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Fostering student teachers' 21st century skills by using flipped learning by teaching in STEM education

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Abstract

In recent decades, STEM has received wide attention in education and educators have been seeking effective approaches for STEM education. Learning by teaching could be a potential solution as it could help students develop 21st century skills. However, the high time cost and lack of relevant knowledge create a great barrier to its users and make the approach unpopular. Thus, this study aims to investigate how flipped learning by teaching could foster STEM education through the improvement of students' understanding and their 21st century skills. By using seven-12 minutes pre-class video followed by 40-minute in-class sections, result suggested that flipped learning could contribute to students' understanding, learning interest, creativity, and soft skill sets in 21st century skills. In view of its merits, flipped learning by teaching could be considered as an effective approach for STEM education.

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

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). The education of this subject is aptly 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 & Knowles, 2016, p. 3). Due to its significant contribution to the society, it was soon adopted by many educators and integrated into the curriculum in the education systems of different countries (Bureau of Labor Statistics, 2008; Marshall, 2015; National Science Board, 2018). The intensification of global competition is one of the potential factors which result in the launch of STEM education program in the United States (Chesky & Wolfmeyer, 2015). Current research reveals that 75% of the positions are suited for employees who are equipped with STEM knowledge and skills (Becker & Park, 2011) while the employment growth rate of the STEM industry is nearly twice faster than others (Craig et al., 2012). Due to its effectiveness in boosting national economic growth, STEM education program continues to spread out and develop in many countries (Australian Industry Group, 2013).

However, conducting a STEM lecture is not an easy task (Sujarwanto et al., 2021; Thomas & Watters, 2015). According to the National Academy of Engineering (NAE) and National Research Council (NRC) (NAE & NRC, 2014), 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 are the major challenges in practice. Meanwhile, the shortage of teacher training and support is another obstacle. As revealed by a survey, almost half of the K-12 in-service teachers are not ready for STEM education (Geng et al., 2019). Teachers in the frontlines are ill-prepared for STEM teaching (Dong et al., 2019; EL-Deghaidy et al., 2017). Even though they are enthusiastic to teach, the absence of effective STEM teaching technique is a great obstacle hindering the effectiveness of their teaching (Rogers & Ford, 1997).

Although one of the main objectives in STEM education is to develop students' 21st century skills (Honey et al., 2014), frontline STEM teachers are not fully familiarized with appropriate pedagogies in achieving them (Hong Kong Federation of Education Workers,

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Contribution to the literature

- Flipped Learning by Teaching could foster students' understanding and 21th century skills, especially creativity. Thus, it is an effective approach for STEM education.
- Flipped Learning by Teaching could enhance students' satisfaction during learning.
- Metacognitive development during the creation of teaching materials may be the key for success.

2017). Under such a context, a relatively new teaching and learning approach called flipping classroom is now gaining popularity (French et al., 2020; Han & Røkenes, 2020; Julia et al., 2020; Mzoughi, 2015; Walsh & 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 & Phillips, 2015; Priyaadharshini & Sundaram, 2018; Ye et al., 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 among undergraduate student teachers.

LITERATURE REVIEW

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, problem-solving skills so that they could be more marketable in the workforce (Butz et al., 2004; Sanders, 2009). The contribution of this subject to students' development is well-recognized and therefore its education is now gaining acceptance in the field (Australian Industry Group, 2013).

However, the status quo of its implementation is far from satisfactory (Thomas & Watters, 2015). Current studies reveal that the lack of teaching and learning materials, laboratories, students' motivation and appropriate teaching and learning pedagogies are the main hindrance (Bosman & Schulze, 2018; Hong Kong Federation of Education Workers, 2017; Mutambara & Bayaga, 2021; NAE & NRC, 2014; Shernoff et al., 2017). Among them, the inefficiency of conventional face-to-face lectures is most problematic in developing a deep STEM learning experience (Bosman & Schulze, 2018). Given the mounting pressure of examinations and administrative work, it is understandable that frontline teachers have to resort to conventional teaching approaches, which focus heavily on introducing exist knowledge and seeking correct answers to problems, rather than implementing STEM-related activities (Dong et al., 2020; Shernoff et al., 2017). Despite its directness in delivering knowledge, conventional classroom is usually less effective in empowering students with 21st century skills than other approaches (e.g., Alwi, 2020; Lamichhane & Karki, 2020).

