2009). (For detail of the definition please refer to Chapter Two, section 2.4.A)

Once the STEM was initiated, its manifest benefits soon make it popular to the world. Studies showed that 75% of the fastest growing occupations are looking for employees with STEM knowledge and skills (Becker, and Park, 2011) while the employment growth rate of the STEM industry is nearly a double compared to others (Craig, Thomas, Hou, and Mathur, 2012). Thus the candidates with strong STEM background is more competitive in the labour market (Aleman 1992; Darling-Hammond 1994). Due to the high labour demand and the effectiveness of STEM in boosting national economic growth, STEM education program continues to spread out and develop in many countries (Australian Industry Group, 2013).

1.2. Current Problems and the origins of the rationale

Although it is widely spread and adopted, the status quo of STEM education is not satisfactory (Thomas and Watters, 2015). Conducting an effective STEM lecture is a challenging task. (Thomas and Watters, 2015; Sujarwanto, Madlazim and Sanjaya, 2021). As revealed by a survey, almost half of the K12 in-service teachers are not ready for STEM education (Geng, Jong and Chai, 2019). According to Rogers and Ford (1997), lack of effective teaching technique is the first to blame. Frontline STEM teachers is lack of appropriate pedagogies to achieve their teaching and learning goals in STEM education (Hong Kong Federation of Education Workers, 2017). Even though some of the teaching approaches may be useful, teachers are reluctant to apply them because of the difficulties of implementation (eg. Hutagaol-Martowidjoyo and Adiningrum, 2019; Vilaythong, 2011). For example, teachers are reluctant to integrate practical work into their teaching although practical is an effective way of teaching STEM (Abrahams and Reiss, 2010; Thair and Treagust, 1997). As National Academy of Engineering (NAE) and National Research Council (NRC) (2014) summarized, the challenges in the current practices are: the weak linkages between knowledge and real-world problems, weak linkages among subject disciplines and the lack of practice for students to establish such linkages. More detail would be discussed in the literature review of Chapter Two and Chapter Three. In response to the genius need, investigation of innovative and effective teaching and learning approach for STEM education is urgent with high priority.

On the other hand, new teaching and learning approaches keep coming up as our advancing in information technology. Flipped classroom is one of the examples. The word "Flipped Classroom" was coined in the late 1990s when educationists started to review and challenge the traditional lecture and homework sequence for better learning outcomes (Baker, 2000; Crouch & Mazur, 2001; King, 1993; Mazur, 1997). Typically, it reverses the traditional lecture-assignment order into an assignment-lecture sequence (Mazur, 1997; Crouch and Mazur, 2001). Since the instructional content is now shifted to the pre-class section, more in-class time could now be spent on meaningful activities such as explaining difficult mathematical concepts or working on problems with guidance and discussion (Delozier and Rhodes, 2017). As a result, students' understanding as well as their academic performance were improved (Mzoughi, 2015; Pfennig, 2016; Sun, and Wu, 2016; Van Alten, Phielix, Janssen and Kester, 2019; Wagner, Gegenfurtner and Urhahne, 2021). Soon, flipped classroom is widely adopted in science (Asiksoy, and Özdamli, 2016; Deslauriers, Schelew, and Wieman, 2011), technology (Amresh 2013; McLaughlin et. al., 2016; Davies, Dean, and Ball, 2013; Shnai, 2017; Yildiz Durak, 2018), engineering (Kanelopoulos, Papanikolaou and Zalimidis, 2017; Le, Ma and Duva, 2015; Warter-Perez and Dong 2012) and mathematics education (Dove and Dove 2017; Graziano and Hall 2017; Lee 2017; Lo and Hew 2017b; Lo, Hew and Chen, 2017; Zengin 2017).

However, some educators criticises the effect of the traditional flipped classroom (Lo and Hew 2017a). For instance, when looking into current empirical studies in mathematics education, it is likely that the traditional flipped classroom (without interactive in-class elements) is not satisfactory as the students' academic performance could be further enhanced if the flipped classroom is enriched by elements such as discussion, feedbacks and peer-collaborative work (via Bhagat, Chang and Chang 2016; Buch and Warren, 2017; Hwang and Lai, 2017; Lo and Hew, 2017b; McGivney-Burelle and Xue, 2013; Sahin, Cavlazoglu and Zeytuncu, 2015; Song and Kapur, 2017; Yousefzadeh and Salimi, 2015; Zengin, 2017). In other words, a simple re-ordering of the lecture and homework section may not truly represent the values of flipped classroom (Lo and Hew 2017a). The use of in-class interactive elements may be an essential factor determining the success of flipped classroom (Fung, 2020). However, what should be employed as the in-class element? As the in-class time is freed up, could it be fulfilled by other traditional teaching and learning approach? How could these combinations contribute to STEM education? What could be learnt by these integrations? This dissertation aimed at answering the above questions by understanding the mechanism of how the elements interacts when flipped classroom is integrated with learning by teaching and practical work with discussion respectively. Furthermore, it aimed at giving us a direction for further innovative approach for STEM education.

1.3. Importance of this dissertation

More importantly, the success of this dissertation not only discover the feasibility of the flipped classroom with practical work, discussion and learning by teaching, but also suggests the possibility of the integration of flipped classroom with other traditional teaching and learning approaches. By revealing the interactions among the elements such as pre-class video, practical work, discussion and learning by teaching section, the mechanism of how flipped classroom could unleash the potential of other teaching and learning approaches could be discovered. It also engenders the study of the relevant integrations for other disciplines as well. Eventually, it leads to a new era of new innovative approaches enriched by flipped classroom.

1.4. Outline of this dissertation

To address the research objectives aforementioned, the study is divided into three stages and the detail was broken down into several chapters (Chapter Two to Chapter Five). In Chapter One, an overview of the dissertation is introduced and the acronym, STEM, as well as its importance are briefly described. More importantly, the current challenges of STEM education and the rationale of the study is discussed.

In response to the current challenges aforementioned an innovative strategy consists of flipped classroom, practical work and discussion is introduced in Chapter Two. It is generally believed that flipped classroom, practical work and discussion could be useful in fostering STEM education (Abrahams and Reiss, 2010; Clark, 2015; Entwistle and Entwistle, 1991; Garrison, 1990; Ramsden, 1988; Thair and Treagust, 1997; Wagner, 1994), a simple use of flipped classroom, practical work or discussion along would be problematic (Kosko and Miyazaki, 2012; Sitole, 2016). Since time constraint is one of the greatest barriers for teachers to employ practical work or discussion in their teaching (Sitole, 2016), integrating flipped classroom with practical work and discussion may be a potential solution to foster STEM education. Thus the objectives of Chapter Two is to investigate whether such integration is feasible or not. Although such integration sound theoretically feasible, could their advantages be retained? Are there any interactions between them? If such integration would be useful to foster students' performance in STEM education, what is the mechanism responsible to these performance? This chapter is already published in Volume 25 of the journal *Technology, Knowledge and Learning*.

Akin to Chapter Two, an innovative strategy consists of flipped classroom and learning by teaching is introduced in Chapter Three. Educators generally believed that learning by teaching is a useful technique in enhancing students' understanding and 21st century skills as well as their performance in STEM education (Aslan, 2015; Stollhans, 2016; Zhou, Chen and Chen, 2019). However, teaching is a very complex task. For effective teaching, the student-teacher have to be equipped with sound subject content knowledge and pedagogical content knowledge (Shulman, 1986; Shulman, 1987; Zhou, Chen and Chen, 2019). Despite there are lots of pre-requisite requirements, time is an enemy to the student-teacher (Aslan, 2015). As a result, a simple use of the learning by teaching approach is very challenging. Integrating flipped classroom with learning by teaching may be a solution to it. By conducting the instruction section pre-class using video, more time could be given to the student-teacher in preparing their lesson as well as to consolidate their knowledge. Although it sound practical, whether the integration of flipped classroom with learning by teaching is feasible or not is still remain to be answered. Could the advantages of flipped classroom and learning by teaching be retained or suppressed? Are there any interactions between them? If it is useful in fostering students' performance in STEM education, what is the mechanism responsible to these performance? The objectives of Chapter Three is to answer the questions mentioned above.

Perhaps someone may start wondering the importance of flipped classroom in the approaches suggested in the Chapters aforementioned. To allow compare and contrast, Chapter Four of this dissertation would like to draw audience's attention to the challenges when using the teaching and learning approach alone. Thus, an investigation of the effectiveness of learning by teaching on is conducted. It served as the grounding elements for the discussion of the importance of flipped classroom in the integrations. Details of the discussion could refer to the next chapter. This chapter is already published in Volume 51 of the journal *Education Sciences & Psychology*. To see the overview of how flipped classroom could benefits other teaching and learning approaches, a cross chapter analysis is conducted in Chapter Five. The role of the flipped classroom and the interactions between the pre-class video with other elements is compared and analysed. It aims to discover the secret of how flipped classroom could unleash the potential of other teaching and learning approaches. In Limitations and further studies are suggested as well.

As last, an overall summary is conducted and significant findings are emphasised again in Chapter Six. More importantly, the impacts of this dissertation are briefly discussed.

Chapter 2. How does Flipped classroom foster the STEM education: A case study of the FPD model

2.1. Abstract

STEM education is essential but challenging. Educators generally believe practical work and flipped classroom are both useful to facilitate STEM education. Practical work is useful in establishing linkages among STEM-related disciplines as well as the connections between knowledge and the real-life problems while flipped classroom could allow more teachers spend more in-class time for individual guidance and feedbacks. This study aims at studying the mechanism of how they could benefit STEM education and their interactions if they are used together. In this study, an innovative strategy called Flipping - Practical - Discussion (FPD), was employed in a STEM lesson among twenty senior high school students of grade eleven. The research follows a qualitative design and individual interviews were conducted on three students and the teacher who conducted the lecture. The result shows that the pre-class video of flipped classroom could act as a medium in providing the pre-requisite knowledge and skills which facilitate the practical work and discussions. Although there is a lack of support in the pre-class section, the questions aroused during watching the video could serve as the raw materials for subsequent class activities, therefore keeping students more focused in the in-class session and potentially boosting the effect of the practical work and discussions.

2.2. Keywords

STEM education, practical work, lab activity, flipped classroom, discussion, lever system

2.3. Introduction

A. What is STEM education?

STEM education is an acronym that refers collectively to the academic disciplines of Science, Technology, Engineering and Mathematics (Education Bureau, 2016). It is an initiative by the National Science Foundation (NSF) and was originally named as Science, Mathematics, Engineering and Technology (SMET), in order to make students creative problem solvers and ultimately more marketable in the workforce (Butz, Kelly, Adamson, Bloom, Fossum, and Gross, 2004; Sanders, 2009). The four strands of STEM are defined as:

> Science: the systematic study of the nature and behaviour of the material and physical universe, based on observation, experiment, and measurement, and the formulation of laws to describe these facts in general terms (Science, 2019).
>
> Technology: the branch of knowledge that deals with the creation and use of technical means and their interrelation with life, society, and the environment, drawing upon such subjects as industrial arts, engineering, applied science, and pure science (Technology, 2019).
>
> Engineering: the art or science of making practical application of the knowledge of pure sciences, such as physics or chemistry, in the construction of engines, bridges, buildings, mines, ships, and chemical plants (Engineering, 2019).
>
> Mathematics: a group of related sciences, including algebra, geometry, and calculus, concerned with the study of number, quantity, shape, and space and their interrelationships by using a specialized notation (Mathematics, 2019).

Traditional education regards the four disciplines as separated components. STEM education, by contrast, integrates the teaching and learning of two or more STEM subjects to meet the 21st-century needs (Sanders, 2009). Thus, STEM does not represent a specific curriculum model and is virtually non-existent (Butz et al., 2004; Herschbach, 2011). In contrast, an implied characteristic underlying STEM is what is termed an "integrated curriculum design" (Herschbach, 2011).

B. Why is STEM education important?

Apart from cultivating students' interest and providing them with knowledge in Science, Technology and Mathematics, STEM education could foster their entrepreneurial spirit and promote creativity, collaboration and problem-solving skills as required in the new century through the integration and application of the knowledge and skills across different STEM disciplines (Education Bureau, 2016). In the meantime, research indicates that STEM skills and knowledge are necessary for 75% of the fastest growing occupations (Becker, and Park, 2011), and employment in STEM-related occupations grows almost twice faster than others (Craig, Thomas, Hou, and Mathur, 2012). Employers are looking for candidates with STEM skill sets, which makes STEM students more competitive in the labour market (Aleman, 1992; Darling-Hammond, 1994). STEM education also fosters national economic growth. In view of this, many countries have started to widely implement integrated STEM education (Australian Industry Group, 2013).

However, the status quo is not always satisfactory (Thomas and Watters, 2015). According to Rogers and Ford (1997), poor STEM teaching technique is the first to blame. Teachers are reluctant to conduct practical work because of the difficulties of implementation (Vilaythong, 2011). The National Academy of Engineering (NAE) and National Research Council (NRC) (2014) argue that the linkages between knowledge and real-world problems as well as those among subject disciplines are weak, due to the lack of practice for students to establish such linkages. On the other hand, with the advance of computer and information technology, a relatively new teaching and learning pedagogy called flipped classroom has aroused our interest (Mzoughi, 2015). By shifting the direct instruction process into the pre-class section, it allows more room for interactive activities in class (O'Flaherty and Phillips, 2015). In consideration of the potential benefits of flipped classroom, this article intends to investigate how this approach, when combined with practical work and discussion, contributes to STEM education.

2.4. Literature Review

A. Definition of STEM education

Although STEM concepts were implemented in many aspects of the world (White, 2014), nowadays educators have adopted different interpretations towards STEM education (Breiner, Harkness, Johnson, and Koehler, 2012). Sanders (2009) defines STEM education as an approach which "explores teaching and learning between/among any two or more of the STEM subject areas, and/or between a STEM subject and one or more other school subjects" (p.21). Moore, Stohlmann, Wang, Tank, Glancy, and Roehrig (2014) defines STEM education as "an effort to combine some or all of the four disciplines of science, technology, engineering, and mathematics into one class, unit, or lesson that is based on connections between the subjects and real-world problems" (p.38). However, these definitions focus too much on the procedural phenomena rather than the gains in learning outcome. Thus, in this thesis, Kelley and Knowles' (2016) definition in which STEM education refers to "the approach to teaching the STEM content of two or more STEM domains, bound by STEM practices within an authentic context for the purpose of connecting these subjects to enhance student learning" (p.3) is adopted.

B. Recent Problems in STEM Education

STEM education is not satisfactory in western and Asian countries (Thomas and Watters, 2015). The NAE and NRC categorize the challenges in current practices as: weak linkages between knowledge and real-world problems; lack of support to elicit students' relevant ideas of disciplinary knowledge and lack of practice for their knowledge (NAE and NRC, 2014).

A review of integrated STEM education programs reveals that only a few of them are making connections within STEM explicitly (NAE and NRC, 2014). Implementing the curriculum individually restricts the STEM development of students (Rennie, Wallace and Venville, 2012). High achievers in a particular subject might not be equally competent in other components since they might find it difficult to apply the knowledge in those lectures (Sithole, Chiyaka, McCarthy, Mupinga, Bucklein and Kibirige, 2017). For example, a student who have well-developed knowledge in calculating "slope" in mathematics might fail to calculate the velocity from an s-t graph because he/she does not know that this particular skill about slope could also be applied to the subject of physics.

Poor STEM teaching technique is also held responsible (Rogers and Ford, 1997). Some educators seem to assume that adopting a problem- or project-based approach automatically means disciplinary integration; however, it's validity remains unclear (NAE and NRC, 2014).

On the other hand, teachers, instructors, and curriculum developers might refine their teaching to their more advanced understanding and thus experience an “expert blind spot” (Nathan and Petrosino 2003). They spontaneously see the deep connections and expect that their students will, too. However, studies suggest that students are less likely to make connections on their own without explicit integration and support (Graesser, Halpern, and Hakel, 2008; Pellegrino, Chudowsky, and Glaser, 2002). For example, the effectiveness of the design approach, which is a popular strategy in learning science concepts, relies on the students’ participation in the design activity (Baumgartner and Reiser 1997; Fortus, Krajcik, Dershimer, Marx, and Mamlok-Naaman, 2005; Mehalik, Doppelt and Schuun, 2008) and the conceptual change following design failure as students have to redesign the product (Lehrer, Schauble and Lucas, 2008). Yet its effectiveness is still inconclusive (Baumgartner and Reiser, 1997; Fortus et al., 2005; Mehalik, Doppelt and Schunn, 2005, 2008; Penner, Giles, Lehrer and Schauble, 1997; Penner, Lehrer and Schauble, 1998; Sadler, Coyle and Schwartz, 2000) because students tend to spontaneously focus on aesthetic or ergonomic aspects of design rather than scientific ones when instructions and/or supports are insufficient (Crismond 2001; Penner et al. 1998). Explicit instructional supports, such as the connections between the representations and notation systems used for both design and science, must be provided (Fortus et al., 2005; Nathan, Srisurichan, Walkington, Wolfgram, Williams and Alibali, 2013), otherwise students are unlikely to connect their ideas with science concepts (NAE and NRC, 2014).

Meanwhile, it is generally believed that practical work is as an effective way of teaching science and STEM curriculum (Abrahams and Reiss, 2010; Thair and Treagust, 1997). Nevertheless, conducting lessons of practical work is very challenging (Jang and Anderson, 2004; Vilaythong, 2011). Despite the availability of equipment, well-qualified teachers, and perfect administrative support, front-line teachers still refuse to use practical work because the class could turn out to be unsuccessful due to student factors (Vilaythong, 2011). Jang and Anderson's work (2004) provides an insight into the field. In actual practice, the lack of pedagogical skills, poor organization of classroom activities and insufficient previous knowledge and experimental skills among students prevent practical work from assisting inquiry learning. If students do not clearly understand what their roles are, the teacher will be kept busy answering their individual procedural questions. Worse still, students waiting for teacher's help will easily lose their focus, which create problems in classroom management. Eventually, Students will not fully engage in the class activities as intended. In some cases, teachers with less subject knowledge and experience rely heavily on textbooks to conduct their lessons. They are proud of the quiet atmosphere established in the classroom, even though they are employing an "inquiry" approach, which is restricted to requiring students to find answers from the books. In a parallel study, Sitole (2016) reported that time constraint is also a factor hindering the use of practical work in classrooms. A tight lecture schedule would make the laboratory period so valuable that the explanation of the prior knowledge and skills is very unfruitful. Consequently, students are given no chance to associate the theoretical knowledge with real life problems or practise them.

C. What is Flipped Learning and Flipped classroom

Recently a relatively new and popular pedagogy called flipped classroom (also called the inverted classroom) has aroused our interest (Mzoughi, 2015; Sahin, Cavlazogula, and

Zeytuncu, 2015). Indeed, the concept of the flipped classroom and flipped learning is not totally new (Baker, 2000; Strayer, 2007). While video instruction had been used to deliver learning content, Baker started to investigate the possibility of using the electronic means, such as making lecture notes available online, extending classroom discussions and the use of online quizzes, to provide the learning opportunities outside classroom and "The Classroom Flip" refers to such strategies (Baker, 2000). Typically, it reverses the traditional lecture-assignment sequence into an assignment-lecture sequence (Mazur, 1997; Crouch and Mazur, 2001). According to The Flipped Learning Network (2014), flipped learning is defined as "a pedagogical approach in which direct instruction moves from the group learning space to the individual learning space, and the resulting group space is transformed into a dynamic, interactive learning environment where the educator guides students as they apply concepts and engage creatively in the subject matter."

In traditional courses, the activities made up of asynchronous web-based video lectures and closed-ended problems or quizzes represent all the instructions students ever get. Flipped classroom, by contrast, includes a lecture completed before class and homework finished in-class (Bergmann and Sams, 2012; Pierce and Fox, 2012; Roehl, Reddy and Shannon 2013). However, a simple re-ordering of teaching and learning activities cannot fully showcase the practice of flipped classroom approach (Lo and Hew, 2017a). It actually represents an expansion of the curriculum (Bishop and Verleger, 2013). As defined by Bishop and Verleger (2013), "flipped classroom is an educational technique that consists of two parts: interactive group learning activities inside the classroom, and direct computer-based individual instruction outside the classroom" (p.5).

