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ORIGINAL RESEARCH

How Does Flipping Classroom Foster the STEM Education: A Case Study of the FPD Model

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Abstract
STEM education is essential but challenging. Educators generally believe that both practical work and flipped learning 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 learning allows teachers to spend more in-class time on individual guidance and feedbacks. This study aims at studying the mechanism of how they could benefit STEM education and their interactions when used together. In this study, a strategy called flipping–practical–discussion was employed in a STEM lesson among twenty senior high school students in 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 flipping 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.

Keywords STEM education · Practical work · Lab activity · Flipping classroom · Discussion · Lever system

1 Introduction

1.1 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 et al. 2004; Sanders 2009). The four strands of STEM are defined as:

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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 n.d.).
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 twenty-first-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).

1.2 Why is STEM Education Important?

Apart from cultivating students' interest and providing them with knowledge in Science, Technology, Engineering 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 et al. 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 flipping 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 flipping classroom, this article intends to investigate how this approach, when combined with practical work and discussion, contributes to STEM education.

2 Literature Review

2.1 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 et al. 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 et al. (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 paper, 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.

2.2 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 et al. 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 et al. 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 et al. 2008; Pellegrino et al. 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 et al. 2005; Mehalik et al. 2008) and the conceptual change following design failure as students have to redesign the product (Lehrer et al. 2008). Yet its effectiveness is still inconclusive (Baumgartner and Reiser

1997; Fortus et al. 2005; Mehalik et al. 2005, 2008; Penner et al. 1997; Penner et al. 1998; Sadler et al. 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, have to be provided (Fortus et al. 2005; Nathan et al. 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. As a consequence, students are given no chance to associate the theoretical knowledge with real life problems or practise them.

2.3 What is Flipped Learning and Flipping Classroom

Recently a relatively new and popular pedagogy called flipping classroom (also called the inverted classroom) has aroused our interest (Mzoughi 2015; Sahin et al. 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."

Flipping classroom includes a lecture completed before class and homework finished in-class too (Bergmann and Sams 2012; Pierce and Fox 2012; Roehl et al. 2013). However, a simple re-ordering of teaching and learning activities cannot fully showcase the practice of flipping classroom approach (Lo and Hew 2017a). Actually, the activities made up of asynchronous web-based video lectures and closed-ended problems or quizzes represent all the instructions students ever get. It represents an expansion of the curriculum (Bishop and Verleger 2013). As defined by Bishop and Verleger (2013), "flipping 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).

2.4 Flipping and Science Education

Studies show that the teaching and learning effectiveness in science lectures could be enhanced by using flipping (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 et al. 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).

2.5 Flipping and Technology

Educators in the field of technology are now working on personalizing the instructions to facilitate students' learning. Flipping might be a sensible approach as it meets the learning needs of individual students (Keefe 2007). Davies et al. (2013) examined the learning effect of 207 students of introductory-level college course on spreadsheet and found that flipping 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 flipping 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 flipping among teachers, this strategy still deserves careful consideration as it could engender a better teaching and learning environment (Amresh et al. 2013; McLaughlin et al. 2016; Shnai 2017).

2.6 Flipping and Engineering

Educators of engineering believe that flipped approach is a revolution in engineering education (Le et al. 2015). Although its effect on academic performance is not obvious, it could activate students and encourage their interaction in class (Kanelopoulos et al. 2017; Warter-Perez and Dong 2012). However, not every student could benefit from it. Since the flipping 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).

2.7 Flipping and Mathematics

Akin to the effect on science, technology and engineering, flipping 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 et al. 2017). Flipping 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).

2.8 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, Statistics and Electrical Engineering courses at The University of New South Wales (Catchpole 2015). Talley and Scherer (2013) flipped the STEM courses and reported that flipping 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).

3 Methodology

3.1 FPD (Flipping–Practical–Discussion) Model

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.

3.2 Why Flipping 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 flipping, 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 et al. 2015) as well as student perception, engagement and satisfaction in learning progress (Gilboy et al. 2015; Gross et al. 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.

3.3 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."(p. 8) Using practical work could be effective in teaching STEM education (Abrahams and Reiss 2010; Thair and Treagust 1997). For instance, Kontra et al. (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).

3.4 Why Discussion?

Discussion is a popular strategy applied in flipping (see Adams and Dove 2016; Bhagat et al. 2016; Hwang and Lai 2017; Wasserman et al. 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.