Its widely used lecture mode of teaching cannot meet the demands STEM education, which aims at developing students' innovation, creativity, diversified thinking as well as their communication skills (Shu & Huang, 2021). To cope with this challenge, flipped classroom with learning by teaching (thereafter called flipped learning by teaching) is suggested.

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 the traditional lecture-assignment sequence into an assignment-lecture sequence (Crouch & Mazur, 2001; Mazur, 1997). More in-class time could now be spent on meaningful activities and individual consultation by shifting the instructional content to the pre-class section while the in-class time could be freed for explaining difficult mathematical concepts, working on problems with guidance and discussion (Delozier & Rhodes, 2017). As a result, flipped classroom could greatly enhance students' understanding as well as their academic performance (Mzoughi, 2015; Pfennig, 2016; Sun & Wu, 2016; van Alten et al., 2019; Wagner et al., 2021). It is thus widely used in science (Asiksoy & Ozdamli, 2016; Deslauriers et al., 2011), technology (Amresh et al., 2013; Davies et al., 2013; McLaughlin et al., 2016; Shnai, 2017; Yildiz Durak, 2018), engineering (Kanelopoulos et al., 2017; Le et al., 2015; Warter-Perez & Dong, 2012), and mathematics education (Dove & Dove, 2017; Graziano & Hall, 2017; Lee, 2017; Lo & Hew, 2017b; Lo et al., 2017; Zengin, 2017).

In spite of its apparent effectiveness (van Alten et al., 2019), researchers are skeptical about the effect of flipped classroom if it is used without interactive in-class elements (Lo & Hew, 2017a). This is echoed by current 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 (via Bhagat et al., 2016; Buch & Warren, 2017; Hwang & Lai, 2017; Lo & Hew, 2017b; McGivney-Burelle & Xue, 2013; Sahin et al., 2015; Song & Kapur, 2017; Yousefzadeh & Salimi, 2015; Zengin, 2017). It is suggested that the values of flipped classroom do not lie in simple re-ordering of the lecture and homework section, but in the use of in-class interactive elements, which may be an essential factor in determining the success of flipped classroom (Fung, 2020). Thus, flipped classroom is defined as a teaching and learning approach which employ an assignment-lecture sequence for interactive in-class elements, such as discussion, feedbacks and peer-collaborative work etc.

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 observing and 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 with sound theoretical foundation (Stollhans, 2016; Zhou et al., 2019). When required to teach a topic in front of his/her peers, students have to select and screen the relevant knowledge, focus, organize and present it in a meaningful way (Torshizi & Bahraman, 2019; Zhou et al., 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; Zhou et al., 2019). More importantly, students have to externalize the content and knowledge using his/her own language during the teaching process. According to Vygotsky's (1978a) theory, the connection between speech and thoughts is explicit and profound. 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, particle and electromagnetic radiation, the understanding of the radioactivity process at microscopic level and the linkage to daily life problems) was improved significantly.

In the meantime, 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 some IT tools such as PowerPoint), their presentation skills, communication skills, self-confidence and computer literacy were improved (Grzega & Klüsener, 2011; Pahl, 2019). In the long run, accomplishing the high-level learning objectives of Bloom's taxonomy, such as synthesizing, evaluating, and creating is made possible since the foundation of knowledge is consolidated (Fiorella & Mayer, 2013).

However, the implementation of learning by teaching is very challenging (Hutagaol-Martowidjoyo & Adiningrum, 2019; Zhou et al., 2019). For instance, class preparation is time-consuming, and it requires a lot of efforts in material preparation (Hutagaol-Martowidjoyo & Adiningrum, 2019). Meanwhile, teaching is obviously a very complex task to students because both subject knowledge and proper teaching pedagogies are required for effective teaching (Shulman, 1986, 1987; Zhou et al., 2019). Given the limited time for preparation, it is challenging for students to become fully familiar with the necessary knowledge and thus misconception and misunderstanding may appear (Aslan, 2015). Without an effective solution, the above challenges would become a great barrier to users and defeat the advantages of the use of learning by teaching.