D. Flipping and science education

Studies show that the teaching and learning effectiveness in science lectures could be enhanced by using flipped classroom (Mzoughi, 2015; Pfennig, 2016; Sun, and Wu, 2016). Flipping a university physics course could double the academic performance among the students (Asiksoy, and Özdamli, 2016; Deslauriers, Schelew, and Wieman, 2011). By turning the traditional lecture–homework model upside down, it allows more in-class time to be dedicated to interactive activities (O'Flaherty and Phillips 2015; Sun, and Wu, 2016). As video watching is done individually, students can review the video several times without worrying about holding the lesson behind or skipping a particular session they are very familiar with (Roehl et al., 2013) and thus the learning of science becomes comprehensive (Asiksoy, and Özdamli, 2016). Eventually, it enhances students' motivation and joy of learning science (Asiksoy, and Özdamli, 2016; Pfennig, 2016).

E. Flipping and Technology

Educators in the field of technology are now working on personalizing the instructions to facilitate students' learning. Flipped classroom might be a sensible approach as it meets the learning needs of individual students (Keefe 2007). Davies, Dean, and Ball (2013) examined the learning effect of 207 students of introductory-level college course on spreadsheet and found that flipped classroom was more instructional and efficient than the traditional teaching. Besides the learning gains, students' attitudes in the topics and likelihood to take a similar course also increased. In a parallel study of 371 middle school students from 5th grade to 8th grade, Yildiz Durak (2018) reports that flipped classroom is effective in enhancing self-efficacy, attitudes as well as the engagement and interactions among students. Although there are still barriers, such as questionable quality of the video and the lack of experience, skills and knowledge in implementing flipped classroom among teachers, this strategy still deserves careful consideration as it could engender a better teaching and learning environment (Amresh 2013; McLaughlin, 2016; Shnai, 2017).

F. Flipping and Engineering

Educators of engineering believe that flipped classroom approach is a revolution in engineering education (Le, Ma, and Duva, 2015). Although its effect on academic performance is not obvious, it could activate students and encourage their interaction in class (Kanelopoulos, Papanikolaou, and Zalimidis, 2017; Warter-Perez, and Dong, 2012). However, not every student could benefit from it. Since the flipped classroom requires strong independent-study abilities, especially in the pre-class section, active participants seem to profit more from this approach while passive participants might find this strategy useless to their learning (Le et al., 2015).

G. Flipping and Mathematics

Akin to the effect on science, technology and engineering, flipped classroom could enhance students' engagement and learning motivation as well as their academic outcomes in mathematics (Graziano, and Hall, 2017; Lee, 2017; Lo, and Hew, 2017b; Lo, Hew, and Chen, 2017). Flipped classroom provides visualization to make learning of mathematics more comprehensive by turning complex ideas into concrete items (Zengin, 2017). It also reduces students' anxiety (Dove and Dove, 2017).

H. Flipping and STEM education

Flipping STEM classroom is not a new concept as some of the universities have already tried it in their teaching, including the Maths, Statstistics and Electrical Engineering courses at The University of New South Wales (Catchpole, 2015). Talley and Scherer (2013) flipped the STEM courses and reported that flipped classroom could foster students' academic results through enriching the in-class time by meaningful activities. Huber and Werner (2016) reviewed 58 articles about the effect of flipping on STEM education. Although some studies state that the results are still inconclusive or even negative, relatively abundant number of others support that students' academic achievement, perception and engagement could be fostered by flipping strategies (Huber and Werner, 2016).

2.5. Methodology

A. FPD model: Flipping - Practical - Discussion

Based on the preliminary views rendered in the previous session, flipped learning could be a feasible approach to facilitate STEM education. In order to maximize the effects by empowering students to apply theoretical knowledge to real-world problems and allowing them to practice their idea in STEM, an approach consisting of flipped learning, practical work and discussion is proposed. It is thereafter called the FPD model. The rationale is discussed in the following paragraphs.

B. Why Flipped classroom?

The most significant advantage is that flipped learning allows additional collaborative in-class teaching and learning activities which enhance STEM education without extending the duration of the lessons. By introducing flipped classroom, the teaching content could now be shifted to out-of-class sections so that more in-class sessions could be reserved for meaningful collaborative work. The quality of instruction and the use of time are greatly improved (Clark, 2015).

In the meantime, the quality of practical work might be enhanced by using flipping. In conventional practical classes, little time is spent by teachers in advising students about matters related to laboratory work or in checking and finding out where potential problems and faults could lie (Vilaythong, 2011). The introduction of flipping ensures that more in-class discussions and feedback could be given. More teachers' involvements are now made possible due to the increase of the in-class time (Grypp and Luebeck, 2015). It also allows students to learn interactively according to their own learning style and thus enhances student-centered learning (Clark, 2015). Eventually, critical thinking, communication skills and higher-order thinking skills (Van Vliet, Winnips and Brouwer, 2015) as well as student perception, engagement and satisfaction in learning progress (Gilboy, Heinerichs and Pazzaglia, 2015; Gross, Marinari, Hoffman, DeSimone and Burke, 2015) could be elevated.

In actual practice, classroom management, poor organization of classroom activities and insufficient previous knowledge and experimental skills among students are three of the root problems deterring teachers' choice of using practical work (Jang and Anderson, 2004; Sitole, 2016). Flipping could potentially be a solution to those headaches. For example, pre-requisite subject knowledge and laboratory skills could be given to the students as pre-class learning content through readings or videos, which free teachers from explaining the procedures in detail. Therefore, classes could start by conducting a demonstration or providing individual guidance and feedbacks. Since students are equipped with knowledge and laboratory skills beforehand, the majority of them can be expected to clearly understand the teaching content under guidance, which ensures that the teaching plan is followed.

C. Why practical work?

Millar (2004) defines practical work as "any teaching and learning activity which involves at some point the students in observing or manipulating real objects and materials." Using practical work could be effective in teaching STEM education (Abrahams and Reiss, 2010; Thair and Treagust, 1997). For instance, Kontra, Goldin-Meadow and Beilock (2012) suggest that students who actually experience the angular momentum change would achieve more in the written test than those who do not. Although the effect of practical work is still being questioned by some researchers (Gallagher, 1987; Hofstein and Lunetta, 1982; White and Tisher, 1986), Sitole (2016) argues that the reason for the ineffectiveness is indeed due to the abuse of practical work without understanding its main purpose in teaching and learning science. Learners who just follow the procedures step by step might get wrong results or miss the points of the whole practical session (Abrahams and Millar, 2008).

Indeed, concepts make sense by integrating elements of structures or knowledge rather than isolated facts (NAE and NRC, 2014) and thus practical work is essential, especially to STEM education, because it could establish a connection between the domain of observables and the domain of ideas (Abrahams and Reiss, 2010). Perhaps the free fall experiment demonstrated by Galileo is one of the good examples (see Drake, 1978). People used to think that heavier mass fell faster and such misconception was generally accepted until Galileo demonstrated that two balls of the same materials but different masses dropped from the Leaning Tower of Pisa reached the ground at the same time. In this story, Galileo proved not only the scientific content but also that practical work and experiment bridge ideas and reality. This is also applicable to the students. Through observations and experiments, students could investigate whether their predictions, calculations, deductions and explanations agree with the real world situation or not (Giere, 1991).

In the meantime, practical work aligns well with modern constructivism. According to Piaget's work, sensory data collected from practical work could either be assimilated into existing schemas or changes should be made to accommodate the new data so that equilibrium between the internal and external realities could be maintained (Lavatelli, 1973). If Piaget is correct, practical work is critical to scientific reasoning and understanding (Millar, 2004).

D. Why discussion?

Discussion is a popular strategy applied in flipped classroom (See Adams and Dove, 2016; Bhagat, Chang and Chang, 2016; Hwang and Lai, 2017; Wasserman, Quint, Norris and Carr, 2017). Although its effect on academic results is still unclear (Kosko and Miyazaki, 2012), a number of studies report that discussion contributes to students' motivation, attitude and satisfaction, in addition to fostering a deeper and more meaningful learning experience (Entwistle and Entwistle, 1991; Garrison, 1990; Ramsden, 1988; Wagner, 1994). As Vygotsky

(1978a) states, “Speech is the external expression of thoughts…A word without meaning is just an empty sound”. Speech, which links with the complex recognition process within our minds, would help integrating idea, analyzing the situation and developing possible solutions (Vygotsky, 1978b). In further elaboration, linkage between the ideas and reality as well as the linkage between different disciplines could be developed with a greater depth by using discussion. By externalizing students’ thoughts, their progress could also be monitored too.

E. What are the characteristics of FPD and why would we need it in STEM?

As the name suggests, FPD refers to a teaching approach which integrates flipping, practical work and discussion. Indeed, practical work conducted with discussion is not totally new. When Thair and Treagust (1997) were looking for the effectiveness of practical work in biology, one-sixth of the studies adopted this approach in their teaching practice. However, in practice, combining practical work and discussion is not popular. One possible reason is that the in-class period in a traditional classroom is fully occupied by the content-teaching and thus any use of the practice session or discussion, be that integrated or alone, would eventually increase the duration of the lesson. Flipped classroom, therefore, finds its role here. Thanks to flipping, discussion could be conducted with practical work in a single period.

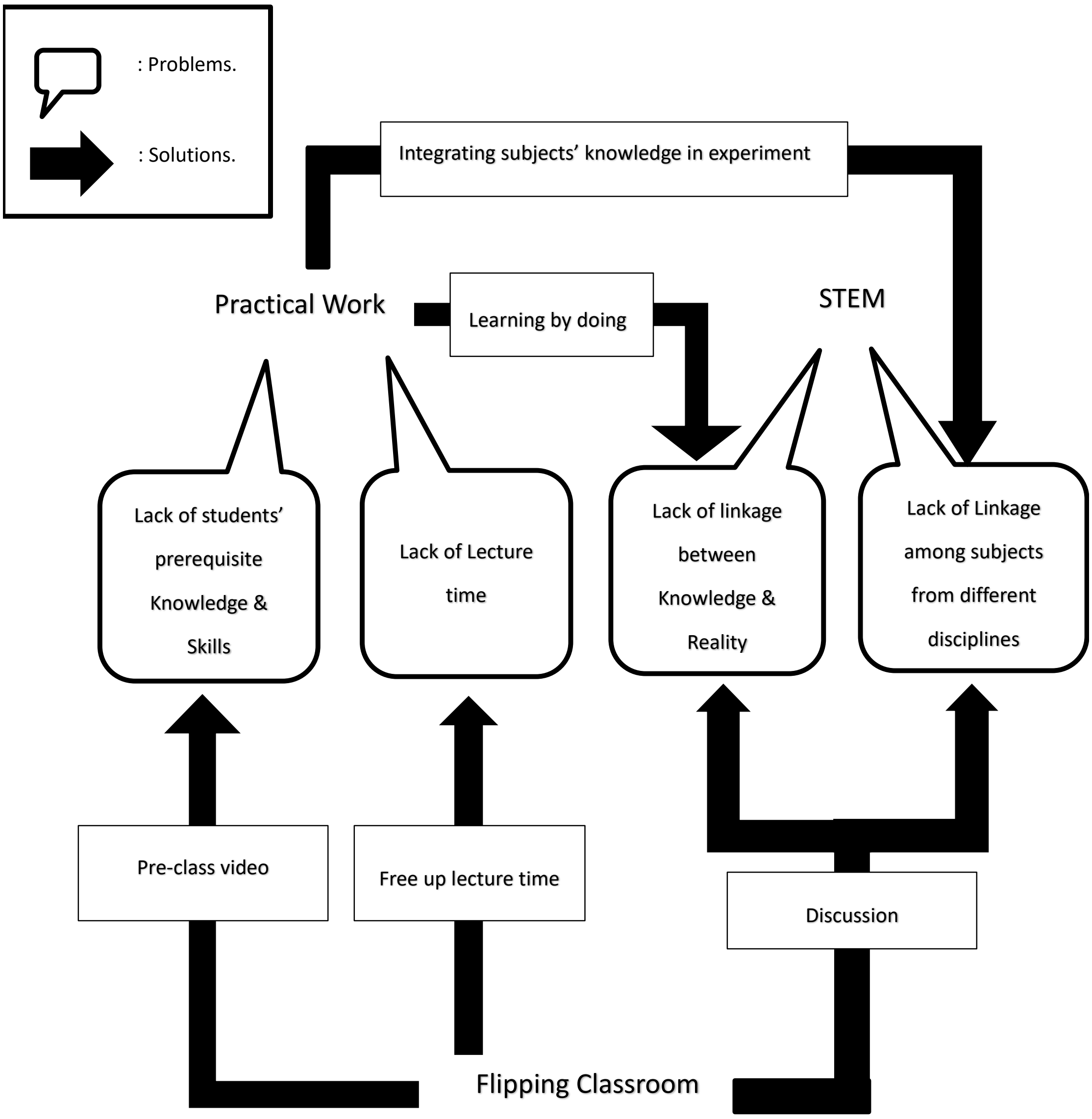
However, a simple integration is not sufficient to represent the FPD model. In order to enhance STEM education, the FPD should be capable of…

1. establishing the linkage within STEM disciplines
2. establishing the linkage between ideas and the realities
3. fostering thinking as well as understanding

4. facilitating communication so that students would be able to express their ideas, process and production to others.
5. promoting students' learning motivation and enthusiasm.

In light of this, the integration of the flipping, practical work and discussion must be "organic". Some teaching contents, which involve knowledge of the theory and formula, are more suitable for pre-class session, while the precaution section would be best included in class. On the other hand, discussion should be conducted in parallel with practical work so that students would translate their ideas into reality by discussing what should be done, what is going to be done, why they should be done and the solutions to problematic situations with others. Meanwhile, the design of the practical work is slightly modified to accommodate discussion. Some values of the independent variables could be decided by the students themselves. Challenging questions are added too. Further procedural details could be referred to the intervention in the method section. A brief summary of the framework is shown in Figure 1 as below.

Figure 1 Framework of the FPD Strategy



2.6. Importance of this study

Despite the significance of establishing connections across the STEM disciplines and the uprising number of efforts to design learning experiences that will foster such connections, there is little research on how best to do so (NAE and NRC, 2014). The FPD might be a breakthrough since this is the first attempt to integrate the practical work and flipped classroom into the STEM education. If the FPD is proved feasible, it might be a practical solution to the existing central problems revolving STEM education because an instructional design is so eagerly demanded by the frontline teachers (Geng, Jong, and Chai, 2019). The underlying mechanism of the flipping pedagogy might serve as a milestone for further improvement of STEM education.

2.7. Research questions

Despite the obvious benefits of integrating flipping and practical work, there are still some questions to be answered. What are the interactions between them? Do they work as hypothesized? To what extent could the degree of their individual strengths be enhanced or weakened? Therefore, the following research questions are developed:

1. How do students perceive the FPD lecture in STEM education? What are the benefits of adopting the FPD? It could be further broken down into…

   A、 How do students perceive the flipped classroom?

   B、 How do students experience with the pre-class video?

   C、 How do students perceive the practical work?

D、 How do students experience with the discussion?

2. What are the interactions within FPD?

A、 How do the components of FPD interact with each other?

B、 How could these interactions produce a better learning outcome in STEM education?

2.8. Research Method

A. Demographic information

In this study, convenient sampling is used because it is efficient and free from some practical constraints such as geographical location (McMillan and Schumacher, 2010). 20 students who were studying the international British A-Level syllabus were selected. They were all 16 to 17 years old studying senior two (equivalent to grade 11) in the same school. The group consisted of 8 boys and 12 girls in total. In a traditional school which emphasized on public examination results, the students had accumulated very limited practical work experience (once per year only) in the past 5 years. Students were not in favour of this approach because they believed that it was not cost-effective. However, students still showed respect to the teacher's authority and would follow instructions or study plans suggested by the teacher.

B. Intervention

Preparation and pre-class section

Lever system was selected as the STEM topic to provide a comparable result to Jang and Anderson's work (2004). It is an International exam (AL GCE, M1) topic which requires a lot of mathematics as well as physics knowledge. According to the teacher's previous experience, students in this school performed poorly in this topic mainly because they failed to integrate knowledge from both subjects. Since STEM might not be the major of the teachers in secondary school (Sithole et. al., 2017), two separated one-hour meetings were arranged to the teacher concerned to equip her with basic STEM knowledge, schedule, procedures and the flow of the research before the intervention. The teacher was responsible for conducting the class and the design of the worksheets while the researcher searched for the pre-class videos.

The pre-class section followed the design of the FPD suggested in the previous section. Since visualization might turn a complex idea into concrete items, flipped classroom is used instead of other materials (eg. Readings) in this case study. An appropriate video in flipping should not be either too short or too long (Dove and Dove, 2017; Lo and Hew, 2017b). Thus in this study, three 5-min pre-class videos, which corresponded to the three tasks in the practical work, were distributed to the students two days before the class, leaving them with sufficient time to prepare.

In-class section

The lecture was scheduled on the weekdays as a 40-min practical work with discussion lecture in the physics laboratory. It began with a 5-min revision about the subject content shown in the videos, followed by a 2-min introduction of the flow of the practical work. Students were then assigned to form their own groups and one complete set of equipment was allocated to each group. Another 5 mins was then spent on a demonstration of the first task and an introduction of the corresponding lab equipment. After that, students were free to interact with their laboratory set-up in order to answer the problems of task 1, 2 and 3 on the worksheet (See

Appendix A).

Collaborative work and inquiry learning were highly encouraged throughout the lesson. In order to provide them with enough space for discussion and inquiry, the content of the tasks was partially fixed only. For example, students were free to try any combination of data in the tasks. For instance, students could determine the values of the weight of the mass and its corresponding distance from the pivot on their own so as to check if their hypothesises were correct or not (eg. See Task 2 in Appendix A). Hence the values of the setting needed to be discussed and their hypothesises were tested by trial-and-error. During the lecture, the teacher kept patrolling, encouraging discussion and helping students with individual learning diversity. Hints and clues were provided for those who might have difficulties while extra questions with a higher level of difficulty were presented to capable students with a faster learning pace. In the last five minutes, a summary was made and the teacher presented a typical answer for each task.

Data collection and data analysis

The interviews started on the next day of the lecture. In order to maximize the sample size to achieve greater validity under the administrative constraints, four students whose student number corresponded to the three integers randomly generated in Excel were selected. One student rejected the interview. For the rest of them, individual interviews were conducted for about 45 mins. It is believed that three students are sufficiently representative since they represent 15% of the population in the study. An interview with the teacher was also conducted to gather insights from the educators' view and to increase the validity by triangulation of data.

The interviews were conducted primarily by using Chinese and were translated into English scripts afterwards. It is believed that the quality of results is guaranteed since interviewees could express themselves best with their mother language. Eventually, their response is recorded as transcripts and coded. Summary of the coding is shown in Table 1 in the result section.

2.9. Ethic concerns

A very high degree of awareness has been put into ethic concerns. The close relationship between teachers and students is a part of the culture of this school. Biased responses might be yielded since the researcher sometimes visits this school for other purposes. Consciousness has also been directed to the equity of computer access. Hence permission was granted from the school's administrative and computers in the library were available in both lunch period and after school period for every student during the study.

2.10.Result

Table 1 Summary of the individual interviews (Teacher + Students)

Categories	Coding	Frequency of Coding[1]	Number of Sources[2]
Effect of Flipped classroom	Quality of instruction increase. Although lesser time is spent on the concepts, students could keep up with the teaching progress	7	4
	Revision is needed because students might forget the content	2	2
	No need to repeat the knowledge covered in the video	2	2
	Video is interesting, dynamic and it enhance active learning	7	2
	(The mindset in) Video is easier to follow than textbook	1	1

[1] Representing the number of frequency that item appears in the script.
[2] Representing the number of participants who contributed to the corresponding code.