3.5 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. Flipping, 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 Fig. 1 as below.

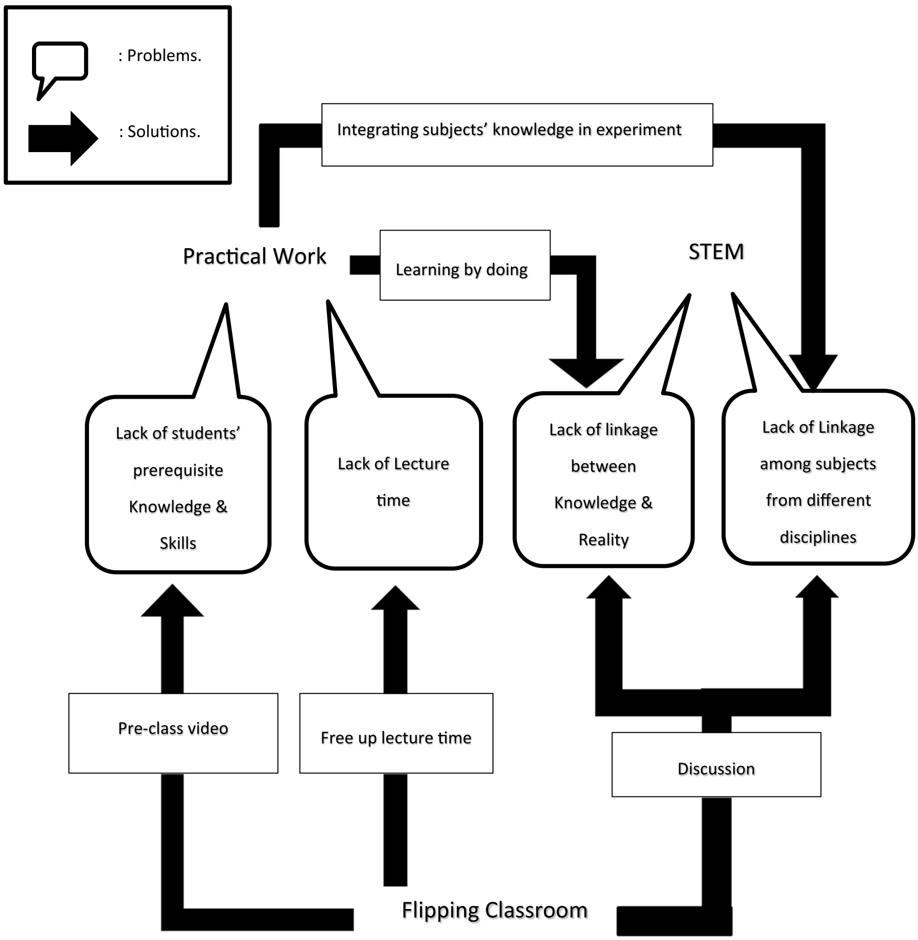


Fig. 1 Framework of the FPD strategy

4 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 flipping 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 et al. 2018). The underlying mechanism of the flipping pedagogy might serve as a milestone for further improvement of STEM education.

5 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 flipping 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?

6 Research Method

6.1 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 16–17 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.

6.2 Intervention

6.2.1 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 1-h 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, flipping classroom is used instead of other materials (e.g. 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 2 days before the class, leaving them with sufficient time to prepare.

6.2.2 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 min 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").

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 (e.g. See Task 2 in "Appendix"). 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 5 min, a summary was made and the teacher presented a typical answer for each task.

6.3 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 min. 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,

Table 1 Summary of the individual interviews

Categories	Coding	Frequency of coding	Number of sources[a]
Effect of flipping 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
	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

Table 1 (continued)

Categories	Coding	Frequency of coding	Number of sources[a]
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

Representing the number of participants who contributed to the corresponding code their response is recorded as transcripts and coded. Summary of the coding is shown in Table 1 in the result section.

7 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. Consiciousness 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.

8 Result

8.1 RQ1: How do Students Perceive the FPD Lecture in STEM Education?

8.1.1 Flipping Classroom Enhances the Quality of Instruction

All interviewees agree that flipping 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.

8.1.2 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 memeoring, 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.

8.2 RQ2: What are the Interactions Within FPD?

8.2.1 Flipping 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.

8.2.2 Flipping 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.

8.2.3 Practical Work with Discussions Promotes 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 through 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.