How Do 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 it is used with learning by teaching. Yet, one of the biggest challenges in implementing learning by teaching is students' lack of pre-requisite subject content knowledge for classroom teaching (Shulman, 1986, 1987; Zhou et al., 2019). As a result, extra time must be spent in equipping students with fundamental knowledge before teaching, which potentially prevents teachers from choosing this teaching method despite its effectiveness. To compensate for the problem, flipped classroom familiarizes students with the necessary knowledge by using the pre-class video without causing additional burden (Fung, 2020). On the other hand, the number of students who would profit from traditional learning by teaching 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 et al., 2020), the lesson flow can be facilitated and learning by teaching is made more feasible. This combination of flipped classroom and learning by teaching could potentially 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 to be one of the most defining characteristics 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 subject knowledge based examination (Fung & Poon, 2020; Honey et al., 2014; Shu & Huang, 2021). Ng and Fung (2020) systematically reviewed about 11,000 websites of secondary and primary schools and found that the cross disciplinary nature did occupy a very little portion in their expected outcomes. This runs contrary to the popular belief among educators 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 the frontline is urging to have an effective teaching and learning technique for effective STEM education (Rogers & 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. Therefore, the following research questions are developed to investigate how flipped learning by teaching contributes to STEM education and to discover the mechanism beneath it.

RESEARCH QUESTIONS

1. How could flipped learning by teaching foster STEM education though the improvement of students' understanding and memory?
2. How could flipped learning by teaching foster STEM education by developing students' 21st century skills?
   A. How could it enhance students' problem-solving skills?
   B. How could it enhance students' creativity?
   C. How could it enhance students' communication skills?
   D. How could it enhance students' computer literacy?
3. What other benefits, in addition to the development of 21st century skills, could be attained by using flipped learning by teaching?

RESEARCH METHOD

Demographic Information

Considering the efficiency of convenient sampling and its power in eliminating some practical constraints, such as geographical location, this sampling method was adopted in this study (McMillan & Schumacher, 2010). Five undergraduates who were studying in universities in Australia were selected. The subjects, consisting of three males and two females, were all aged between 19 and 20. Three of them majored in data science, while the others were commerce and software engineering students. The participants in this study received their pre-tertiary (primary and secondary) education in China (Confucian heritage culture, CHC) for more than 17 years and chose to study abroad in in Australia, a country with significantly different educational culture. Therefore, unlike other local students in China, they were considered as "relatively familiar with both Eastern and western educational culture" and "relatively open to innovative teaching and learning approach".

Preparation, Pre-Class, and In-Class Section

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

In terms of length, all videos used in this study were seven to twelve minutes long, which was based on previous findings that neither an excessively short nor an excessively long video was appropriate for use in flipped classroom (Dove & Dove, 2017; Lo & Hew, 2017b). The videos were distributed to the students three[1] days before the class to leave them with sufficient time for the 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 1**), all of which required substantial mathematics, physics as well as engineering knowledge. The PowerPoint should contain the content knowledge as well as a sample question with a corresponding solution.

The whole 40-minute in-class section was conducted using zoom due to the restrictions of the social contact under the spread of COVID-19. It was divided into five mini-lecture sessions. Students were required to teach in

[1] Videos were originally scheduled to be distributed two days in advance. However, they were distributed one day earlier per students' request.

Table 1. Topics used & their corresponding description of content

Topics	Description	Video link
Viscous drag forces	-Understand viscous/drag forces including air resistance -Understand that objects moving against a resistive force may reach a terminal (constant) velocity	https://www.youtube.com/watch?v=HVdCyCf7eG8
Hydrostatic pressure	-Derive, from definitions of pressure & density, equation for hydrostatic pressure $\Delta p=\rho g\Delta h$ & application of equation $\Delta p=\rho g\Delta h$	https://www.youtube.com/watch?v=kkq8ruV8_Jw
Kinetic energy	-Derive, using equations of motion, formula for kinetic energy $E_K=1/2mv^2$	https://youtu.be/kA5-6eqwS2g
Drift velocity	-Use, for a current-carrying conductor, expression $I=Anvq$, where n is number density of charge carriers	https://youtu.be/-KM5bq0O48o
Resistivity	-Resistance & resistivity -Recall & use $R=\rho L/A$	https://www.khanacademy.org/science/physics/circuits-topic/circuits-resistance/v/voltmeters-and-ammeters?utm_source=YT\u0026utm_medium=Desc\u0026utm_campaign=physics