Categories	Coding	Frequency of Coding[1]	Number of Sources[2]
	Both video and traditional lecture are difficult to understand	1	1
Effect of Practical Work	Practical work is interesting and it enhance active learning	8	4
	It fosters learning and develops a better linkage between the knowledge taught with the problem in daily life	8	4
	It enhances understanding rather than memorizing facts. Better impression and memory compared to the traditional teaching methods	5	4
Video facilitates Practical Work	Video serves as a preparation of the experiment to provide fundamental knowledge of the practical work such that students know well about what to do in the lecture. It enhances learning.	5	2
	When students got questions in the video, they could investigate and find out the answers in the experiment	1	1
Video facilitates Discussion	When students got questions in the video, they could ask their classmates in the discussion. Thus they got more questions to discuss.	4	1
	In the past, students are easy to go off topic. With the video, they know exactly what is going to be done. They become more focus and active in discussion.	1	1
Practical Work facilitates discussion	Questions could be discussed with investigations and concrete facts rather than abstract concepts only in their imagination.	1	1
Overall effect of the FPD	Weighting of the effect in the FPD: Practical Work > discussion > video	5	4
	FPD enhances learning interest and it is worthwhile to use	11	4
	It achieves better memory of the knowledge and better engagement	5	4
	The practical work and discussion serve as a platform for students to investigate the problems they had got in watching the pre-class videos. It minimizes the disadvantage of using pre-class video	3	2
	Could accomplish the exercises easier since understanding is improved	1	1
	No support in watching video	2	2
	Low monitoring in pre-class video	1	1
	Video is suggested to be introduced 2 days before the lecture.	1	1

A. RQ1: How do students perceive the FPD lecture in STEM education?

i. *Flipped classroom enhances the quality of instruction*

All interviewees agree that flipped classroom could enhance the quality of instruction in terms of time arrangement. Since the practical work section is believed to be more useful in enhancing understanding, using the video for direct teaching and replacing it by practical work in class is favorable to students. Although there is hardly any consensus about whether videos are better than textbooks or traditional direct teaching in terms of understanding, interviewees generally agree that video watching is interesting, dynamic and could enhance active learning.

ii. *Practical work could stimulate interest, foster learning, enhance memory and connect knowledge with reality*

Align with previous studies (see Abrahams and Reiss, 2010; Kontra et al., 2012; Thair and Treagust, 1997), the results of this study also support that practical work might engender more interesting learning experience. All interviewees seem to agree on the significant benefits which practical work could bring to them. In traditional teaching using black and white, students are always very passive and just sit in the classroom waiting for answers. However, they behave very differently in practical work because it is fun when learning is facilitated by "doing", which promotes active learning and students' engagement in the class. In the meantime, practical work makes the learning more explicit, rendering abstract or difficult concepts real and concrete. For example, in traditional classroom, teachers used to demonstrate concepts of the clockwise moment, anticlockwise moment and equilibrium by the static drawings on blackboard. Even though students could follow, they might not indeed understand how it actually works. In contrast, practical work allows students to "experience" the concepts and thus learning becomes intuitive because equilibrium becomes more tangible. The concept moment appears not only as a "number" but also a concrete physical item associated with "a magnitude of turning". As a result, understanding is enhanced and theoretical theories are linked with real-life problems.

In addition, all interviewees agree that practical work could foster their memory. Since the concept is learned by understanding rather than memorizing, students could deduce it again by themselves even if they forget it. The concepts or formula learnt would last longer compared to lectures without practical work.

B. RQ2: What are the interactions within FPD?

i. *Flipped classroom fosters practical work*

Interviewees generally believe that videos could serve as a preparation for practical work. When provided with necessary information of the experiment, such as relevant concepts, formula, guidelines, procedural knowledge or precautions, students are well-informed about what and how to achieve it. This contributes to their readiness to practical work section, thus making practical work smoother and easier.

ii. *Flipped classroom enhances the effectiveness of discussion*

Results indicate that pre-class videos provide the fundamental knowledge which turns students into active participants in discussions. But why does this happen? An amazing fact is discovered when the mechanism behind is being hunted down. Student A talked about the effect of videos on the discussion as follow …

"…because we had all watched the video. We all had problems to ask and it was usual to raise such questions in the discussion. It motivated us to think and discuss together."

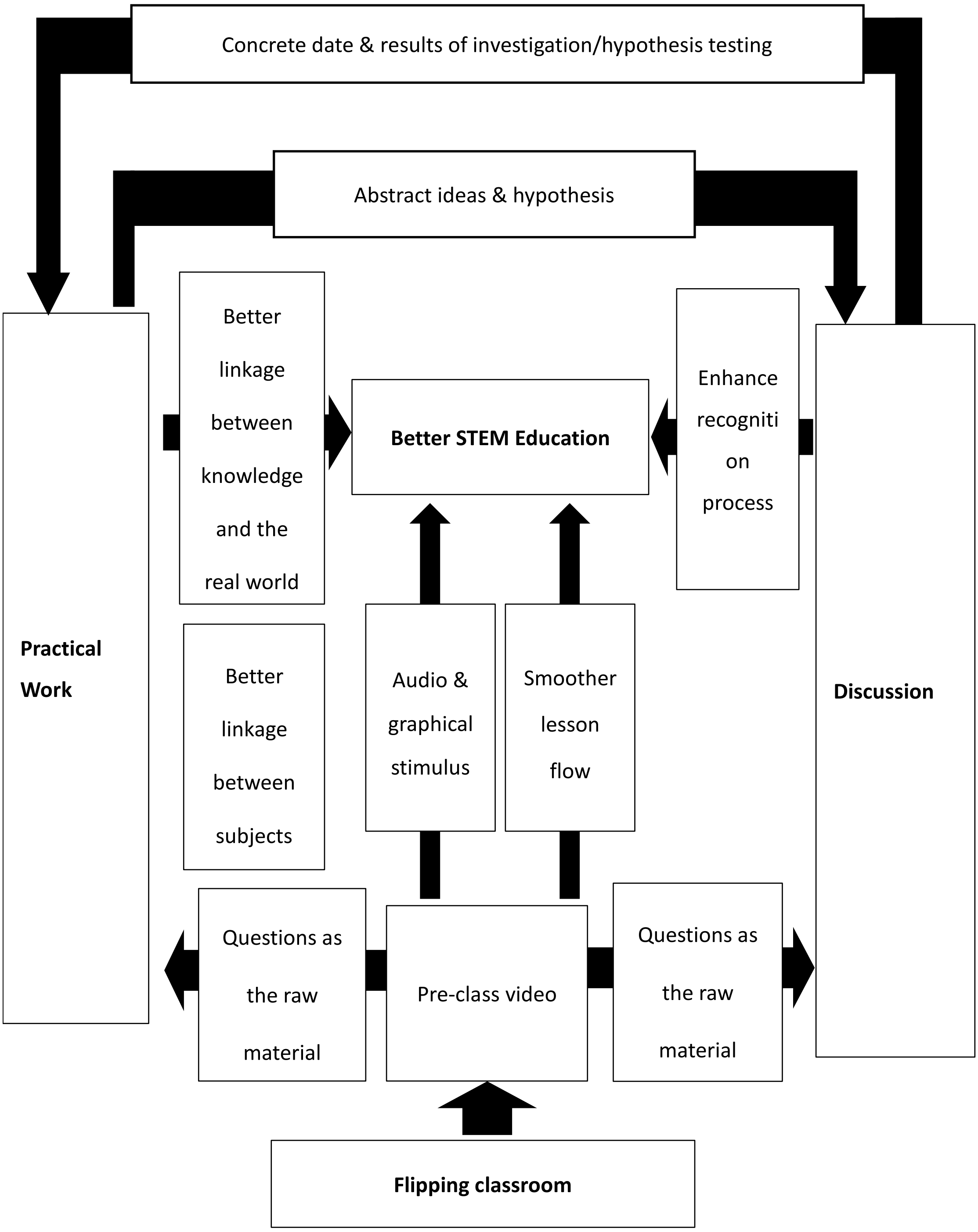
Figuratively speaking, the questions generated by watching the video fuels their discussion.

iii. *Practical work + discussion = better understanding*

Without practical work, elaborating to others or debating on abstract concepts heavily relies on textbooks and they could only be achieved within students' own imagination. However, the situation is reversed once discussions interact with practical work. For example, if a student disagrees with a concept such as the position of the weights, he/she could demonstrate it and express his thought to the fellow students based on the "evidence" provided by practical work. Since speech helps organising concepts and thoughts as well as clearing misconceptions (Vygotsky, 1978a) before formulating a better understanding.

Figure 2 summarizes the revised framework of the FPD model.

Figure 2 Revised framework of the FPD model.



2.11.Discussion and further elaboration

A. Better Perception and Lower Anxiety

Interestingly, there is an argument between the interviewees about the workload of the assigned in-class exercises. In the teacher's view, more time was spent on exercises, thanks to the introduction of pre-class videos. In the past, finishing three class works in a single period was rare. However, students opposed this view. They believed the workload was nearly the same as that before. A possible reason is that learning is now intellectually stimulating. Although the number of questions covered might have increased, the enjoyable "learning by doing" experience reduces the anxiety among the students which affects their perceived class duration.

B. Irreplaceable Uniqueness of Practical Work

All interviewees believe that practical work is the most essential component to foster a better understanding, whereas the pre-class videos, which introduce the main knowledge and skills, lay a foundation for in-class activities only. Without practical work, students could only form imaginations within their mind and make arguments based on those imaginations, which is not only difficult but also hard for them to reach a correct judgement. In contrast, practical work provides them with concrete facts to test their hypothesis by trial-and-error, argue and discuss with others, and make their own judgements. The cognition development process is mostly established during the learning-by-doing practical work session. It implies that practical work is critical in the FPD model and STEM education.

C. Turning Weaknesses into a Strengths

Recently, playing video is a frequent pre-class activity used by the researchers on flipped classroom (Adams and Dove, 2016; Chen, Wang, Kinshuk, and Chen, 2014; Fautch, 2015; Hwang and Lai, 2017). However, watching video cannot provide students with enough support such as feedbacks (Bhagat et. al., 2016). In this regard, the effectiveness of video watching is being questioned (Kettle, 2013). For example, Delozier and Rhodes (2017) suggest that "Video themselves do not affect learning…any advantage of providing lectures outside the classroom should come from releasing in-class time for active learning". Many researchers have thus turned their focus to the provision of support in the pre-class sessions. However, this view is still believed to be very teacher-centred. The results of this study suggest that perfect support in the pre-class session might not be necessary if the FPD is considered as a whole teaching and learning process. Despite insufficient support, the practical work and discussion could served as a platform for students to investigate the problems they had in watching the pre-class videos. Questions and problems in watching the video are welcomed because they are the raw materials to be discussed and investigated. For example, new terms, such as pivot and moment in the video could be discussed and answered by the groupmates during the discussion. These provide a central focus which prevents students going off the topics in the discussion and make their actions in practical work meaningful. In other words, the weakness of video in flipping contributes to the inquiry-learning and collaborative learning in practical work and discussion. In summary, the above implies that the FPD model is a feasible model in conducting STEM education. The interactions provide a cocktail effect in which the weaknesses of components are compensated. A flipping model with pre-class videos and discussions only or one with pre-class video and practical work only could be also feasible but less effective. By simple deduction, a simply re-ordered flipped classroom with no collaborative activity is believed to be the least effective.

D. Flipped classroom might be a Solution to the Problems of Practical Work

Jang and Anderson (2004) report that the traditional ways of using practical work might lead to a disaster in the teachers' teaching experience. The lack of pre-requisite knowledge confuses students about what to do and how to collect the data appropriately. The teacher will be kept busy answering those instructional questions. Eventually, the class will not run as intended. However, this study suggests the pre-class videos providing fundamental knowledge of the practical work, such as the formula of the moment, calculated examples of investigation of equilibrium, give a clear direction to students, thereby engaging them in meaningful laboratory work in the lecture. In other words, students are more "ready" to be involved in practical work. As a result, classroom management may be improved as teachers could focus more on individual learners and monitor the progress, all of which improves the quality of the lecture.

E. Miscellaneous of Using Pre-class Video: the Duration of the Video

Many researchers have put their focus on the duration of the videos but they seldom discuss one of the most important issues in flipping: when is the optimal time to introduce the pre-class videos (See Dove and Dove, 2017; Lo and Hew, 2017b). A very early introduction of the pre-class video is not preferred while a very last one is also inappropriate. Enough time should be reserved for students to watch the pre-class video. According to student B, "if it is done three days or more before, some content will be lost". The optimum time for announcing the video is believed to be two days before in-class activities.

Moreover, whether students did watch the pre-class video before the lecture is uncertain. Teachers are advised to assign a worksheet with some fill-in-the-blank questions relevant to the video content. Alternatively, students are required to take notes for both the content and questions they encountered in the video as a preparation for the practical work and discussion. As suggested by the interviewees, a short revision was essential to help students organizing the content they had collected from the video. However, a full revision is not necessary because repeating the video content is not generally welcomed.

2.12.Conclusion

Overall, STEM education is essential but challenging. Although practical work is believed to be one of the best solutions to apply STEM knowledge to real-world problems, to construct the linkages between different disciplinary knowledge and to provide students with a platform to elicit relevant knowledge, educators are still reluctant to adopt it. Teachers' lack of subject knowledge or pedagogical skills, insufficient pre-requisite experimental skills among students, problems of the classroom management, tight teaching schedule and lack of equipment could all lead to a terrible practical work session.

With the advance of computer and information technology, flipped classroom might help. By integrating flipping, practical work and discussion into the FPD model, those dreadful problems might be solved. Discussion could now be conducted in parallel with the practical work without occupying any additional lecture time. By the means of graphical and audio stimulus, the pre-class video could act as a better medium in providing the pre-requisite knowledge. By equipping students such knowledge and briefing them with intended procedures, lectures become smooth. Although there is a lack of support in the pre-class section, the questions aroused during watching the pre-class video also serve as the raw material for the discussion and the practical work. As a result, it makes students more focused in the in-class session. Unexpectedly, the FPD model turns the weakness of the pre-class video into an advantage, maximizing the effect of the practical work, discussion, and STEM education at large.

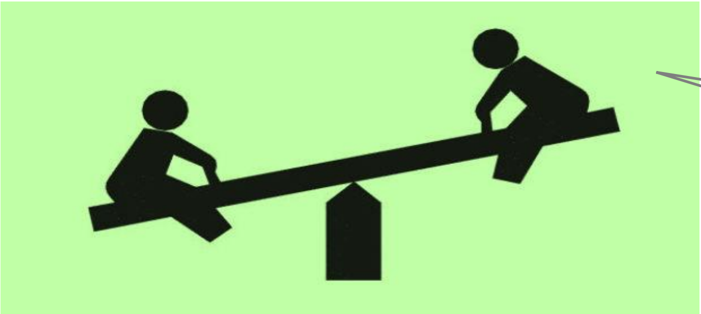
2.13.Limitation and further study

Extra care should be made when quoting the results due to the small sample size and the limited subject disciplines and topic chosen. The geographical and cultural factors may also threaten the validity of this study. Further studies on different topics with different cultures are suggested.

2.14.Appendix of Chapter Two

Appendix A: Student Worksheet

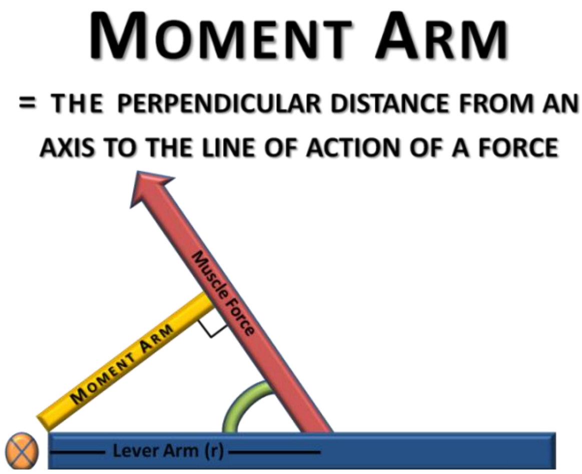
Class: ____________ Name：________________ Date：___________



Have you ever played on a seesaw? It is a plank balanced in the middle so that two people seated on the ends can ride up and down by pushing on the ground with their feet.

MOMENT

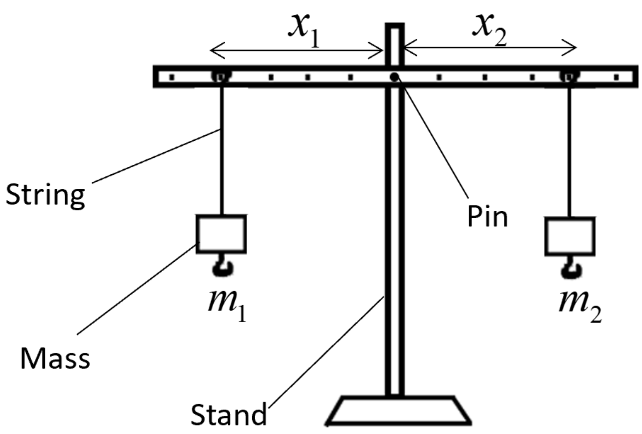
The moment of a force F about a point P is the product of the magnitude of the force and the perpendicular distance of the line of action of the force from the point P.



Teacher's Demo

Equipment:

Stand	x1
Mass	x8
Meter ruler	x1
Pin	x1
String(~10cm)	x4



Experimental Set-up:

Diagram 1: experimental set-up of moment investigation

Procedures:

① Set up the equipment as shown in diagram 1 by using x_1= 10cm, m_1= 50g and m_2= 50g.
② Vary the value of x_2 until an equilibrium state is reached
③ Record x_2

Alternative method

Therefore, check if your calculated value matches your experimental value.

Task 1: Try it yourself

Procedures:

④ repeat procedure ① by using x_1= 10cm，m_1= 100g and m_2= 100g.，
⑤ repeat procedure ② & ③。

Result：x_2=______________

Your calculation：

Task 2: Try different setting

Procedures:

⑥ repeat procedure ① by using different masses and different corresponding distances. (e.g. m_1= 100g and m_2= 100g and x_1= 5cm)

⑦ repeat procedure ② & ③

Result：x_2=______________

Your calculation：

Task 3: More challenging question 1:

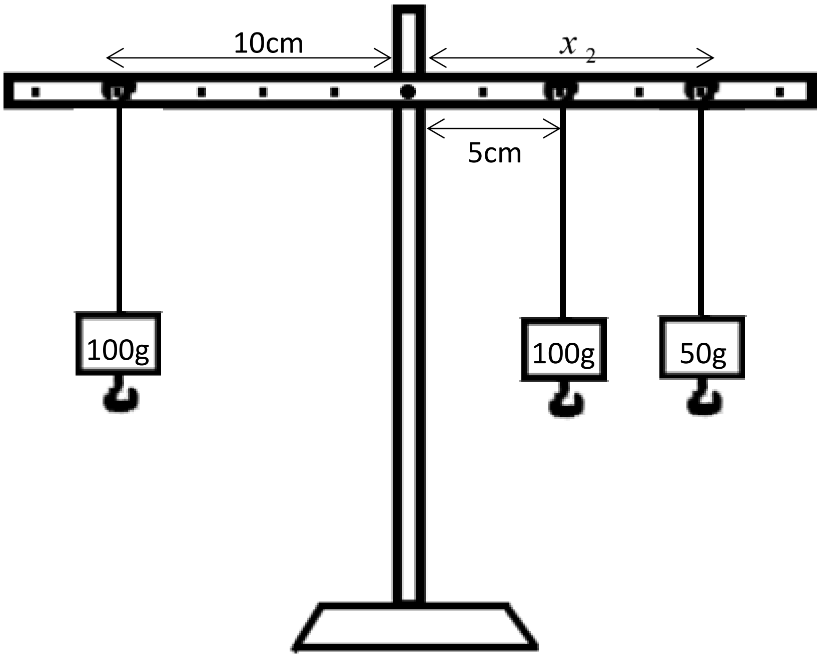


Diagram 2

Procedures:

⑧ Set up the equipment according to diagram 2

⑨ Vary x_2 until an equilibrium is reached

⑩ Result：x_2=______________

Your calculation：

Task 3: More challenging question 2:

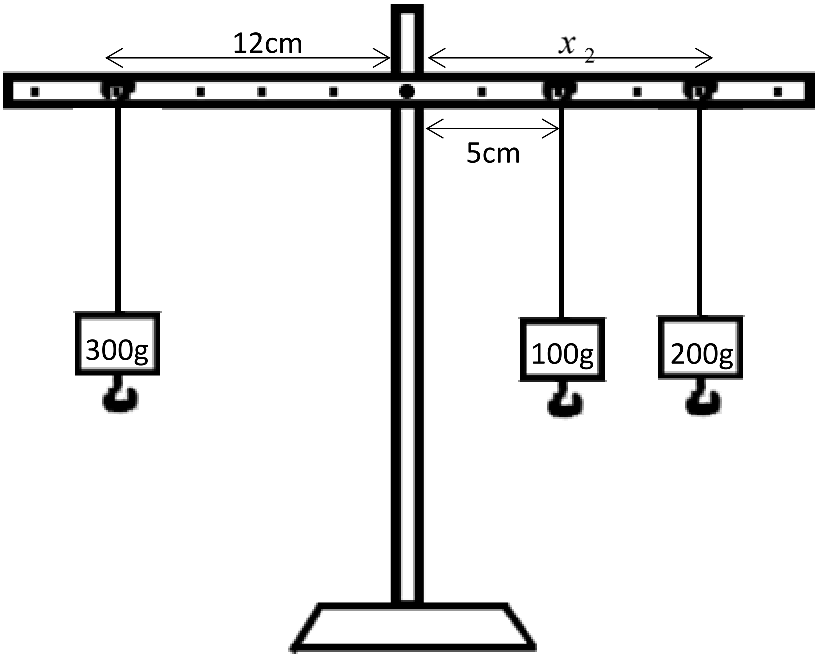


Diagram 3

Procedure

⑧ Set up the equipment according to diagram 3

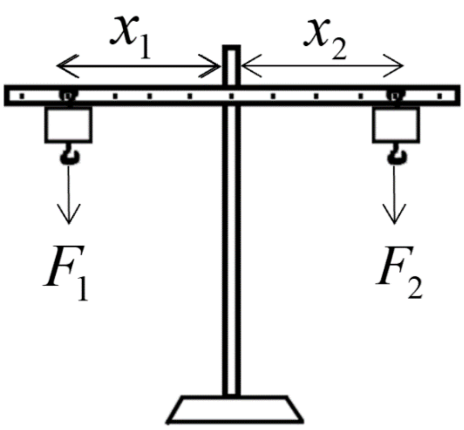
⑨ Vary x_2 until an equilibrium is reached

⑩ Result：x_2=______________

Your calculation：

What is your conclusion?