9 Discussion and Further Elaboration

9.1 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

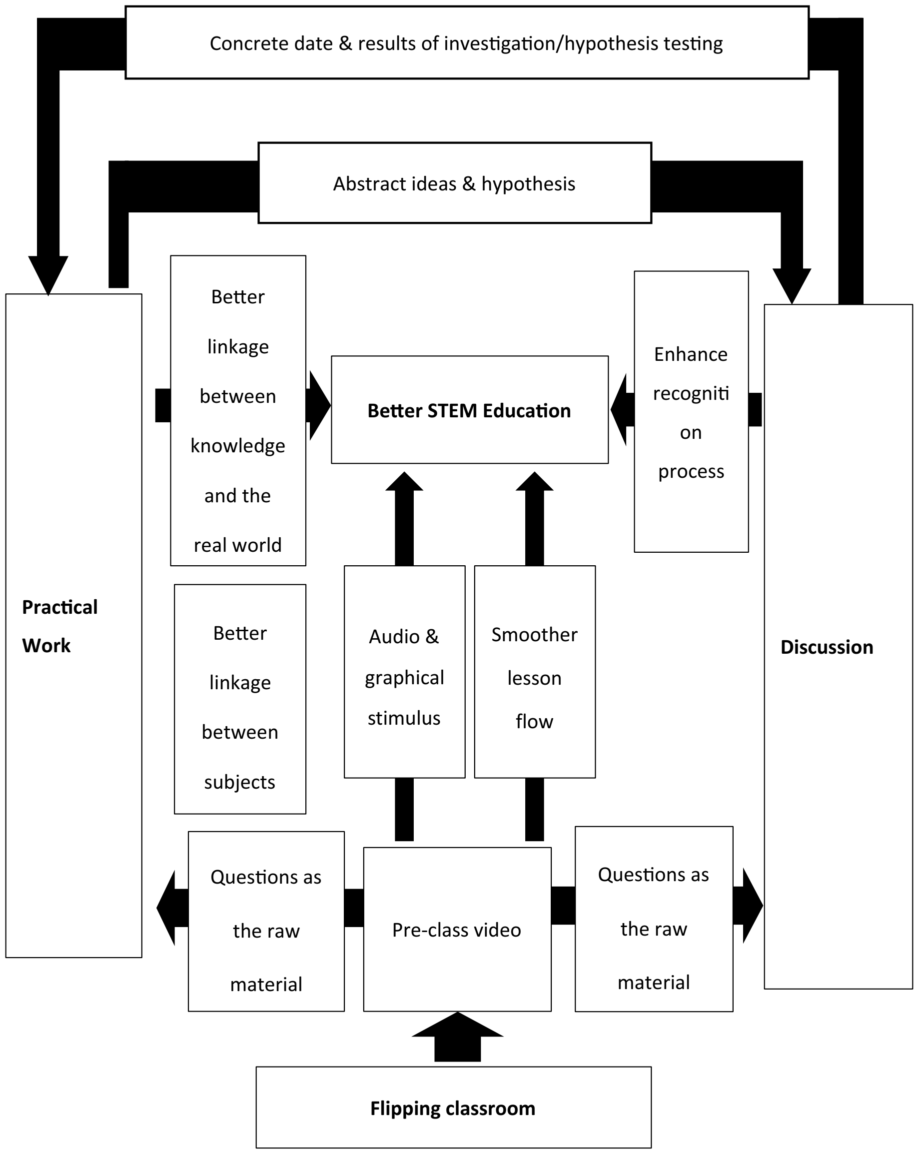


Fig. 2 Revised framework of the FPD model

"learning by doing" experience reduces the anxiety among the students which affects their perceived class duration.

9.2 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.

9.3 Turning Weaknesses into a Strengths

Recently, playing video is a frequent pre-class activity used by the researchers on flipping classroom (Adams and Dove 2016; Chen et al. 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.

9.4 Flipping 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 is no longer a headache and teachers could focus more on individual learners and monitor the progress, all of which improves the quality of the lecture.

9.5 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 3 days or more before, some content will be lost”. The optimum time for announcing the video is believed to be 2 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.

10 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.