Table 2. 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 does not know how to respond, (3) When a student-teacher overruns, (4) When a student misbehaves, such as being noisy, & (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 (i.e., 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 misleading or will limit the scopes of the data mining[2], (4) When a student misbehaves, such as being noisy, & (5) When a student encounters a technical problem,

turn and their order was decided and announced by the researcher at the beginning of the lecture. To eliminate the uncertainty due to language problem, students were free to use their mother language to express their idea during their teaching. Class was dismissed after the completion of mini lectures and no homework was assigned, which ensured that the total length of learning in this study is comparable to traditional 40-minute lectures with seven to twelve minutes homework.

Assessment Tool and Data Collection

To increase the validity of this research with triangulation of data, observation and focus group were selected as the assessment tools for this study. The observation spanned from the pre-class section to the in-class section. Although some important information was not accessible as face-to-face contact was restricted due to the COVID-19 epidemic, 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 beginning of the study that both the in-class section and the focus group section would be videotaped. The events and content of the question were noted and recorded (via **Appendix A**), while the interviews, which was 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 and conducted in the next day after the completion of the in-class section. Since the participants had no prior experience in a focus group meeting, a two-minute introduction was given, and the common practice was described.

Objectives and the research questions were introduced (via **Appendix B**) so that the discussion would be on the right track. Participants were notified that they could discuss and express their views freely as long as these views are important or relevant to this study. For details of the research flow please refer to **Appendix C**.

The role of researcher remained passive during the whole intervention. To ensure a fair result, his main duty was to set the topics, to determine the research flow and to monitor the research progress. He interrupted only if one of the following scenarios arose (via **Table 2**).

[2] 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 exploring, distinguishing or classifying it from their real experience.

Table 3. Mechanism of flipped learning by teaching enhances STEM education

Category	Item	R (F)[a]	O (F)[b]	Main content/idea
Flipped learning by teaching approach is helpful to STEM education	Flipped learning by teaching fosters understanding	1.0 (4)	A (4)	(1) It allowed students to gain exposure to knowledge for four times (during video watching, material preparation, teaching, & Q&A section), (2) More in-depth learning achieved & better memory of content knowledge, (3) By developing teaching materials such as organizing points & preparing PPT, blind-spots could be cleared, & (4) Understanding was enhanced.
	Flipped learning by teaching fosters problem-solving skills	1.0 (1)	A (1)	(1) Answering unexpected questions from others allowed students to review & organize content because it required them to think, plan, & organize steps to solve problems.
	Flipped learning by teaching fosters communication skills	1.0 (3)	A (3)	(1) Solving other's problems required uses of communication skills, (2) Communication skills were enhanced because whole teaching was basically (similar to) a discussion, & (3) Explaining abstract ideas required communications skills.
	Flipped learning by teaching fosters creativity	.67 (6)	A (4)	(1) Organizing lesson was main reason for improvement of creativity, (2) Regarding STEM, understanding is very important. It is impossible to apply knowledge of these subjects without understanding them in advance, (3) If students encountered a difficulty, student-teacher should try a new approach. These skills could not be learnt from a traditional classroom, (4) A good knowledge foundation would allow us to draw inferences about other cases from one instance. In meantime, it allowed us to discover, elaborate, link, & apply them in our daily life. These are all practices of creativity, (5) Through process of developing materials, connections between fact-based knowledge & daily life could be observed. It inspired students to explore & try to develop some solutions (about learning content) in daily life.
			D (2)	(1) The improvement of creativity is limited & (2) A simple use of model would not enhance creativity.
	Flipped learning by teaching fosters logical thinking	1.0 (2)	A (2)	(1) If a student had to teach others, he must list pre-requisite knowledge, define items, construct equations, & demonstrate how to use those equations & knowledge to solve problems. This was a good training in logical thinking & (2) student-teacher had to (i) extract key information, (ii) explain concepts fluently, & (iii) understand logics behind content.
	Flipped learning by teaching fosters learning interest	1.0 (3)	A (3)	(1) Helping others understand abstract knowledge gave us a strong sense of satisfaction, (2) Active learning offered much higher level of satisfaction than spoon-feeding education, & (3) Since we could choose a topic of our own interests, we were highly motivated & fascinated by the idea.
	Flipped learning by teaching fosters computer skills	1.0 (1)	A (1)	(1) During preparation process, software, such as PPT, was used. It allowed us to practice our computer skills.