When an object is in equilibrium, it means that ......



When an object is in equilibrium, the formula connecting F_1, F_2, x_1 and x_2 is …

Chapter 3. Fostering students' 21 century skills by using Flipped Learning by Teaching in STEM education

3.1. Abstract

In recent decades, STEM has received wide attention and educators have been seeking effective approaches to ensure its success. Learning by teaching has become a potential solution as it could help students develop 21st-century skills. However, time cost and lack of relevant knowledge create a great barrier to its users and make the approach unpopular. Aided by flipped classroom, the situation could be improved as flipped learning's contribution to students' understanding, learning interest and 21st-century skills has been confirmed by research results. In view of its merits, learning by teaching could be considered as an ideal approach for effective STEM education.

3.2. Keywords

STEM education, flipped classroom, learning by teaching, 21st century skills, innovative teaching and learning approach

3.3. Introduction

What is STEM education? Why do we need STEM?

STEM, a term initiated by the National Science Foundation in 2000s, refers to acronym of science, technology, engineering, and mathematics (STEM) (Sanders, 2009). Its education is defined as "the approach to teaching the STEM content of two or more

STEM domains, bound by STEM practices within an authentic context for the purpose of connecting these subjects to enhance student learning" (Kelley and Knowles, 2016, p. 3). Due to its significant contribution to the society, the subject was soon adopted by educators and integrated into the national curriculum of different countries (Bureau of Labor Statistics, 2008; Marshall, 2015; National Science Board, 2018). Current research reveals that 75% of job vacancies are reserved for employees equipped with STEM knowledge and skills (Becker, and Park, 2011) while the employment rate of the STEM industry grows nearly twice faster than others (Craig, Thomas, Hou, and Mathur, 2012). STEM education programs' effectiveness in boosting national economic growth allows it to spread out in many countries (Australian Industry Group, 2013).

However, conducting a STEM lecture is not an easy task (Sujarwanto, Madlazim and Sanjaya, 2021). According to the National Academy of Engineering (NAE) and National Research Council (NRC) (2014), the weak linkages between knowledge and real-world problems, among subject disciplines and difficulties for students to establish such linkages are the major challenges in practice. Meanwhile, the shortage of teacher training and support is another obstacle. As revealed by a survey on K12 in-service teachers, those in the frontlines are ill-prepared for STEM teaching (Geng, Jong and Chai, 2019). Despite their enthusiasm, the absence of effective STEM teaching technique undermines the effectiveness of teaching (Rogers and Ford, 1997).

Under such a context, a relatively new teaching and learning approach called flipping classroom is gaining popularity (French, Arias-Shah, Gisondo and Gray, 2020; Han and Røkenes, 2020; Mzoughi 2015; Julia et al., 2020; Walsh and Rísquez, 2020). It engenders a more meaningful teaching and learning environment by shifting the direct instruction process into the pre-class section while fulfilling the in-class sections with more meaningful activities (O'Flaherty and Phillips 2015; Priyaadharshini and Sundaram 2018; Ye, Chang and Lai, 2019). In addition to investigating how flipped classroom could facilitate STEM education, this paper attempts to explore whether flipped classroom together with learning by teaching contributes to STEM education.

3.4. Literature Review

A. Recent challenges in STEM education

STEM, which was originally named as Science, Mathematics, Engineering and Technology (SMET), was developed in the 2000s to equip students with creativity and problem-solving skills which raised their employability (Butz et al. 2004; Sanders, 2009). This subject's significance for students' development is well-recognised and therefore its education is gaining acceptance in the field (Australian Industry Group 2013).

However, the status quo of its implementation is far from satisfactory (Thomas and Watters, 2015). Current studies reveal that the lack of teaching and learning materials, low motivation among students and improper pedagogies are the main hindrance (Hong Kong Federation of Education Workers, 2017; Mutambara and Bayaga, 2021; NAE and NRC 2014). Among them, the inefficiency of conventional face-to-face lectures is most problematic in creating a deep STEM learning experience (Bosman and Schulze, 2018). Given the mounting pressure of examinations and administrative work, it is understandable that frontline teachers have to resort to conventional approaches, which focus heavily on introducing existing knowledge and seeking correct answers to problems, rather than implementing STEM-related activities (Dong, Wang, Yang, Kurup, 2020; Shernoff, Sinha, Bressler, and Ginsburg, 2017). Conventional classroom is usually less effective in empowering students with 21th century skills (eg. Alwi, 2020; Lamichhane and Karki, 2020). Its direct lecture mode of teaching cannot meet the demands STEM education, which aims at developing students' innovation, diversified thinking as well as their communication skills (Shu and Huang, 2021). To cope with this challenge, flipped classroom with learning by teaching (thereafter called flipped learning by teaching, FLT) is suggested.

B. What is flipped classroom?

With advance in information technology, educationists started to review and challenge the traditional lecture and homework sequence for better learning outcomes (Crouch &

Mazur, 2001; King, 1993; Mazur, 1997). The word “Flipped Classroom” was thus coined in the late 1990s (e.g. Baker, 2000). Typically, it is a teaching and learning approach which reverses traditional lecture-assignment sequence into an assignment-lecture sequence (Crouch and Mazur, 2001). More in-class time could be spent on meaningful activities and individual consultation by shifting the instructional content to the pre-class section. In-class time could be allocated to explaining abstract concepts and working on problems with guidance and discussion (Delozier and Rhodes, 2017). Consequently, flipped classroom could greatly enhance students’ understanding and academic performance (Pfennig, 2016; Sun and Wu, 2016; Van Alten, Phielix, Janssen and Kester, 2019; Wagner, Gegenfurtner and Urhahne, 2021). This approach has witnessed a widespread application in science (Asiksoy, and Özdamli, 2016; Deslauriers, Schelew, and Wieman, 2011), technology (Amresh 2013; McLaughlin et. al., 2016; Davies, Dean, and Ball, 2013; Shnai, 2017; Yildiz Durak, 2018), engineering (Kanelopoulos, Papanikolaou and Zalimidis, 2017; Le, Ma and Duva, 2015; Warter-Perez and Dong 2012) and mathematics education (Dove and Dove 2017; Graziano and Hall 2017; Lee 2017; Lo and Hew 2017b; Lo, Hew and Chen, 2017; Zengin 2017).

In spite of the apparent effectiveness (Van Alten et. al., 2019), researchers are still sceptical about its outcomes when used without interactive in-class elements (Lo and Hew 2017a). This is supported by empirical studies, for example in mathematics education, where students' academic performance could be enhanced if the flipped classroom is enriched by discussion, feedbacks and peer-collaborative work (Fung, Besser and Poon, 2021). It seems the values of flipped classroom do not lie in simple re-ordering of the lecture and homework section, but in the integration of in-class interactive elements, which may be the essence for a successful flipped classroom (Fung, 2020).

C. What is learning by teaching?

Learning by teaching (German: Lernen durch Lehren, LdL) is not a new strategy. Basically, it is a special type of peer education in which students are responsible for conducting the teaching, preparing as well as controlling the learning progress (Aslan, 2015; Legenhausen, 2005). As described by Aslan (2015), the routine of learning by teaching begins with a student (or a group of students) teaching a topic either suggested by the teacher or chosen on his/her own. Normally, students are asked to prepare their own teaching materials in the meantime. During the teaching process, the role of teacher becomes passive as he/she remains in the background monitoring. The teacher will only interfere if a problem or misunderstanding arises (Aslan, 2015).

The unique nature of learning by teaching means that it could benefit students more than traditional teaching (Zhou, Chen and Chen, 2019). When required to teach a topic in front of peers, students have to select and screen the relevant knowledge, focus, organise and present it in a meaningful way (Torshizi and Bahraman, 2019). As a result, the limited processing capacity (as suggested by cognitive load theory) is used effectively and deep learning could be facilitated (Stollhans, 2016). More importantly, students have to externalise the knowledge with their own language during the teaching process. According to Vygotsky's theory, the connection between speech and thoughts is explicit and profound (Vygotsky, 1978a). Speech itself is an externalization process of the thoughts, even to the extent that "A word without meaning is just an empty sound" (Vygotsky, 1978a, p.244). It could help analyzing the problems, generalizing ideas and developing possible solutions (Vygotsky, 1978b). With students' fundamental understanding ensured after giving a speech, their memory about STEM contents could be enhanced. For example, Pizzolato and Persano Adorno (2020) examined the benefits of learning by teaching on physics undergraduates and found that students' memory (such as the definition of isotope, understanding of radioactivity process at microscopic level and the linkage to daily life problems) was improved significantly.

Meanwhile, the effect of learning by teaching is not limited to the acquisition of the knowledge in a particular subject. It could be an effective means to foster students' essential abilities and skills, such as 21st century skills (Aslan, 2015). By allowing students to engage in teaching (generally aided with I.T. tools such as PowerPoint), their presentation skills, communication skills, self-confidence and computer literacy were improved (Grzega and Klüsener, 2011; Pahl, 2019). Gradually, accomplishing the high-level learning objectives of Bloom's taxonomy, such as synthesizing, evaluating, and creating becomes possible since the foundation of knowledge is consolidated (Fiorella and Mayer, 2013).

However, the implementation of learning by teaching is very challenging (Hutagaol-Martowidjoyo and Adiningrum, 2019). For instance, class preparation is time-consuming as it requires lots of efforts in material preparation (Hutagaol-Martowidjoyo and Adiningrum, 2019). Meanwhile, teaching is obviously a very complex task for students because both subject knowledge and proper teaching pedagogies are required (Zhou, Chen and Chen, 2019). Given the limited preparation time, students may find it challenging to become fully familiar with necessary knowledge and thus misunderstanding may appear (Aslan, 2015). Without an effective solution, the above challenges would defeat the advantages of learning by teaching.

D. How flipped classroom and learning by teaching help STEM education?

In light of previous sections, flipped classroom could play a significant role in fostering the effectiveness in STEM education when aided by learning by teaching. Yet, one major challenge in its implementation is students' lack of pre-requisite subject content knowledge for classroom teaching (Shulman, 1986; Shulman, 1987). As a result, extra time must be spent in equipping students with fundamental knowledge beforehand, which potentially prevents teachers from choosing this teaching method despite its effectiveness. To compensate for this problem, flipped classroom familiarises students with the necessary knowledge by using the pre-class video with no additional burden (Fung, 2020). On the other hand, the number of students who would profit from traditional pedagogy is limited as the interaction between students and teachers is not always available (via Aslan, 2015). But when this approach is integrated into a flipped classroom where the in-class time is reserved for meaningful activities (Fung, 2020), the lesson flow can be facilitated and learning by teaching becomes more feasible. This combination of flipped classroom and learning by teaching could foster student's understanding towards subject knowledge as well as their 21st century skills (such as presentation skills, communication skills, self-confidence and computer literacy).

In the meantime, the cross-disciplinary nature is considered a defining characteristic of STEM which adds to the importance of STEM education (Sanders, 2009). Yet such feature creates a great challenge in revealing the contribution of STEM education as it extends beyond the development of knowledge in a particular subject. In this regard, students' learning outcomes cannot be simply assessed by the traditional knowledge-based examination (Ng and Fung, 2020; Honey, Pearson and Schweingruber, 2014; Shu and Huang, 2021). Ng and Fung (2020) systematically reviewed about 11000 websites of secondary and primary schools and found that the cross disciplinary nature did occupy a very little portion in their expected outcomes (Ng and Fung, 2020). This runs contrary to the popular belief that an effective teaching and learning approach for STEM Education should be one that helps students develop both subject knowledge and their 21st century skills.

As frontline teachers are desperate for an effective teaching and learning technique for effective STEM education (Rogers and Ford, 1997), the results of this study could serve as a foundation which provides insights into flipped classroom, learning by teaching and effective STEM teaching and learning approaches. Eventually, it could even initiate innovative and effective teaching and learning approaches for STEM education. The following research questions are thus developed to investigate how FLT contributes to STEM education and to discover the underlying mechanism.

3.5. Research Questions

1. How could FLT foster STEM education by improving students' understanding?
    A. How could it foster students' understanding?
    B. How could STEM education be facilitated if students' understanding is enhanced by using FLT?
2. How could FLT foster STEM education by developing students' 21 century skills?

A. How could it enhance students' problem-solving skills?

B. How could it enhance students' communication skills?

C. How could it enhance students' creativity?

D. How could it enhance students' computer literacy?

3. What other benefits, apart from the development of 21st century skills, could be attained by using FLT?

3.6. Research Method

A. Demographic information

Considering the efficiency of convenient sampling and its power in eliminating practical constraints, such as geographical location, this method was adopted in current study (McMillan and Schumacher, 2010). 5 university students (3 males and 2 females) aged between 19 and 20 were selected. Three of them majored in data science, while the others studied commerce and software engineering in Australia. These participants had received their pre-tertiary (primary and secondary) education in China (Confucian heritage culture, CHC) for over 17 years and chose to study abroad in Australia, a country with significantly different educational culture. Therefore, unlike other students in China, they were considered as "relatively familiar with both Eastern and Western educational philosophy" and "relatively open to innovative teaching and learning approaches”.

B. Preparation, pre-class and in-class section

The pre-class section followed the design of the FLT model suggested in previous sections. Since visualization could turn complex ideas into concrete items (Fung and Poon, 2020), a flipped classroom was used instead of other materials such as readings. Participants reported that they had very limited experience about learning by teaching and flipped classroom, so a 15-minute meeting was arranged so that they were familiarised with the research flow, fundamental concepts of STEM and practical procedures of FLT model.

All videos in this study were seven to twelve minutes in length, which was based on previous findings that video length should be properly managed in flipped classroom (Dove and Dove, 2017; Lo and Hew, 2017b). The videos were distributed to the students three days before the class to leave them with sufficient time for class preparation. Each student was asked to prepare a PowerPoint for an eight-minute lecture on viscous drag forces, hydrostatic pressure, kinetic energy, drift velocity and resistivity (see Table 2), all of which required substantial mathematics, physics and engineering knowledge. The PowerPoint should include the content knowledge as well as a sample question with a corresponding solution.

Table 2 Topics used and their corresponding description of content

Topics	Description
Viscous drag forces	● Understand viscous/drag forces including air resistance. ● Understand that objects moving against a resistive force may reach a terminal (constant) velocity
Hydrostatic pressure	● Derive, from the definitions of pressure and density, the equation for hydrostatic pressure $\Delta p = \rho g \Delta h$ and the application of the equation $\Delta p = \rho g \Delta h$
Kinetic energy	● Derive, using the equations of motion, the formula for kinetic energy $EK = 1/2mv^2$
Drift velocity	● Use, for a current-carrying conductor, the expression $I = Anvq$, where n is the number density of charge carriers
Resistivity	● Resistance and resistivity ● Recall and use $R = \rho L / A$

The whole 40-minute in-class section was conducted using zoom due to the restrictions of social contact under the spread of COVID-19. It was divided into five mini-lecture sessions. Students were required to teach in turn and their order was decided and announced by the researcher at the beginning of the lecture. To minimize language-related problems, students were free to use their mother tongue as the medium of instruction. Class was dismissed after the completion of mini lectures and no homework was assigned, which ensured the total length of learning in this study is comparable to traditional 40-minute lectures with homework of seven to twelve minutes.

C. Assessment tool and Data Collection

To ensure the validity of this research with triangulation of data, observation and focus group were selected as the assessment tools. The observation spanned from pre-class section to in-class section. Although some important information was not accessible as face-to-face contact was restricted, quality interactions were still maintained with communication tools such as WeChat, zoom and mobile phones, which allowed researchers to provide immediate advice and feedback to students anywhere and anytime. Participants had been informed before the study that both in-class section and focus group section would be videotaped. The events and questions were noted and recorded (via Appendix B), while the interviews, which were conducted primarily in students' mother language (Chinese) in order to ensure the quality of results, were translated into English scripts afterwards.

A 25-minute focus group meeting was scheduled next day following the completion of in-class section. Since the participants had no prior experience in such meeting, a two-minute introduction was given and common practice was described. Objectives and research questions were introduced (via Appendix C) so that the discussion would be on the right track. Participants were notified that they could express their views freely provided that their discussions were relevant to this study. For details of the research flow please refer to Appendix D.

The role of researcher remained passive during the whole intervention. To ensure a fair result, his main duty was to determine the topics, maintain research flow and monitor research progress. He interrupted only if one of the following scenarios arose (via Table 3).

Table 3 Scenarios the researcher would interrupt in this study.

Section	**Scenarios**
Pre-class section	(1) When a student raises a question about the subject content knowledge (2) When a student encounters a technical problem in watching the video (3) When a student asks for additional information for the content (4) When a student asks about the pedagogical knowledge
In-class section	(1) When a student-teacher asks him a question (2) When a student audience asks a difficult question which the student-teacher is incapable of responding (3) When a student-teacher overruns (4) When a student misbehaves (5) When a student encounters a technical problem
Focus group	(1) When a student is in absolute silence for a very long time (2) When a student goes off the topic. (3) When a student asks him a relevant question to the study (ie. clarifying key words in the questions). However, the researcher would neither answer what should be discussed nor explain some critical keywords if he thinks that may be

Section	Scenarios
	misleading or will limit the scopes of the data mining. [3] (4) When a student misbehaves (5) When a student encounters a technical problem

D. Data handling and data analysis

Data from the observation and focus group meeting was translated into English in Appendix B and Appendix E respectively. To ensure a fair result, coding of observation and focus group meeting were performed by two third-party tutors who were doing their master's degrees. All scripts and coded data were then sent to the participants to confirm if the translation truly reflected their views and modifications were made per request. The participants were then coded as Student A, Student B etc to erase the trace of their identity. Since there were disagreements in some ideas, the reliability of the qualitative results in this study was calculated by the formula Reliability=Agreements/ (Agreements + Disagreement) as suggested by Miles and Huberman (1994). In addition, if a student expressed that he/she agreed with a point with certain conditions, his/her opinions will be counted in both agreement and disagreement. However, when statements repeated, rephrased or further elaborated previous statements, they counted

[3] For example, in this study the word *creativity* was not explained when asked. It is because students may focus on what the researcher described and try to provide the expected answers, instead of deriving its meaning from their own experience.

once only. The results are presented as Table 4 and Appendix F.