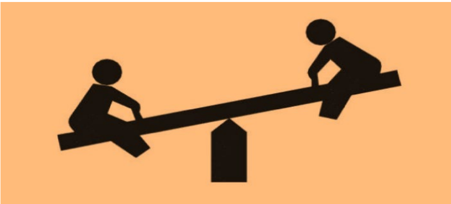
With the advance of computer and information technology, flipping classroom might help. By integrating flipping, practical work and discussion into the FPD model, those dreadful problems might be solved. Discussion could now be conducted in parallel with the practical work without occupying any additional 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.

11 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.

Appendix: Student Worksheet

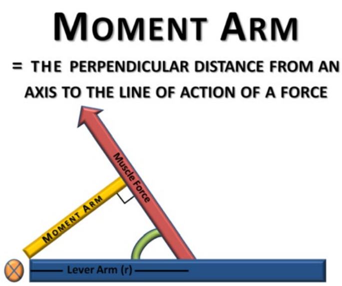
Class:____________ Name: ______________________ Date: ____________



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

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.



<u>Teacher's Demo</u>

Equipment:

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

Experimental Set-up:

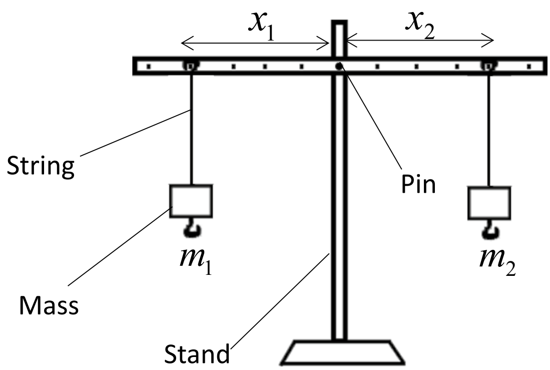


Diagram 1: experimental set-up of moment investigation

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. (eg. 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:

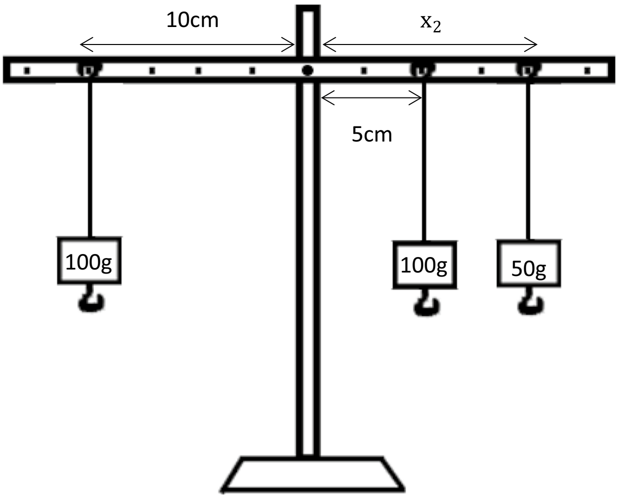


Diagram 2

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:

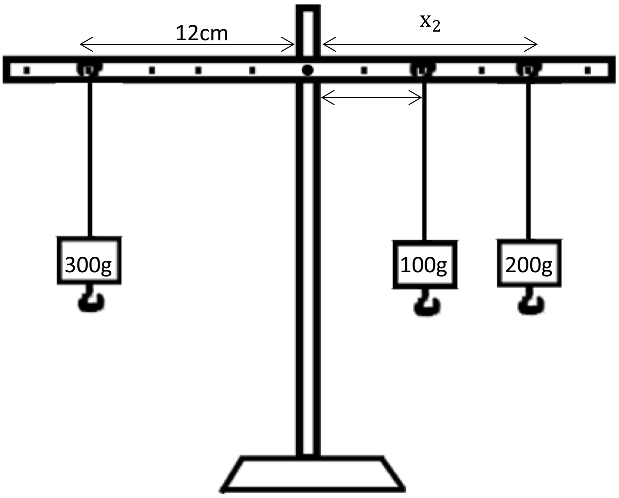


Diagram 3

Procedure

⑧ Set up the equipment according to diagram 3

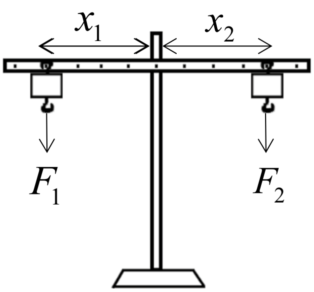
⑨ Vary x_2 until an equilibrium is reached

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 …

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