E. Ethnic concerns

A high degree of awareness has been put into ethic concerns. Biased responses might be yielded due to the teacher-student relationships between the researcher and participants because students from CHC tend to avoid disagreements with teachers. Therefore, the researcher emphasized the importance of expressing their real feelings and participants were given complete freedom to quit at any stage of the experiment whenever they felt uncomfortable to continue.

3.7. Result

Table 4 Mechanism of Flipped learning by teaching enhances STEM education

Category	Item	Reliability (Frequency[4])	Opinion (Frequency[5])	Main Content / idea
Flipped learning by teaching approach is helpful to STEM education	Flipped learning by teaching fosters understanding.	1.0 (4)	Agree (4)	● It allowed students to gain exposure to the knowledge for four times (during video watching, material preparation, teaching and Q&A section). ● More in-depth learning achieved and better memory of the content knowledge. ● By developing the teaching materials, such as organizing the points and preparing the PPT, the blind-spots could be cleared. ● Understanding was enhanced
	Flipped learning by teaching fosters problem-solving skills	1.0 (1)	Agree (1)	● Answering unexpected questions from others allowed students to review and organise the content because it required them to think, plan and organise the steps to solve the problems.
	Flipped learning by teaching fosters	1.0 (3)	Agree (3)	● Solving other's problems required the uses of communication skills. ● Communication skills were enhanced because the whole teaching was basically (similar to) a

[4] Total number of agreements and disagreements

[5] Number of students who expressed an agreement / disagreement

Category	Item	Reliability (Frequency[4])	Opinion (Frequency[5])	Main Content / idea
	communication skills			discussion. ● Explaining abstract ideas required communications skills.
	Flipped learning by teaching fosters creativity	.67 (6)	Agree (4)	● Organizing the lesson was the main reason for the improvement of the creativity. ● Regarding STEM, understanding is very important. It is impossible to apply the knowledge of these subjects without understanding them in advance. ● If the students encountered a difficulty, the student-teacher should try a new approach. And these skills could not be learnt from a traditional classroom. ● A good knowledge foundation would allow us to draw inferences about other cases from one instance. In the meantime, it allowed us to discover, elaborate, link and apply them in our daily life. These are all practices of creativity. ● Through the process of developing the materials, connections between fact-based knowledge and daily life could be observed. It inspired students to explore and try to develop some solutions (about the learning content) in daily life.
			Disagree (2)	● The improvement of creativity is limited.

Category	Item	Reliability (Frequency[4])	Opinion (Frequency[5])	Main Content / idea
				● A simple use of the model would not enhance creativity.
	Flipped learning by teaching fosters logical thinking	1.0 (2)	Agree (2)	● If a student had to teach others, he must list pre-requisite knowledge, define the items, construct the equations and demonstrate how to use those equations and knowledge to solve the problems. This was a good training in logical thinking. ● Student-teacher had to (1) extract the key information; (2) explain concepts fluently, and (3) understand the logics behind the content.
	Flipped learning by teaching fosters learning interest	1.0 (3)	Agree (3)	● Helping others understand abstract knowledge gave us a strong sense of satisfaction. ● Active learning offered much higher level of satisfaction than spoon-feeding education. ● Since we could choose a topic of our own interests, we were highly motivated and fascinated by the idea.
	Flipped learning by teaching fosters computer skills	1.0 (1)	Agree (1)	● During the preparation process, software, such as PPT, was used. It allowed us to practice our computer skills.

A. Flipped learning by teaching foster students' understanding and memory

According to Table 4, a striking benefit of using FLT is that it could enhance students' understanding and memory of the learning content. Traditionally, teachers are responsible for determining and developing the teaching materials. Students are rarely involved in the process until the materials are distributed in-class. However, a higher degree of engagement is achievable in flipped teaching and learning. From video watching, course material preparation, in-class teaching to in-class Q&A section, students were exposed to the learning content four times. In the meantime, one commonly found problem in traditional teaching is students' overestimation of their mastery of knowledge. This undesirable situation could be minimised with the use of FLT. As revealed by Student B, "if (student) could develop the teaching materials, such as organizing the points and creating the PPT, the blind-spot could be cleared."

B. Flipped learning by teaching foster students' communication skills and Computer literacy

Additionally, participants find that FLT is particularly useful in enhancing their communication skills. To deliver a course, the student-teacher has to first understand the content (ie. abstract ideas) well and transform it into his/her own words. Communication skills are required for such process and the in-class teaching section provides them with an opportunity to practice, especially when the student-teacher is going to take unexpected questions in Q&A. This is best seen in how a student cleverly used an effective communication strategy to avoid embarrassment: when asked about the meaning of “q” in the equation during the teaching section, Student C immediately replied that they could identify its meaning by completing the homework planned for them. As Student A said:

> If a student-teacher does not know the answer, it will be very embarrassing. Student-teachers with high EQ may, I mean those with good communication skills, will act similarly as Student C did, saying “That’s a good question and especially good as being the Homework for today.”. However, student-teachers with inadequate communication skills may just be stunned at that moment (Student A).

In the meantime, since computer software was used as the teaching instrument, the process of teaching also boosts IT skills. As a result, students’ communication skills and computer literacy could be improved due to the enriched teaching section.

C. Flipped learning by teaching foster students’ Learning interest

Through watching video and developing teaching materials, flipped teaching by learning facilitates active learning. Students can derive a greater sense of satisfaction from this approach than from teaching methods which rely heavily on mechanical memorisation. This is supported by the observation that students requested an earlier distribution of the video which was scheduled to be made accessible only on the experiment date, implying an increased learning motivation among students.

D. Flipped learning by teaching foster students' logical thinking and problem-solving skills

As indicated by the participants, class preparation and Q&A section boost students' logical thinking and problem-solving skills. As described by Student C on the process of FLT, "Student teachers have to (1) extract the key information; (2) translate them into their own words, and (3) help (audiences) understand the logics behind knowledge." In other words, if a student needs to play a teaching role, he/she must list pre-requisite knowledge, define the items, construct the equations and demonstrate how to use those equations and knowledge to solve problems. In the meantime, questions may arise during the Q&A section. To answer these unexpected challenges, student teachers must review the content, plan and develop strategies, which promotes their logical thinking and problem-solving skills.

E. Flipped learning by teaching foster students' creativity

Although participants were generally in favour of the claim (3/5 supportive, 1/5 conditional and 1/5 against), opinions were divided when it came to whether creativity could be enhanced by FLT. Advocates of this claim maintain that a more thorough understanding is the root cause for the improvement. Since STEM is a complex acronym involving four different disciplines, it is very unlikely to apply the STEM knowledge without a complete understanding. The solid knowledge foundation developed by FLT allows students to draw inferences about a case from other instances and to discover, elaborate, and apply theoretical knowledge in their daily life. As described by Student D, “I see that air resistance is connected with many different aspects in our daily life and its impact is significant. I will start to study and try to develop some solutions to reduce air resistance in different circumstances.” In other words, a better understanding serves as a foundation on which students can connect and extend their knowledge to other aspects, thereby boosting creativity.

Furthermore, organizing lessons and the use of alternative method also contribute to creativity. As illustrated by Student A…

> As students, we will focus only how to solve the problems; however, we will try to illustrate the same idea with different methods if our role is shifted from students to teachers. For example, during the teaching session conducted by Student B, he demonstrated two different methods to solve a single question. This is how students differ from teachers. Such a difference would lead to a significant improvement in creativity.

In other words, FLT shifted the role of students to teachers and raised their awareness of the learning process. Students’ creativity could be substantially promoted either by preparing alternative solutions or by illustrating the same idea with different methods. Judging from previous results, FLT may generate various benefits (via Figure 3). It can thus foster STEM education by promoting students' 21st century skills in some aspects. The seven benefits are re-organised in Table 5 based on the active components of flipped teaching by learning.

Figure 3 Seven Benefits of using Flipped teaching by learning

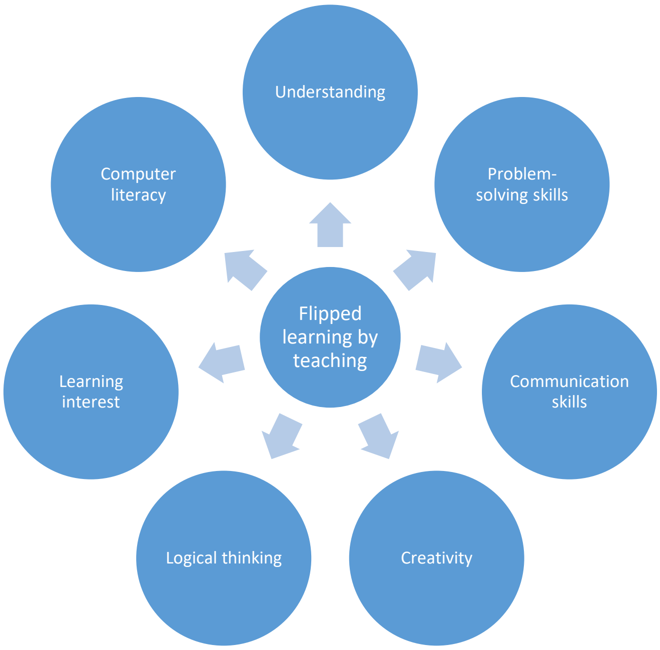


Table 5 Mechanism of Flipped teaching by learning benefits students

Section of Flipped teaching by learning	**Active Component**	**Actions**	**Students' Improvements in …**
Pre-class section	Watching video	● 1st engagement of the materials	● Understanding
	Class	● 2nd engagement of the	● Understanding

Section of Flipped teaching by learning	**Active Component**	**Actions**	**Students' Improvements in …**
	preparation	materials	
		● Clearing blind-spot Organizing of the lesson (such as demonstrated two different methods in solving a single question).	● Understanding Creativity ● Logical thinking ● Computer literacy
In-class teaching	Teaching	● 3rd engagement of the materials	● Understanding
		● Teaching by illustrating ideas	● Communication skills
	Q&A	● 4th engagement of the materials	● Understanding
		● Developing strategy to answer unexpected questions	● Problem-solving skills ● Communication skills
		● The use of alternative method	● Creativity

3.8. Discussion

A. Challenges of using Flipped learning by teaching

Despite a consensus on the contribution of FLT to students' 21st century skills, all participants suggested that FLT may not be suitable to every student because it required a higher degree of discipline. As explained by Student B, "If a student does not understand the content thoroughly, he/she does not know how to teach others. It is impossible to explain if I myself do not understand." For less able students with low learning interest, spending more time on lecture preparation becomes a great burden. "As a result, it may be more effective to directly demonstrate how to solve the problems." said Student D.

B. Good medicine for health tastes bitter

Echoing previous studies (e.g Aslan, 2015; Hutagaol-Martowidjoyo and Adiningrum, 2019), results in this study also reveal that teaching by learning is a very time-consuming strategy from students' perspective and teachers may also encounter confusion. However, participants did provide interesting comments as they believed the time spent is a necessary cost for their gain in learning outcomes. In traditional teaching models, students have to finish their homework, check the answers and do revisions after class. By contrast, these steps are already embedded in learning by teaching. For instance, the in-class teaching and Q&A section are useful for clearing students' misconception, being equivalent to the answer checking and after-class revisions under a traditional context. The extra time may indeed be a necessity for learning. In light of these facts, whether learning by teaching is indeed more time-consuming remains inconclusive.

C. May Metacognition be related to creativity?

Interestingly, findings in this study support that creativity could be enhanced under the setting of flipped learning. Both Student A and B suggested that students became more innovative when they prepared two different methods to solve a single question. Since planning is an important component of Metacognition (Fung and Leung, 2017; Fung, 2020), this aligns with current suggestions that metacognition and creativity should be explicitly involved in higher education (Armbruster 1989; Lizarraga and Baquedano, 2015). Although evidence in this study is not sufficient enough to support the claim, it could still be a possible direction for further research.

3.9. Limitations

Although all efforts were made to ensure a fair result, extra care is advised to be taken when interpreting the results of this study. While triangulation was employed, the sample size is relatively small, which could undermine the generalisation power. Extra caution needs to be exercised especially when the results of this study are to be used to explain scenarios under the context of primary or secondary schools. Meanwhile, the results of the focus group meeting depend highly on the participants' awareness of the content and relevant skills. Further researches, especially those with different measuring instruments, are needed to provide additional evidence.

3.10.Conclusion and Impacts to the Society

In the pursuit of successful STEM education, educators have been experimenting with pedagogies that assist in problem-solving and exploratory learning. Learning by teaching seems to be a promising candidate that fuels students' success across tasks and disciplines. However, high time cost and lack of relevant knowledge create a great barrier to education practitioners and render this approach relatively unpopular. Aided by flipped classroom, the situation could be improved and students would become critical thinkers, innovators, and analysers.

The importance of this research lies in two aspects. First, it provides evidence suggesting that FLT could be an effective STEM teaching and learning approach as it cultivates critical thinking and instils a passion for innovation. Although not all 21st century skills were improved, educators could still use it to fulfil their teaching goals. On the other hand, the feasibility of FLT in this study lightens the path of integrating flipped classroom with other teaching and learning approaches on macro level. This suggests the end of an era when simple uses of flipped classroom are dominant and the emergence of a new era of flipped classroom.

3.11.Appendix of Chapter Three

A. Appendix B

Appendix B Summary of Observation

Date (Chronological order)	**Participant**	**Event**
5 days before Day 1	All	1. Recruitment of the participants completed. 2. A 15 minutes meetings was arranged. 3. Participants expressed that they were happy to engage in the study. 4. Topics were assigned according to their preference.
Day 1	Student A and Student D	1. Students would like to get the video earlier so that they could have more time for preparation. 2. Videos were thus given one day before the original plan.
Day 1	Student D	1. Student asked about the priority among the 21th century skills. Does innovation have the least importance? What is the definition of creativity? Is the ability to extend and link the content to other topics or daily life a kind of creativity?
Day 4	All	***In-class Teaching***
		1. 12:24 - In the Q&A session of Student C's presentation, Student A raised a question "what's the constant in the drift velocity equation?" Student C answered it's just a constant. Student A asked again "So what constant is it and what's the magnitude?" With this unexpected question, Student C didn't answer directly and tried to find the answer from his notes. Finally Student C didn't give an exact answer of the question and told the audience students this is homework for you to figure out what is this constant after this class. [communication skills]

Date (Chronological order)	Participant	Event
		2. 27:00 - Student B used two approaches to derive the equation of kinetic energy. [Creativity]. For the demonstration of deriving the KE equation, the researcher and Student A pointed out a mistake of the formula transformation. Student B paid close attention to this feedback [communication (active listening)], and tried to find the source of mistake by reassessing the derivation process. [problem-solving (resilience)] Finally, Student B realized his misunderstanding of concepts, and gave a response saying himself is not circumspect enough when solving the questions. [communication] 3. 30:14 To show the relationships between the force exerted cross-sectional area and pressure with the pressure formula learned, Student A used two examples computing pressures: fixed cross-sectional with different force and fixed force with different cross-sectional area. The calculations show that with the same area of 1m, the pressure is larger for a force of 200N than a force of 100N; with the same force of 100N the pressure is smaller for an area of $2m^2$ than an area of $1m^2$. Using these results as reasons, she reached a conclusion that pressure is positive proportional to force exerted while it is negatively proportional to cross-sectional area. [problem solving / logical thinking (consistent reasoning)] 4. 35:30 After introducing the equations of pressure,

Date (Chronological order)	Participant	Event
		Student A used the equations to solve two sample questions. When solving the questions, Student A first identified the problems. Specifically, how many and what variables need to be computed in a question. Then she gathered the given information (known variables) in the questions, followed by applying the equations learned to calculate answers. [problem-solving (analytical skills)] 5. All students used PowerPoints to present. They highlighted key terminologies, definitions and equations by different font sizes and colours. Graphics and animations were used to serve visualization. [computer skills] [understanding of STEM(understand what key concepts are)]
Day 5	All	***Focus Group Meeting***
Day 5	Student D	1. Student texted the researcher and expressed that other participants may not be very familiar with STEM.
Day 7	Student A	1. Student texted the researcher and expressed that some participants went off topics during the meeting. 2. Student believed that other participants may not be very familiar with the 21th century skills such as problem-solving, creativity etc.
Day 8	Student C	6.1. Student texted the researcher to add supplementary information in order to clarify his point made in the focus meeting.

B. Appendix C

Appendix C Questions for focus group to discuss

1. Do you think this learning approach helpful to your study of STEM?

   A. Do you think watching video (pre-class) is helpful?

   B. Do you think teaching (in-class) is helpful?

2. Why do you think this learning approach helpful to your study of STEM?

   A. How does watching video (pre-class) help your learning?

   B. How does teaching (in-class) help your learning?

3. Could this learning approach foster your problem-solving skills, creativity, communication skills and computer literacy?

4. How could this learning approach foster your problem-solving skills, creativity, communication skills and computer literacy? Can you give me some examples?

5. Have you encounter any difficulties during the pre-class video session? How do you solve the problem?

6. What is the pros and cons of this learning method compared to traditional direct lecture-based teaching?

7. What are the difficulties of using this approach?

C. Appendix D

Appendix D Detail of the pre-class, in-class and focus group meeting for each student

	Stu A	**Stu B**	**Stu C**	**Stu D**	**Stu E**
Intervention (Pre-class) (Day 1)	~15-minute video with class preparation (a PowerPoint with one sample question for the audiences)				
Intervention (In-class) (Day 4)	Conducting a 8-minute lecture	Being as audience	Being as audience	Being as audience	Being as audience
	Being as audience	Conducting a 8-minute lecture	Being as audience	Being as audience	Being as audience
	Being as audience	Being as audience	Conducting a 8-minute lecture	Being as audience	Being as audience
	Being as audience	Being as audience	Being as audience	Conducting a 8-minute lecture	Being as audience
	Being as audience	Being as audience	Being as audience	Being as audience	Conducting a 8-minute lecture
After the intervention (Day 5)	~25-minute group interview				

D. Appendix E

Appendix E Script of focus group (in English translation)

Researcher: (Turned on the voice recorder) Ok, let us start.

Student B: In my opinion, I am wondering if the video can be replaced by paper-materials. I think it is also workable. If I must learn something for teaching others, I would like to have my teacher next to me ensuring my learning is on the right track and I am teaching it right. You know, as a student-teacher, if I learnt it wrong, others would learn it wrong too. Especially when the knowledge is new to me and I am presenting it with high confidence.

Student A: I believe making mistakes is also a part of the learning process even though there is no teacher present. For example, when Student C mentioned about the constant q in his lecture session yesterday, I asked about the meaning of q and thus we found that there is a piece of important concept is missing. If we don't point it out, that piece of knowledge will be kept missing and he will never know such concept is important. In other words, the rest of the students could be served as teachers monitoring his learning process. They could show him what to learn, what must have been learnt.

Student B: Okay, good idea.

(Dead air for 10 seconds)

Researcher: Do you think this learning approach helpful to your study of STEM?

Student A & Student E (at the same time): Yes, it is useful.

Student A: Okay, you first.

Student E: I think watching the video is equivalent to the first engagement of the new knowledge. It is not enough for us to prepare our class and develop the teaching material by using the video solely. We have to search for additional information and it forms the second engagement. Third engagement happened when we are teaching in class as the presentation is equivalent to a revision of the knowledge we have learnt in the previous two engagements. If questions were raised in the Q&A and a problem in the learning process is founded, like in our previous discussion, it served as an additional revision of the knowledge and thus the fourth engagement is formed. So, teaching something using this method allows us to engage with the knowledge for four times. The learning is deeper and the memory is enhanced.

Student B: I am wondering if the teacher will go through those materials and content again.

(Dead air for 5 seconds)

Researcher: It depends. Do you think it is necessary to go through the content again?

Student D: I think the role of the teacher should be passive in STEM education. He could serve as a helper or mentor answering our problems when it is needed.

Student B: I suggest there is a session in which we could communicate with the teacher about our teachings. He could provide us some useful advice especially when we encounter some difficulties in class preparations.

Researcher: I see. Do you think this learning approach is useful in fostering your problem-solving skills, creativity, communication skills, computer literacy and learning interest?

All students (at the same time): yes. It can.

Researcher: Can you give me some examples? Why? How?

Student A: I think it could have significant improvement in our problem-solving skills. Different from traditional method in which students learn by reading books or watching video, answering unexpected questions from others allow us to review the content we have learnt. During the Q&A, we have to think about how to answer or solve their problems. Our communication skills are improved as well.

Student B: In addition, we have to pay attention to the lesson structure. More importantly, one of the main problems in traditional lecture is that students think that they've already understood the content but in fact they are not. But if they could develop the teaching materials, such as organizing the points and creating the PPT, the blind-spot could be cleared.

Researcher: So, how about creativity? Can you give me some examples?

Student B: I think the organizing of the lesson is the main reason for the improvement of the creativity.

Student E: But in my point of view, the improvement of creativity is limited. I think the most significant improvement lies in our logical thinking. If a student have to teach others, he must list those pre-requisites knowledge, define the items, constructing the equations and demonstrate how to use those equations and knowledge to solve the problems. This is a good training in logical thinking.

Student A: I see creativity in a very different way. To me, using different method to solve the same problem is a kind of creativity. As students, we will focus only how to solve the problems; However, we will try to illustrate the same idea with different method if our role is shifted from student to teachers. For example, during the teaching session conducted by Student B, he demonstrated two different methods in solving a single question. This is what make the difference between student and teacher. Such difference would lead to a significant improvement in creativity.

Researcher: So, how about communication skills?

Student C: I think the enhancement in creativity is little. I think, in metaphor, if learning is consists of deducing concepts by examples, identifying the input, model and output.

The role of student-teacher is to use to model while traditional teacher is to develop the model. Although understanding is enhanced, a simple use of the model will not enhance creativity. (Supplemented and rephrased by Student C two days after the discussion: student-teacher have to (1) extract the key information; (2) translate them into language; and (3) help students to understand the logics behind the knowledge. If the students encounter a difficulty, the student-teacher should try a new approach. And these skills could not be learnt from a traditional teacher.)

Researcher: Could that understanding served as a foundation in learning STEM?

Student C: What?

Student A: Regarding to STEM, a discipline consists of science, technology, engineering and mathematics, understanding is very important. It is impossible to apply the knowledge of these subjects without understanding them in advance. That is what he said “foundation”. It means the knowledge base. Once you learn a method to solve the problem, you would start trying another method to solve it. As a result, creativity increase. On the other hand, I think this teaching method could also improve our communication skills as well. For example, I raised a question during the teaching session conducted by Student C. If a student-teacher do not know the answer, it is very embarrassing. Those student-teacher with high EQ may, I mean those with good communication skills, will act similarly as Student C did, say “That’s a good question and especially good as being the Homework for today.”; however, those student-teacher with low EQ and inadequate communication skills may just stun and freeze at that moment. The process of teaching is indeed a process of communication. That is why I think it could enhance communication skills.

Researcher: Oh, I do not see Student D here. Let us check if she is still online.

Student D: I am here.

Researcher: Do you have any idea to share?

Student D: I think a good knowledge foundation would allow us to draw inferences about other cases from one instance. In the meantime, it allows us to discover, elaborate, link and apply them to our daily life. I think these are all creativity.

Researcher: Do you think this method could enhance creativity?

Student D: Yes. For example, the topic I taught about yesterday is air resistance. Though the teaching, I see that air resistance is connected with many different aspects in our daily life and its impact is manifest. And I will start to study and try to develop some solutions to reduce air resistance in my daily life. Therefore I think it could enhance creativity.

Researcher: So you mean when you develop the materials and teach in the class, you could link the content with your daily life?

Student D: Yes.
Researcher: Ok.
Student D: Next, I think it could enhance communication skills for certain because the whole teaching is (similar to) a discussion. My point is similar to Student A and I totally agree with her.
Student B: In addition, to teach others the abstract ideas requires communications skills.
(Dead air for 3 seconds)
Researcher: I see. Do you think this learning approach is useful in enhancing your learning interest?
Student E & D: Yes.
Student D: Due to the active learning, the satisfaction gain in learning is much greater than passive learning. Thus, the learning interest is enhanced.
Student E: Making other understand contribute to our satisfaction too.
Student B: Since we could choose our own topic, the learning interest is boosted.
Researcher: Have you encounter any difficulty?
Student C: Yes. This learning approach is very time consuming. It is not bad but…
Researcher: Can I clarify whether you are talking about the teacher's view or the students' view?
Student C: The one who is responsible to teach in the class will spend more time.
Student D: Despite the more time is spent, the elements they are spent are parts of learning process.
Student A: Agree.
Researcher: I still do not understand who you are talking about. Can you please clarify it in detail?
Student C: The student-teacher. To me, listening to the teacher in direct teaching, is already enough. I cannot see why I have to come out to teach.
Student A: The quality is the point.
Student C: But for students who are with low learning incentive and low motivation like me, I think this approach is wasting my time.
Student B: The compatibility is not good. This approach may not be suitable to all types of students.
Student C: I think this approach is wasting my time as my target is to get a "60" only. That is the challenge which STEM may faces as STEM is for elite students.
Student A: My point is that you may not be able to understand the content well enough to get a "60" if you come across it once in traditional direct lecture. In traditional teaching model, you have to finish the homework after the lesson, check the answers

and do some revisions. However, these steps are already embedded in learning by teaching. As Student E said before, it allows us to engage with the content knowledge for four times. Do I still need time for completing homework, checking answers or doing revisions in learning by teaching? Therefore, whether learning by teaching is more time-consuming is not yet conclusive. That’s why I disagree with you.

Student B: However, there may be a possibility that it is biased as we are all volunteers. For example, for those students with lower ability in English, they may need more time to prepare the lesson. I do not know, maybe it could be a factor we should concern with.

Student A: I guess language is not the focus of this study. As you can see, we can use our mother language during the teaching in this study. In real practice, students could also apply their mother languages in their teaching. Language is not a problem. We should focus on the outcomes.

Student B: That is! The efficacy is affected by the language problem.

Student A: No, such barrier is eliminated if mother language is used!

Student B: Yeah, so it depends on whether mother language is used or not.

Student A: Yup.

Student B: Okay. Language may be one of the factors, there may exists some other factors…

Researcher: I see. In Student B’s view, language is a difficulty in using the learning by teaching.

Student B: Let us put it in this way. Each of us may have our own difficulty.

Researcher: I see.

Student D: I think the object you are talking about is the less able students. I think the downside of what you are talking about is that some less able students are more struggling in their studies.

Student B: Yes.

Student D: It is because these students have shortcomings in other aspects.

Researcher: (Talk to Student D) Did you encounter any difficulties in the learning process?

Student D: Because this subject is not my major, I am not very familiar some basic formulas which I have to teach in class. As a result, I have to spend additional time to search for relevant information on the Internet.

Researcher: Had the problem been resolved in the end?

Student D: Yes, it is solved. However, for those relatively less able students, I think they may need to spend more time studying than others. In comparison, I mean to those relatively less able students, it may be more effective to help them to solve the problems directly.

Researcher: Student E, how about you? Did you encounter any difficulties in the learning process?

Student E: My problem is…

Student B: (interrupted) I want to add a point. It may also take into account the potential pressure which may be produced to the students. In traditional teaching method, I may learn something simply by using pen and paper. But for STEM, computer may be needed although their family conditions are different. Pressure may be produced if they do not have a computer and the school is unable to provide it.

Researcher: I see.

Student D: For some students who seldom use computer, or for students with relatively weak computer knowledge, pressure may be produced when computer is used.

Researcher: Could it enhance computer skills?

Student D: Yes. During the preparation process, software, such as PPT, will be used. It allows us to practice our computer skills.

Researcher: Student A, did you encounter any difficulties in the learning process?

Student A: I did not encounter any difficulty. But I can come up with a problem that students may encounter. When we are watching the video, we will follow the ideas shown in the video to solve the problem. But if I don’t understand when watching the assigned video at home, I cannot get an immediate response. You know, in the traditional teaching method, I can ask the teacher on the spot during class. "Teacher, how should I do this, why should I do this." The teacher can answer students' questions immediately. When video is used, you may need to pause or ask the teacher after the watching. The feedback you receive will have a certain degree of delay. Another point is that there is no such thing as an "instant response" for students. I think it is a relatively big problem.

Student D: But I think this is not necessarily a disadvantage. If you rely too much on the teacher, the intention and objective of the STEM is lost.

Student A: It does not mean being overly dependent on the teacher. When a student is listening to the teacher or watching a video, his mind follows the logics and the flow of the lecture or video. He thinks and he will find the problem. He asks the teacher if he does not understand it. This is not over-reliance. In fact, the teacher's assistance is still needed throughout the teaching.

Researcher: Can you come up with some solutions that can solve these problems?

Student D: About the feedback, I think one of the disadvantage of this teaching method is that there is no test, exam of evaluation to check whether we have really mastered

the knowledge after all. If the teacher can assign some test papers and give us a feedback, then it would check and evaluate whether we have really mastered this content knowledge.
Researcher: I see. As a single lesson, this part is not included this time.
Student B: I think the coverage of topics is relatively large as they include mechanics, electricity etc. I suggest may be you can achieve the student teaching by using projects and each student is responsible to one part of the project. For example, some for mechanics and some for electricity. In the end, all of their works are integrated. I think it is better. Also, the topics chose could be related to each other. Thus, I can ask other students if I encounter problems.
Researcher: You means the topics should be relevant to each other.
Student B: Yes.
Researcher: Okay. Any else?
Student D: I think … we have already watched the video at home, so if we go back to school, it would be better to arrange a discussion among the students with teachers monitoring. Tutoring or assistance could then be given if we encountered great difficulties.
Researcher: Do you mean after the students' teaching sessions?
Student D: Yes. A discussion after the teaching sessions.
Researcher: I see. This is also a good suggestion.
Student B: I think a fixed period could be arranged for students to prepare the lecture content, individually or in group. It could be similar to self-study. And the teacher can offer help to students who are in need.
Researcher: I see. This is a good suggestion too. So is there anything you would like to add?
Student E: So far so good.
Researcher: It is also okay if you want to go back to the previous topic and add further comments.
Student B: About the preparation period I mentioned before, I think it could be conducted in a computer room. Therefore, some problems, such as the hardware problems and financial problems, could be solved as well. Immediate assistance could be provided to students who encounter difficulties. It also improves students' concentration so that they could be more focus in the preparation.
Researcher: Student A, do you want to make a comment?
Student A: I agree with Student B that the school could arrange a period for watching video with hardware provided. Immediate assistance could be provided in the next session. It could be done by a modification of the course arrangement.

Student C: I got two questions. First, the output of the model by the student is incomplete. I mean if the student, like me, does not understand the content thoroughly, I do not know how to teach others. It is not possible to explain something to others if I do not understand it. Next, if my teaching is boring and dull while Student A's teaching is well prepared with an attractive PowerPoint. Students may prefer to listen to her interesting lessons enthusiastically and don't want to listen to my lessons. Then everyone is unwilling to receive my model. And I believe that most of the classes prepared by students are not as attractive and capable as Student A. So I think this situation should be improved.

Researcher: Could it be an opportunity to learn?

Student C: Yes, probably. Some students have high motivation to learn from able students. If it were me, I would think about the reason why Student A can learn so well. But if I was a less able student, I would not be reflective and I would not learn from an able student.

Researcher: So, do you mean this method favor able students?

Student C: Yes.

Student A: I agree too. I think this teaching method is an extreme. For less able students, they have low interest in the content knowledge and now they are required to spend more time to prepare the lecture. Just like what l mentioned before, if I don't understand it but still I have to teach, it makes me feel difficult. For the less able students, this burden is great.

Student E: And I think this learning method requires a high degree of self-discipline of students. If the self-discipline and self-awareness are not strong, his lesson preparation will be poor.

Student C: Because the output of the model is incomplete.

Student E: Yes.

Student D: I think such difference can be solved by using student's discussion I mentioned before. Able students can help and direct less able students. As a result, for able students, their knowledge can be consolidated. While for the less able students, their problems can be solved and learning is facilitated.

Researcher: I see. Using group work may be better you mean.

Student C: I do not agree with it. According to recent research, the workload in a group is shared by 40% of the members only. In other words, considering a group of five people, the workload will be allocated to two while the rest of three will do nothing. This is problematic. The situation will be worse if group work is used.

Student A: And I think group work is applied, students prefer teaming up with people with similar level. Able students think that less able students are burden while less able students think that able students are strong and can finish all tasks themselves. This may happen among junior students.

Student B: And there is another situation, I don't know whether the output of students is a factor to consider. For example, when we were giving a lecture yesterday, I was very nervous. I only care if I can give a good lecture and I didn't pay attention to listening others when they were giving a lecture. That is, I only care about my own stuffs, but not the others.

Researcher: I see.

Student B: For example, when doing presentations, I focus on the quality of my own presentation and don't listen to others' presentations carefully..

Student E: Sensible.

Researcher: I see it is already overran. Let’s see if any of you would like to add some points or make some clarifications.

All: No.

Researcher: I see. So that’s the end of this focus meeting. Thank you.

E. Appendix F

Appendix F Summary of the Focus Group Meeting

Category	**Item**	**Reliability (Frequency[6])**	**Opinion**	**Main Content / idea**	**Reference**
Which teaching method do student prefer	Prefer traditional method	.50 (2)	Agree	● Teacher can ensure the learning is on the right track and student is teaching it right	B L5-7
			Disagree	● Making mistakes is also a part of the learning process even though there is no teacher present. In other words, students could be served as teachers monitoring his learning process. i. For example, "when Student C mentioned about the constant q in his lecture session yesterday, I asked about the meaning of q and thus we found that there is a piece of important concept is missing. If we don't point it out, that piece of knowledge will be kept missing and he will never know such concept is important."	A L10-16
Flipped learning by teaching approach is helpful to STEM	Flipped learning by teaching approach is helpful to the study of	1.0 (4)	Agree	● It allows students to engage in the knowledge for four times (during video, material preparation, teaching and Q&A section). The learning is deeper and the memory is enhanced. ● One of the main problems in traditional lecture is that students think that they've already understood the content but in fact they are not. But if they could develop the teaching materials, such as	A L21 & E L21, L23-32 B L52-56

[6] Total number of agreements and disagreements

Category	Item	Reliability (Frequency[6])	Opinion	Main Content / idea	Reference
education (fostering 21st century skills)	STEM, understanding increase.			organizing the points and creating the PPT, the blind-spot could be cleared. ● Understanding is enhanced	C L76
	Flipped learning by teaching approach is useful in fostering problem-solving skills	1.0 (1)	Agree	● Answering unexpected questions from others allow us to review the content we have learnt. During the Q&A, we have to think about how to answer or solve their problems.	A L49-57
	Flipped learning by teaching approach is useful in fostering communication skills	1.0 (3)	Agree	● During the Q&A, we have to think about how to answer or solve their problems. Our communication skills are improved as well. i. For example, I raised a question during the teaching session conducted by Student C. If a student-teacher do not know the answer, it is very embarrassing. Those student-teacher with high EQ may, I mean those with good communication skills, will act similarly as Student C did, say "That's a good question and especially good as being the Homework for today."; however, those student-teacher with low EQ	A L50-51 A L90-97

Category	Item	Reliability (Frequency[6])	Opinion	Main Content / idea	Reference
				and inadequate communication skills may just stun and freeze at that moment. The process of teaching is indeed a process of communication. ● Communication skills is enhanced for certain because the whole teaching is (similar to) a discussion. ● To teach others the abstract ideas requires communications skills.	D L114-115 B L117-118
	Flipped learning by teaching approach is useful in fostering creativity	.67 (6)	Agree	● Organizing of the lesson is the main reason for the improvement of the creativity. i. As students, we will focus only how to solve the problems; However, we will try to illustrate the same idea with different method if our role is shifted from student to teachers. For example, during the teaching session conducted by student B, he demonstrated two different methods in solving a single question. This is what make the difference between student and teacher. Such difference would lead to a significant improvement in creativity. ● Regarding to STEM, understanding is very important. It is impossible to apply the knowledge of these subjects without understanding them in advance. ● If the students encounter a difficulty, the student-teacher should	B L58-59 A L66-72 A L84-89 C L80-81

Category	Item	Reliability (Frequency[6])	Opinion	Main Content / idea	Reference
				try a new approach. And these skills could not be learnt from a traditional teacher.	
				● A good knowledge foundation would allow us to draw inferences about other cases from one instance. In the meantime, it allows us to discover, elaborate, link and apply them to our daily life. I think these are all creativity.	D L 100-103, L105
				● I see that air resistance is connected with many different aspects in our daily life and its impact is great. And I will start to study and try to develop some solutions to reduce air resistance in my daily life.	D L106-108
			Disagree	● The improvement of creativity is limited. ● A simple use of the model will not enhance creativity.	E L60 C L76
	Flipped learning by teaching approach is useful in fostering logical thinking	1.0 (2)	Agree	● If a student have to teach others, he must list those pre-requisites knowledge, define the items, constructing the equations and demonstrate how to use those equations and knowledge to solve the problems. This is a good training in logical thinking.	E L60-64
				● Student-teacher have to (1) extract the key information; (2) translate them into language; and (3) help students to understand the logics behind the knowledge.	C L77-80

Category	Item	Reliability (Frequency[6])	Opinion	Main Content / idea	Reference
	Flipped learning by teaching approach is useful in fostering learning interest	1.0 (3)	Agree	● Making other understand contribute to our satisfaction. ● Due to the active learning, the satisfaction gain in learning is much greater than passive learning. ● Since we could choose our own topic, the learning interest is boosted.	E L122 - 124 D L122 L125 B L126
	Flipped learning by teaching approach is useful in fostering computer skills	1.0 (1)	Agree	● During the preparation process, software, such as PPT, will be used. It allows us to practice our computer skills.	D L200-201
Difficulty in using flipped learning by teaching	Difficulty, very time consuming	.33 (3)	Agree	● Very time consuming. Listening to the teacher in direct teaching, is already enough for students who are with low learning incentive and low motivation.	C L128
			Disagree	● Despite the more time is spent, the elements they are spent are parts of learning process. In traditional teaching model, you have	D L132-133 L147-

Category	Item	Reliability (Frequency[6])	Opinion	Main Content / idea	Reference
approach				to finish the homework after the lesson, check the answers and do some revisions. However, these steps are already embedded in learning by teaching. As Student E said before, it allows us to engage with the content knowledge for four times. Do I still need time for completing homework, checking answers or doing revisions in learning by teaching? Therefore, whether learning by teaching is more time-consuming is not yet conclusive. Quality is the point	153 A L134
	This approach may be more suitable to able students, with higher degree of discipline	1.0 (5)	Agree	● This approach may not be suitable to all types of students. If a student does not understand the content thoroughly, he does not know how to teach others. It is not possible to explain something to others if I do not understand it. ● Some students have high motivation to learn from able students. If it were me, I would think about the reason why Student A can learn so well. But if I was a less able student, I would not be reflective and I would not learn from an able student. ● Some less able students are more struggling in their studies because these students have shortcomings in other aspects. ● In comparison, I mean to those relatively less able students, it may be more effective to help them to solve the problems directly.	B L142 L261-263 C L270-273 D L172-176 D L185-186

Category	Item	Reliability (Frequency[6])	Opinion	Main Content / idea	Reference
				● I think this teaching method is an extreme. For less able students, they have low interest in the content knowledge and now they are required to spend more time to prepare the lecture. Just like what l mentioned before, if I don't understand it but still I have to teach, it makes me feel difficult. For the less able students, this burden is great. ● And I think this learning method requires a high degree of self-discipline of students. If the self-discipline and self-awareness are not strong, his lesson preparation will be poor. ● Because the output of the model is incomplete.	A L276-280 E L281-283 C L284
	Difficulties competition	1.0 (1)	Agree	● If my teaching is boring and dull while Student A's teaching is well prepared with an attractive PowerPoint. Students may prefer to listen to her interesting lessons enthusiastically and don't want to listen to my lessons. Then everyone is unwilling to receive my model. And I believe that most of the classes prepared by students are not as attractive and capable as Student A. So I think this situation should be improved.	C L263-268
	Difficulty Pressure due to hardware or	1.0 (2)	Agree	● In traditional teaching method, I may learn something simply by using pen and paper. But for STEM, computer may be needed although their family conditions are different. Pressure may be	B L191-194

Category	Item	Reliability (Frequency[6])	Opinion	Main Content / idea	Reference
	financial			produced if they do not have a computer and the school is unable to provide it. ● For some students who seldom use computer, or for students with relatively weak computer knowledge, pressure may be produced when computer is used.	 D 196-198
	Difficulty without immediate response	.5 (2)	Agree	● When we are watching the video, we will follow the ideas shown in the video to solve the problem. But if I don't understand when watching the assigned video at home, I cannot get an immediate response. You know, in the traditional teaching method, I can ask the teacher on the spot during class. "Teacher, how should I do this, why should I do this." The teacher can answer students' questions immediately. When video is used, you may need to pause or ask the teacher after the watching. The feedback you receive will have a certain degree of delay. Another point is that there is no such thing as an "instant response" for students. I think it is a relatively big problem.	A L204-212
			Disagree	● This is not necessarily a disadvantage. If you rely too much on the teacher, the intention and objective of the STEM is lost.	D L213-214
	Difficulty No	1.0 (1)	Agree	● I think one of the disadvantages of this teaching method is that	D L221-

Category	Item	Reliability (Frequency[6])	Opinion	Main Content / idea	Reference
	evaluation			there is no test, exam of evaluation to check whether we have really mastered the knowledge after all. If the teacher can assign some test papers and give us a feedback, then it would check and evaluate whether we have really mastered this content knowledge.	225
Suggestions from students	After-teaching Evaluation	1.0 (1)	Agree	● It would check and evaluate whether we have really mastered this content knowledge.	D L221-225
	Topics should be relevant	1.0 (1)	Agree	● I think the coverage of topics is relatively large as they include mechanics, electricity etc. I suggest may be you can achieve the student teaching by using projects and each student is responsible to one part of the project. For example, some for mechanics and some for electricity. In the end, all of their works are integrated. I think it is better. Also, the topics chose could be related to each other. Thus, I can ask other students if I encounter problems.	B L227-232
	Discussion could be added	1.0 (1)	Agree	● We have already watched the video at home, so if we go back to school, it would be better to arrange a discussion among the students with teachers monitoring. Tutoring or assistance could then be given if we encountered great difficulties. ● Learning difference can be solved by using student's discussion I mentioned before. Able students can help and direct less able students. As a result, for able students, their knowledge can be	D L236-239 D L286-289

Category	Item	Reliability (Frequency[6])	Opinion	Main Content / idea	Reference
				consolidated. While for the less able students, their problems can be solved and learning is facilitated.	
	Able student can help less able student in group work	.33 (3)	Agree	● Learning difference can be solved by using student's discussion I mentioned before. Able students can help and direct less able students. As a result, for able students, their knowledge can be consolidated. While for the less able students, their problems can be solved and learning is facilitated.	D L286-289
			Disagree	● I do not agree with it. According to recent research, the workload in a group is shared by 40% of the members only. In other words, considering a group of five people, the workload will be allocated to two while the rest of three will do nothing. This is problematic. The situation will be worse if group work is used. ● And I think group work is applied, students prefer teaming up with people with similar level. Able students think that less able students are burden while less able students think that able students are strong and can finish all tasks themselves. This may happen among junior students.	C L290-294 A L295-298
	Assistance should be provided in	1.0 (3)	Agree	● I think a fixed period could be arranged for students to prepare the lecture content, individually or in group. It could be similar to self-study. And the teacher can offer help to students who are in need.	B L243-245, L251-255

Category	Item	Reliability (Frequency[6])	Opinion	Main Content / idea	Reference
	lecture preparation			I think it could be conducted in a computer room. Therefore, some problems, such as the hardware problems and financial problems, could be solved as well. Immediate assistance could be provided to students who encounter difficulties. It also improves students' concentration so that they could be more focus in the preparation. ● Immediate assistance could be provided in the next session. ● He could serve as a helper or mentor answering our problems when it is needed. He could provide us some useful advice especially when we encounter some difficulties in class preparations.	A L258-259 D L38, S L39
	The role of teacher should be passive	1.0 (1)	Agree	● The role of teacher should be passive.	D L37

Chapter 4. Stop Using Learning-by-Teaching. A Simple Revision Could Provide Similar Efficiency: A Case Study on Metacognitive Benefits.

4.1. Abstract

Earlier studies have shown that the learning-by-teaching pedagogy could be an effective pedagogy. As being a peer tutor, students might learn better than just sitting and listening in the classroom. Studies also reveal that there are two types of strategies which tutors would adopt, named as knowledge-building and knowledge-telling strategy. Although the former one could provide a greater learning outcome, tutors trend to use the later one more often. Metacognition is thus believed to be essential because it is a factor of such selection. This study contributes towards exploring the potential of the knowledge-telling strategy to promote college students' metacognitive skills. Results indicate that no significant metacognitive skills improvement could be founded in the tutors compared to their tutees. Knowledge-telling strategy does not help in promoting knowledge-building strategy. It implies that measurements have to be taken; otherwise, tutors will keep using the low efficient knowledge-telling strategy in LdL.

4.2. Keywords

Learning-by-Teaching, Metacognition, Metacognitive skills, Knowledge-Telling Strategy

4.3. Introduction

A. The Learning-by-Teaching Pedagogy

The learning-by-teaching pedagogy was perhaps first applied as a formal educational tool named as *Lernen durch Lehren* (LdL) by Jean-Pol Martin in German in the 1980's (Grzega & Schöner, 2008). As the French essayist Joseph Joubert said, "To teach is to learn twice over." Aligning well with this hypothesis, earlier studies show that tutors might learn as much as or even learn greater than their tutees during the teaching and learning process (Allen & Feldman, 1973; Cloward, 1967).

Later study suggests that the interactions between the tutor and tutees, especially the explanation and feedback process, are indeed the key factor in the teacher's learning (Annis, 1983). As Vygotsky stated, "Speech is the external expression of thoughts" while "A word without meaning is just an empty sound" (Vygotsky 1987). In order to express themselves through dialogues, tutors have to do the mind reviews, reformulates information into knowledge and reorganise the content materials (Gartner, Kohler & Riessmann, 1971; Zajonc, 1966). It could benefit tutors from all age groups across different subject domains (Cohen, Kulik, & Kulik, 1982; Cook, Scruggs, Mastropieri, & Casto, 1986; Mastropieri, Spencer, Scruggs, & Talbott, 2000; Mathes & Fuchs, 1994; Rohrbeck, Ginsburg-Block, Fantuzzo, & Miller, 2003).

B. The Knowledge-Building and the Knowledge-Telling LdL Model

However, recent studies show that such benefits are not guaranteed (Cohen, Kulik, & Kulik, 1982; Mathes & Fuchs, 1994; Renkl, 1995; Rohrbeck et al, 2003). The effect sizes for elementary and middle school tutor are always small while greater gains always exist in Math or Science compared to reading programs (Roscoe & Chi, 2007). In order to account for these findings, the terms *knowledge-building* and *knowledge-telling* are thus proposed. Knowledge-building is defined as the "metacognitive reflection upon their own expertise and comprehension, and constructively establishment upon their prior knowledge by generating inferences, integrating ideas across topics and domains, and repairing errors" while knowledge-telling is defined as "lecturing or stating what they already know by summarizing facts with little elaboration or self-monitoring". Although self-explanation could also facilitate such activities (Chi, Bassok, Lewis, Reimann, & Glaser, 1989), explaining to others seems to be more effective since it provides more potential benefits by having the gaps and inconsistencies clarified during the explanation process (Coleman, Brown, & Rivkin, 1997; Webb, 1989). Although knowledge-telling can have a positive impact on the tutor's learning, the knowledge-building process is argued to result in a better understanding (Roscoe & Chi, 2007).

C. How do tutors choose between them?

Despite the benefits of knowledge-building, tutors always rely heavily on knowledge-telling even training had been provided (Dufrene, Noell, Gilbertson & Duhan, 2005; King, Staffieri, & Adelgais, 1998) while untrained tutors will adopt knowledge-telling spontaneously (Roscoe, & Chi, 2008). Roscoe (2014) suggests that lack of expertise knowledge and metacognitive skills might be the reason. In most cases, peer tutors are unlikely to be experts in the corresponding domain or pedagogy content knowledge. They might not possess the abilities (eg. Questioning, Reasoning, explanation and metacognitive skills) for knowledge-building strategies. Eventually, tutors choose knowledge-telling for "comfortable" and "safety" without being criticised.

D. Hypothesis and Research Questions

Based on the content aforementioned , metacognitive skills are indeed very essential and critical to the LdL. As noted before, the two main factors determining the use of knowledge-building and knowledge-telling strategy are expertise knowledge and metacognitive skills. The domain knowledge is indeed the product of the whole teaching-and-learning process. It is the goal we want to achieve and thus an assumption of strong domain knowledge before the teaching-and-learning process could be considered as "unreasonable". As reported by King et al. (1998) knowledge-building could be facilitated by training, which implies that it could be enhanced by high pedagogy content knowledge (Roscoe, 2014). However, the effect is very limited (Dufrene et al. 2005; King et al., 1998) and knowledge-telling is still dominant. The choice between knowledge-building and knowledge-telling strategy is, therefore, determined by the tutors' metacognitive skills. Given that knowledge-building strategy could result in better learning outcomes while tutors usually start by using the knowledge-telling strategy, promoting the knowledge-telling to knowledge-building is the key to the success of LdL. If there exists any metacognitive benefit after introducing the knowledge-telling strategy, tutors will be promoted to knowledge-building strategy and thus greater learning outcomes could be achieved eventually. In other words, if an educator would like to adopt the LdL as his major teaching pedagogy rather than a one-time-use strategy, the effects of the knowledge-telling strategy on the metacognitive skills would be critical to his success in LdL.

However, study about the knowledge-telling and its effect on metacognitive skills is very limited. The present study contributes towards filling this gap by exploring the potential of the knowledge-telling strategy to promote college students' metacognitive skills. According to Brown (1978, 1987), metacognitive skills could be divided into (a) Prediction (eg. How difficult is the task), (b) Planning (eg. What shall I do to execute the task), (c) Monitoring (eg. What do I yet not know in order to attain my objective) and (d) Evaluation (eg. Have I got the full meaning of the answer), the potential of the knowledge-telling strategy to promote college students' prediction, planning, monitoring and evaluation skills will also be examined.

4.4. Methodology

Bargh and Schul's (1980) study is believed to be one of the first studies to separate the stages of LdL into preparation and in-class activities. They founded that there do exists a cognitive effect during the preparation phase. Additional studies further suggest that expecting to teach could result in a better gain than expecting to take a test in terms of learning outcomes (Benware & Deci, 1984; Fiorella & Mayer, 2013; Fiorella & Mayer, 2014; Nestojko, Bui, Kornell, & Bjork, 2014). Therefore, this study will follow their design for a fair test. It is divided into three stages: mixed-classes lecture, preparation and group presentation.

A. Stage One: Mixed-Classes Lecture

In the first phase, 35 senior one students of two classes in a public school in China are arranged to a 3-hour normal lecture (4.5 periods) to equip them with the basic knowledge of a particular mathematical topic, statistics. It includes the sub-topics of mean, mode, median, variance and standard deviation. Lecture-cum-Demonstration Method is used because it includes the merits of both the lecture and demonstration method meanwhile their shortcomings or limitations are removed (Suneetha , Rao, &

Dr Rao, 2004). It allows the teacher to distribute large amount of information within a limited teaching period of time while demonstration allows students to understand the principles or laws effectively. The metacognitive pre-test is then conducted.

B. Stage Two: Preparation

In the preparation phase, participants are divided into two groups, named as sample and control, by random selection. Eventually, the sample group and control group contain 17 and 18 students respectively. The details of the presentation in the next phase are told to the sample group only. Within the group, participants are free to divide into 4 mini-groups without any restriction. However, the maximum size of each mini-group is set to be 5 in order to maximize the chance to express themselves in presentation in limited hours of lecture. Methods such as peer discussion, use of the internet and seeking advice from teachers are all allowed. In other words, participants are free to prepare their presentation materials by any means while there is no specific action or duty for the control group in this phase.

C. Stage Three: Group Presentation

Overall speaking, the design of this phase follows one of the common practice of LdL reported by Duran (2017). Each mini- group in the sample group is given half an hour to report summarize what they have learnt in the lecture. The workload is shared among members in a mini-group and all members are required to take part in their presentation. The use of PowerPoint is compulsory and at least one sample question with solutions is required to be presented. However, classwork is encouraged but not compulsory.

To balance the studying hours spent in both groups, the control group is assigned as audiences during the presentation. Since Knowledge-telling strategy is the focus, interactions such as discussion are allowed but not compulsory. After all, the second metacognitive test (The pro-test) is given to them and the scores are recorded. 15 mins Individual interviews are conducted to 4 students (Two per each group) in order to further investigate the result qualitatively.

4.5. Method of Evaluation

Assessment of metacognition is difficult because metacognition is a complex construct and might be confounded in practice with both verbal ability and working memory capacity (Lai, 2011). Although students' academic performances and achievements, standardized achievement scores such as GPA are correlated, they are not good indicators for metacognition (Favieri, 2013).

In the meantime, recent metacognitive instruments might not be appropriate to this study. Although instruments such as questionnaires, interviews, observations, thinking-aloud protocols, eye movements, computer registrations of activities, note taking, stimulated recalls have been widely used (Desoete & Veenman, 2006), each of them has its own strengths and weaknesses (Sperling, Howard, Miller, & Murphy, 2002). For example, the oral interview could externalize participants' thoughts, however, it might not be a good choice for children because there could be a gap between children' conversations and actions (McLain, Gridley, & McIntosh, 1991). Moreover, metacognition could be domain-specific or at least partially domain-specific (van der Stel & Veenman 2008; Wang, 2015). A student could show variations in metacognition across different domains or Key Learning Areas such as Mathematics and English reading comprehension. Therefore, a tailor-made metacognitive pre-test and protest are used.

Both metacognitive pre-test and protest consist of four parts: Prediction, Planning, Monitoring and Evaluation. In *prediction*, participants will be given certain types of question and they are asked to indicate which one is the most difficult. One point will be scored if the correct answer is chosen. In *planning*, some steps about solving a certain question but in disorder. Their task is to rearrange them in the correct order. One point will be scored if the correct answer is chosen. Next, participants will be asked to mention at least one possible common error occurs in solving a particular problem in *monitoring*. One point will be scored if the statement is correct. Finally, in *evaluation*, numerical questions are given and they are requested to calculate the answers. Participants have to choose an option which indicates whether they feel about the correctness of the answer. However, marks are given according to the consistency between their feelings and the correctness of the answer. For example, if "absolutely certain" is chosen while the answer is correct, two points are scored; if "partially certain" is chosen while the answer is correct, one point is scored; if "absolutely certain" is chosen while the answer is incorrect, zero points are scored. A percentage over full mark will be used for consistency.

4.6. Ethics Concern

Extra care is taken on the interpersonal relationship between the researcher and the participants because the researcher is one of the teachers in the school. Since students tend to be afraid of the teachers' authority, direct contact between them is thus avoided as best as it could. Therefore, the interview is conducted by a student helper who is selected by the researcher from the senior three students in the same school. The choice of the interviewees is decided by the student helper without any prior consent from the researcher.

In order to avoid any misleading questions and answers, the interviews are conducted in Chinese, the mother language of both the interviewer and interviewees. Moreover, a brief introduction is given by the teacher before the two metacognitive tests. The use of difficult vocabulary is also avoided or being further explained.

4.7. *Handling of data*

All quantitative data collected is analysed by using SPSS 24. 2x2 ANOVA is conducted such that all simple and interaction effects are revealed. One sample group and one control group student are absent in the pre-test and the pro-test respectively and thus their data is replaced by using the mean of the corresponding data set

4.8. *Result*

The effects of the knowledge-telling strategy on both the sample and control group were examined in terms of metacognitive benefits. The results revealed that there was no significant interaction effect between the groups and their overall metacognition level with $F(1, 33) = .001$, $p = .975$ (Further details please refer to Table 6). The main effect of participant groups and metacognition levels were not significant with $F(1, 33) = .414$ $p = .524$ and $F(1, 33) = 2.876$ $p = .099$. It suggests that there are no significant differences in metacognition level between the pre-test and the pro-test.

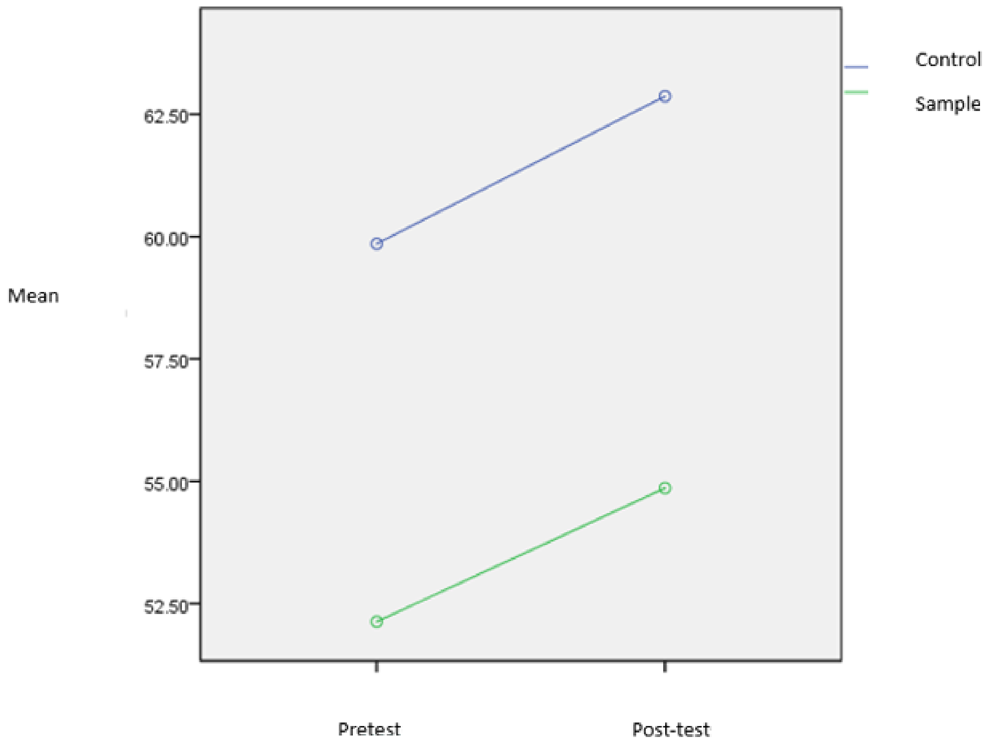
Table 6 Descriptive Statistics of LdL

	Group	Mean	Std. Deviation	N
Pretest	Control	59.8529	19.53504	17
	Sample	52.1324	18.76167	18
	Total	55.8824	19.25909	35
Post-test	Control	62.8676	18.32734	17
	Sample	54.8611	19.44964	18
	Total	58.7500	19.07079	35

Table 7 ANOVA Table of LdL

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Pre_Post Test	144.202	1	144.202	.414	.524	.012
Pre_Post Test * Group	.357	1	.357	.001	.975	.000
Error(Pre_Post Test)	11488.337	33	348.131			

Figure 4 Mean Plots of LdL



Further analysis revealed that there was no significant interaction effect between the groups and their prediction skill too with F (1, 33) = .402, p = .530. In contrast, the main effect of participant groups and prediction skill were significant with F (1, 33) = 10.515 p =.003 and F (1, 33) = 4.773 p =.036. It suggests that the prediction skill of the tutor is significantly greater than the audience and there are significant differences in prediction skill between the pre-test and the pro-test. In other words, both groups have similar gains in prediction skill from the intervention.

Similar to the above, planning skill shows no significant interaction effect with $F(1, 33) = 1.064$, $p = .310$. The main effect of participant groups was not significant too with $F(1, 33) = .108$ $p = .745$. However, significance result is obtained in the main effect of planning skill $F(1, 33) = 4.41$ $p = .043$. It suggests that the planning skill of the tutors is significantly greater than the tutees due to the higher initial level of background among the tutors.

There was also no significant interaction effect between the groups and their monitoring skill with $F(1, 33) = .135$, $p = .715$. The main effect of participant groups and monitoring skill were significant with $F(1, 33) = .002$ $p = .962$ and $F(1, 33) = .028$ $p = .869$. There are no significant gains in monitoring skill during the intervention.

In the meantime, no significant interaction effect between the groups and their evaluation skill could be obtained with $F(1, 33) = 2.194$, $p = .148$. Both the main effect of participant groups and evaluation skill were not significant with $F(1, 33) = .079$ $p = .780$ and $F(1, 33) = .650$ $p = .426$. It means that no significant difference is observed in evaluation skill before and after the intervention.

4.9. Discussion

Although LdL might be effective in promoting learning outcomes (Allen & Feldman, 1973; Cloward, 1967), the result suggests that the overall metacognitive benefit from adopting knowledge-telling is ambiguous. The contribution of knowledge-telling shows a variation among the metacognitive skills with the greatest significance gains exists in prediction skill. A simple summarization does not deepen students' planning, monitoring and evaluation skills towards the learning context. As student B stated, "because each group are presenting the same content, if someone cannot get it at the first time, they won't do it in the second time and so the third … (Knowledge-telling) is useful to familiarize the concepts, but this does not mean understanding." It is very unlikely that students would switch into knowledge-building strategy after the use of the knowledge-telling strategy. In the meantime, the metacognitive gains among tutors are indifference compared to those of the tutees. This further implies that listening to the same context again could be a substitute to knowledge-telling strategy in terms of metacognition gain. Therefore, the significance of knowledge-telling strategy is very limited. Without any precautions or measurements to facilitate the use of the knowledge-building strategy, the effects of LdL is questionable.

4.10.Conclusion

The successfulness of LdL depends on whether the knowledge-building strategy or the knowledge-telling strategy is used by the tutor. However, tutors have a very high tendency to adopt the knowledge-telling strategy. The result of this study shows that the knowledge-telling strategy is very unlikely to enhance the metacognitive skills of the tutor and thus it has no improvement in shifting towards knowledge-building. It implies measurements have to be taken; otherwise, tutors will keep using the low efficient knowledge-telling strategy.

4.11.Limitation and Further Study

Care should be taken when interpreting the result of this study due to the small sample size. Dilution effect might exist because the workload of presentation is shared among the group mates. Further study in investigating the solutions to shift knowledge-telling strategy into knowledge-building strategy, is suggested.

4.12.Appendix G

Appendix G Sample Questions for Metacognitive Test

Name :________________________

Class :________________________

Answers:

1.	2.	3.	4.	5.

Part A: (Prediction) in the following questions, please select among the options the one you think is the most difficult question.

1	The midnight temperature for each of the first five days of a given week is recorded in the following table. Midnight Temperature Reading in Lab H in Degrees Fahrenheit Monday: 76 Tuesday: 62 Wednesday: 65 Thursday: 70 Friday: 77

	A. Find the mean of the midnight temperature in the first five days of the given week. B. Find the minimum of the midnight temperature in the first five days of the given week. C. Find the range of the midnight temperature in the first five days of the given week. D. Find the standard deviation of the midnight temperature in the first five days of the given week.

2	In the following numbers: 9,8,7,6,5,4,3,2,1
	A. Find the mean B. Find the maximum C. Find the interquartile range D. Find the variance

3	Which of the following is the most difficult question?
	A. Find the interquartile range in a non-grouped data B. Find the interquartile range in a grouped data C. Find the median in a non-grouped data D. Find the median in grouped data

4 The following table shows the distribution of the heights of students in a class.

Height (cm)	Frequency
120–129	8
130–139	12
140–149	10

A. Find the variance
B. Find the sum of the students in the class
C. Find the class mark of each interval
D. Find the mean

5 The frequency distribution table below shows the results of 40 golf players in a tournament.

Strokes	70	71	72	73	74	75
Frequency	4	5	8	11	8	4

A. Find the mode

	B. Find the mean C. Find the median D. Find the range

Part B: (Planning) in the following questions, please arrange the steps in correct order

6	In the following numbers: 0, 8, 2, 5, 4, 5, 3, 1, 8, if the interquartile range is going to be calculated, please arrange the process in correct order.
	___ find out the value of the lower quarter and the upper quarter ___ arrange the numbers in ascending order ___ calculate the value of upper quarter minus lower quarter

7	The following shows the age of 16 students attended in an activity as non-grouped data. 22 18 20 21 17 16 16 17 20 17 18 19 18 20 17 16 If the standard deviation is going to be calculated, please arrange the process in correct order. ($\bar{x} = \text{mean}$)
	___ find out the total number of elements ___ find out the variance ___ find out the $\bar{x}$ ___ take the square root of the variance

8	The following shows the age of 16 students attended in an activity as non-grouped data. 20 20 19 19

	18 19 18 20 20 16 19 20 17 19 20 18 If the interquartile range is going to be drawn, please arrange the process in correct order.
	___ find out Q1 and Q3 ___ find out the median ___ arrange the data in ascending order (smallest to largest) ___ find out Q3 – Q1

9	In a group of data with n items where n is even, if the median is going to be calculated, please arrange the process in correct order.
	___ divide the elements into two group from the middle ___ arrange the numbers in ascending order ___ take the average of the $\frac{n}{2}$th item and the $\frac{n}{2}+1$ item

10	In a group of data 8,4,6,3,5,6,7,8,2,3,1 , if the range is going to be calculated, which of the following information or procedure should be necessary?
	___ arrange the numbers in ascending order (smallest to largest) ___ find out the value of the minimum and the maximum value ___ calculate the value of maximum value minus the minimum

Part C: (Monitoring) in the following questions, please decide what kind of mistake do students always make in the question

11	In a group of data 5,15,12,8,9,9,1,12,5 , if the range is going to be calculated, in your opinion, what kind of mistake do students always make in this question?

	____________________ ____________________ ____________________ ____________________

12	Four subject marks of a student is collected as below: The mean of the data is 67

Marks	
English	70
Math	64
Physics	58
Chemistry	76

if the standard deviation is going to be calculated, in your opinion, what kind of mistake do students always make in this question?

____
____
____
____

13	The studying hours per week of 16 students is recorded as below:

20	20	19	19
18	19	18	20
20	16	19	20
17	19	20	18

if the median is going to be calculated,

what kind of mistake do students always make in this question?

____

	____ ____ ____

14	For the number 1, 2, 3, 4, 5, 6 ,7 . If the standard deviation is going to be calculated, in your opinion, what kind of mistake do students always make in this question?
	____ ____ ____ ____

15 The frequency distribution table below shows the results of 40 golf players in a tournament.

Strokes	69.5-70.5	70.5-71.5	71.5-72.5	72.5-73.5	73.5-74.5	74.5-75.5
Frequency	2	5	8	13	9	3

If the median is going to be calculated, in your opinion, what kind of mistake do students always make in this question?

____

____

____

____

Part D: (Evaluation) Answer AND Calculate the following and circle in the opinion which best describe you.

16	The frequency distribution table below shows the height of 30 students

Height (cm)	145-149	150-154	155-159	160-164	165-169	170-174
Frequency	4	5	5	8	3	5

Find the median.

Your Calculation here:

A. I am absolutely sure I did the answer in the right way.

B. I am quite sure I did the answer in the right way.

C. I am not sure whether I did the answer in the right way or not.

D. I know that I made a mistake.

17 The frequency distribution table below shows the height of 100 students

Height (cm)	145-149	150-154	155-159	160-164	165-169	170-174
Frequency	4	20	27	25	15	9

Find the interquartile range.

Your Calculation here:

	A. I am absolutely sure I did the answer in the right way. B. I am quite sure I did the answer in the right way. C. I am not sure whether I did the answer in the right way or not. D. I know that I made a mistake.

18	In the following numbers: 6,9,12,3,4 Find the variance. Your Calculation here:
	A. I am absolutely sure I did the answer in the right way. B. I am quite sure I did the answer in the right way. C. I am not sure whether I did the answer in the right way or not. D. I know that I made a mistake.

19	In the following numbers: x+3, x+4 , x+5 , x+10 , x+15 Find the mean. Your Calculation here:
	A. I am absolutely sure I did the answer in the right way. B. I am quite sure I did the answer in the right way.

	C. I am not sure whether I did the answer in the right way or not. D. I know that I made a mistake.

20	In a group of numbers having a mean of 15 and standard deviation of 4 Find the variance. Your Calculation here:
	A. I am absolutely sure I did the answer in the right way. B. I am quite sure I did the answer in the right way. C. I am not sure whether I did the answer in the right way or not. D. I know that I made a mistake.

Chapter 5. Discussion

As aforementioned in section 1.4, the primary objective of this dissertation is to test whether flipped classroom could be used together with practical work and discussion as well as learning by teaching respectively. It also aims at investigating the interactions among the elements employed and test if their advantages could be retained after the integration. Eventually, it tries to reveal the mechanism of how the flipped classroom with practical work and discussion as well as the flipped classroom with learning by teaching could foster students' learning in STEM education. However, what does it mean? What is its significance? Is there any impact to educators? The following sections aimed to answer them by looking at the result of the chapters collaboratively.

5.1. The Role of flipped classroom in the innovative STEM approaches

A. Freed up in-class time for the time-consuming teaching and learning approaches

Perhaps one of the most distinctive features of flipped classroom is that the instruction section is shifted to the pre-class. As a result, more in-class time could then be freed up for meaningful activities (Delozier and Rhodes, 2017). This characteristic provides the first rationale of why flipped classroom could play a significant role in innovative STEM approaches as it could spare the in-class time for some teaching and learning approaches. It is especially useful for those approaches which are useful but time-consuming.

For example, teachers are reluctant to use practical work and discussion although they are believed to be useful element in STEM education (Jang and Anderson, 2004; Vilaythong, 2011). As revealed in section 2.11B, all participants believed that practical work is the most essential component to foster a better understanding. Without practical work, they could make arguments based on imaginations which form within their mind. It is not only difficult but also hard for them to reach a precise and correct judgement. In opposite, practical work provides them with concrete facts to test their hypothesis by trial-and-error so that they could argue and discuss with others, and make their own judgements. The cognition development process is mostly established. However, using practical work alone may not be the best way as misconceptions and misunderstandings may be hindered in the blind-spot. In contrast, using practical work with discussion may improve the situation. Misconceptions and misunderstandings could be cleared when practical work is conducted in parallel with discussions. If there is a misconception within a student which is spotted by his groupmate during the discussion, they could demonstrate the concept and express their thoughts based on the solid evidence provided by practical work.

However, arranging instruction section, practical work and discussion at the same time in the same lecture is not efficient. Let us do some simple mathematics to illustrate this concept. For a 40-minute lecture with 15 minutes instructional section, the time remain for practical work and discussion is 25 minutes. If the preparation and cleaning-up procedures for practical work takes 10 minutes in total, the effective duration for practical work and discussion is 15 minutes. The efficiency, which is calculated by the effective duration / total time spent, is 60%. In contrast, the use of in-class time is more efficient in the FPD model. Since the instruction section is moved into the pre-class section, the whole in-class time is now reserved for practical work and discussion. If the preparation and cleaning-up procedures for practical work still takes 10 minutes, the effective duration for practical work and discussion is 30 minutes. The efficiency of practical work and discussion is thus increased to 75%. Thus, flipped classroom could increase the incentive of teacher to employ the practical work and discussion by increasing their efficiency.

This advantage seems to be more obvious when flipped classroom is used together with learning by teaching. As revealed by the result in section 3.7, class preparation is one of the main elements in fostering students' 21st century skills in STEM education. Since a great amount of time have to be spent for student-teachers to prepare their lectures, it is nearly impossible to conduct the student-teacher lecturing section immediately after the instruction section. In traditional learning by teaching, it is very likely that it will take at least two separate half-lessons. With the aid of flipped classroom, the situation is greatly improved. A flipped learning by teaching lesson could be completed in one single lesson as it was shown in the method section of Chapter Two. As the operational difficulties decrease, the incentive of using the learning by teaching increases.

B. Equip students with pre-requisite knowledge for the teaching and learning approaches.

On the other hand, flipped classroom could facilitate the use of STEM teaching and learning approaches which required students to be equipped with pre-requisite knowledge. The result of the Chapter Two and Three (via section 2.10 and section 3.7) seems to support this claim. By shifting the instruction section out of class, the necessary knowledge could be equipped in advance so that the traditional teaching and learning approaches could be more feasible.

As revealed by Jang and Anderson’s work (2004), one of the greatest challenges in implementation of practical work is the lack of insufficient previous knowledge and experimental skills among students. Since students do not familiar with their roles, the teacher will be kept occupied in providing them individual guidance. Hence, problems in classroom management are generated when students are losing focus and are waiting for teacher’s help. Eventually, teachers are reluctant to employ practical work in their teachings. Flipped classroom seems to be a good solution here. As stated in section 2.10, participants believed that the video could serve as a preparation of the experiment to provide fundamental knowledge of the practical work. By providing students the relevant concepts, formula, guidelines, procedural knowledge or precautions, students knew better about what to do in the lecture. Figuratively, flipped classroom could provide students with the knowledge they need so that students are more likely to conduct their work on the right track.

Akin to the above, the learning by teaching is facilitated by flipped classroom too. Obviously, one of the biggest difficulties in using learning by teaching is that student-teacher is not able to teach well as they lack relevant subject content knowledge and pedagogical content knowledge (Shulman, 1986; Shulman, 1987; Zhou, Chen and Chen, 2019). Eventually, it may lead to a wasting of valuable in-class time. As a result, a teaching section must be conducted to the student-teacher in advance. Thus teachers are reluctant to implement learning by teaching as is would significantly increase their workload. With the aid of flipped classroom, the situation could be greatly improved. As revealed by the result in section 3.7, flipped classroom could provide the student-teachers the relevant concepts, formula and content for their teaching. As a result, student-teachers could get the necessary knowledge without increasing the workload of the teacher. The incentive of using the learning by teaching increases.

In short summary, the practical work and discussion approach as well as the learning by teaching approach are believed to be very time consuming. They require a lot of pre-requisite knowledge to ensure they are conducted on the right track. Thus teachers are reluctant to apply them although they are effective in fostering STEM education. By integrating flipped classroom into them, the situation could be improved. As the instruction section is now shifted to the pre-class section, the in-class time could be reserved and the pre-requisite knowledge could be delivered to students. As a result, the practical work and discussion approach as well as the learning by teaching approach are becoming more feasible and the incentive of using those approaches increases. The flipped classroom could facilitate the uses of traditional effective STEM teaching and learning approaches.

5.2. *Flipped classroom unleash the potential of the traditional teaching and learning approach for effective STEM education*

Apart from making the approaches more feasible, results of this dissertation also suggest the effect after the integration could be greater due to the interactions of the traditional elements (eg. Practical work, discussion, learning by teaching section) with flipped classroom. For instance, more in-class time could be reserved for the practical work as the instruction section was arranged in the pre-class section. By providing students relevant knowledge for conducting the practical work, students were more focus and concentrate on their work (via section 2.10). Thus the efficiency and the quality of the practical work increased (via section 2.10 and section 5.1). In the meantime, the efficiency of discussion was also enhanced as students were more familiar with the discussion materials. As a result, students are more active in the discussion and less likely to go off the topic. Eventually, the potential of practical work and discussion were unleashed.

On the other hand, the benefits gained from traditional learning by teaching is not guaranteed (Cohen, Kulik, & Kulik, 1982; Mathes & Fuchs, 1994; Renkl, 1995; Rohrbeck et al, 2003). According to current literatures, there exists two types of learning by teaching model named as the Knowledge-Building and the Knowledge-Telling (via section 4.3B). Although the former one is more effective in enhancing students' understanding than the later one (Roscoe & Chi, 2007), Knowledge-Telling is still dominant among student-teachers (Dufrene, Noell, Gilbertson & Duhan, 2005; King, Staffieri, & Adelgais, 1998). It is not a good news to educators as students may keep using the Knowledge-Telling strategy instead of changing to the more effective Knowledge-Building strategy simultaneously (via section 4.8 in Chapter 4). It greatly hinder the effectiveness of learning by teaching in STEM education.

When flipped classroom is used, there seems to exist some improvements. Since more in-class time was reserved, more activities such as Q&A section are available. The Q&A sections could provide students the chance for interactions to occur. When being challenged with a difficult question, student-teacher have to review the content, construct the answer and deliver it in a meaningful way (via Table 4). Those cognitive process aligns well with the metacognitive skills (including prediction, planning, monitoring and elaboration) which were suggested by Brown (1978, 1987). It suggested that Knowledge-Building was used in flipped learning by teaching. In further elaboration, flipped learning by teaching may provide more metacognitive activities to students than the simple learning by teaching approach.

In the meantime, the weaknesses of the practical work, discussion and learning by teaching may be turned into strengths due to the interactions with flipped classroom. As aforementioned in section 2.10B, section 3.7 and section 5.1, the questions and problems which students faced in the pre-class video is in fact an essential ingredient to boost the quality of the following-up in-class activities. Those problems provide the raw materials for students to investigate and verify in the practical work and discussion. It does not only give students the direction to learn but also providing them the meaning of the learning. On the other hand, one of the most important element in learning by teaching is the Q&A section as it could contributes to several essential 21st century skills such as creativity (via Table 5). As seen by the study in Chapter Four, students did not have much to ask in simple learning by teaching approach if the content was delivered to the student-teacher by the teacher. In contrast, student-teacher received quite a lot questions to answer in the flipped learning by teaching approach in the study in Chapter Three. As revealed by the student-teachers, the lack of immediate feedback in the pre-class section using video is to be blame. It seems to be a disadvantage but it is in fact necessary for the success of flipped learning by teaching on second thought. The questions or problems generated in the pre-class section are the essential ingredient to facilitate the Q&A section. Figuratively speaking, the flipped classroom could provide the fuels for the engine (eg. practical work, discussion and learning by teaching) to function effectively. In further elaboration, flipped classroom could unleash the potential of the traditional teaching and learning approach for effective STEM education.

5.3. Limitations

To avoid duplication, the limitations specific to each study will not be covered in this section again. However, it is still worthy to declare the threats due to small sample sizes again because it may affect the generalization power of this chapter as well as this dissertation. Due to the difficulties in conducting the studies at the same time, the studies were arranged and were conducted in order. Although participants in Chapter Three and Chapter Four are selected from the same group of students (different classes), study in Chapter Three was conducted some time later and was conducted when they were enrolled in university. It also affect the generalization power although participants were selected from the same population.

5.4. Further Study

To enhance the generalization power of this dissertation, further studies (especially quantitative studies) are suggested to be conducted using participants with different cultural backgrounds, different age groups and different education levels. Repeated studies consists of quantitative research method is also suggested due to the limited power of the qualitative methods adopted in this dissertation.

Chapter 6. Conclusion

6.1. Summary

STEM education is important but conducting STEM lecture is challenging. Educators believed that there are some teaching approaches (such as practical work, discussion, learning by teaching etc.) which are effective in STEM education. However, teachers are reluctant to apply them into their teaching due to some operational difficulties. To improve the current situation, flipped classroom is suggested.

In this dissertation, two innovative approach named as FPD and flipped learning by teaching were suggested. As new attempts, qualitative studies were conducted to investigate the possibility, feasibility and the possible outcomes of such integrations and the details were shown in Chapter Two and Chapter Three respectively.

As indicated by the results, flipped classroom was compatible with practical work and discussion as well as learning by teaching. FPD and flipped learning by teaching were not only theoretically but also practically effective in fostering students' learning in STEM. Further investigations revealed that integrating flipped classroom may retain and strengthen the existing advantages of the practical work and discussion as well as learning by teaching. It also suggested that the use of video, which was considered as a weakness of the use of simple flipped classroom, was an essential ingredient in boosting the effects of practical work, discussion and learning by teaching. Figuratively speaking, the problems of using pre-class video served as the fuels for the engine (eg. practical work, discussion and learning by teaching) to function effectively. Eventually, FPD and flipped learning by teaching could result in a bigger gain than using those elements (eg. Video, practical work, discussion and learning by teaching) independently.

6.2. Impacts to educators

Perhaps one of the greatest importance of this dissertation is that it indicated that flipped classroom could unleash the potential of traditional teaching and learning approach in STEM education. By integrating flipped classroom, practical work, discussion and learning by teaching would become more effective in fostering students' learning in STEM education. Educators would apply the FPD and the flipped learning by teaching in their STEM lessons to enhance student's understanding as well as their 21st century skills.

More importantly, the success of this dissertation also suggests the possibility of the integration of flipped classroom with other traditional teaching and learning approaches. It is worthy to investigate further in this aspect as the improvement in some 21st century skills (such as critical thinking skills) are still unclear. It also engenders the study of the relevant integrations for other disciplines as well. Eventually, it leads to a new era of new innovative approaches enriched by flipped classroom.

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