Note. R: Reliability; O: Opinion; F: Frequency; A: Agree; D: Disagree; [a]Total number of agreements & disagreements; & [b]Number of students who expressed an agreement/disagreement

Data Handling and Data Analysis

Data from the observation and focus group meeting was translated into English scripts in **Appendix A** and **Appendix D**, 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. If keywords of relevant items of understanding and 21st century skills (such as problem-solving skills) is identified, the relevant paragraph will be put into further analysis. 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, as follows (Miles & Huberman, 1994):

Reliability=Agreements/(Agreements + Disagreement).

In addition, if a student expressed that he agreed with a point with certain conditions, his/her opinions will be counted in both agreement and disagreement. However, when statements were repeated, rephrased or further elaborated previous statements, they counted once only. For instance, the student's suggestion that "discussion may be added at the end of the teaching to provide monitoring effect" and his/her statement suggesting that "learning diversity could be solved by discussion" were regarded as identical and both categorized as "discussion should be added" because the second statement is an elaboration of the first one. The result was presented as **Table 3** and **Appendix E**.

Ethic 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. Meanwhile, students from CHC may show more respect to their teachers and avoid making disagreements. Therefore, the researcher emphasized the importance of expressing their real feelings and participants were also given complete freedom to quit at any stage of the experiment whenever they felt uncomfortable to continue with this study.

RESULTS

Flipped Learning by Teaching Fosters Students' Understanding and Memory by Achieving Higher Degree of Engagement

According to **Table 3**, one of the most obvious benefits of using flipped learning by teaching 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 watching video, course material preparation, in-class teaching to the in-class Q&A section, students are exposed to the learning content four times.

In the meantime, one of the commonly found problems in traditional teaching is that students believe they have fully mastered the learning contents, but in reality they have not. This undesirable situation could be minimized with the use of flipped learning by teaching. 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."

Flipped Learning by Teaching Fosters Students' Logical Thinking and Problem-Solving Skills

As indicated by the participants, the class preparation and the Q&A section contribute to students' logical thinking and problem-solving skills. In accordance with the description from student C on the process of flipped learning by teaching, "student teachers have to

(1) extract the key information,

(2) translate them into their own words, and

(3) help (audiences) understand the logics behind the 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 the problems. In the meantime, questions and challenges may arise during the Q&A section. To answer these unexpected questions, student teachers must review the content, plan and develop strategies to cope with the challenges, which offers them the opportunity to cultivate their logical thinking and problem-solving.

Flipped Learning by Teaching Fosters Students' Creativity

Although participants were generally in favor 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 flipped learning by teaching. Advocates of this claim maintain that a more thorough understanding is root cause for the improvement. Since STEM is a complex acronym consisting of four different disciplines, it is very unlikely to apply the STEM knowledge without fully understanding them in advance. The solid knowledge foundation developed by flipped learning by teaching allows students to draw inferences about other cases from one instance and to discover, elaborate, link 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, flipped learning by teaching 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, flipped learning by teaching may provide seven benefits, which are re-organized according to the active components of flipped teaching by learning (**Table 4**). It can thus foster STEM education by promoting students' 21st century skills in some aspects. They are summarized in **Figure 1**.

Flipped Learning by Teaching Fosters Students' Communication Skills and Computer Literacy

In addition, participants find that flipped learning by teaching is particularly useful in enhancing their communication skills. To deliver a course, the student-teacher has to first understand the content (i.e., abstract ideas) well and transform it into his/her own words.

Table 4. Mechanism of flipped teaching by learning benefits students

Section of flipped learning by teaching	Active component	Actions	Students' improvements in …
Pre-class section	Watching video	-1st engagement of the materials	-Understanding
	Class preparation	-2nd engagement of the materials	-Understanding
		-Clearing blind-spot -Organizing of the lesson (such as demonstration of two different methods to solve 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 strategies to respond to unexpected questions	-Problem-solving skills -Communication skills
		-The use of alternative methods	-Creativity

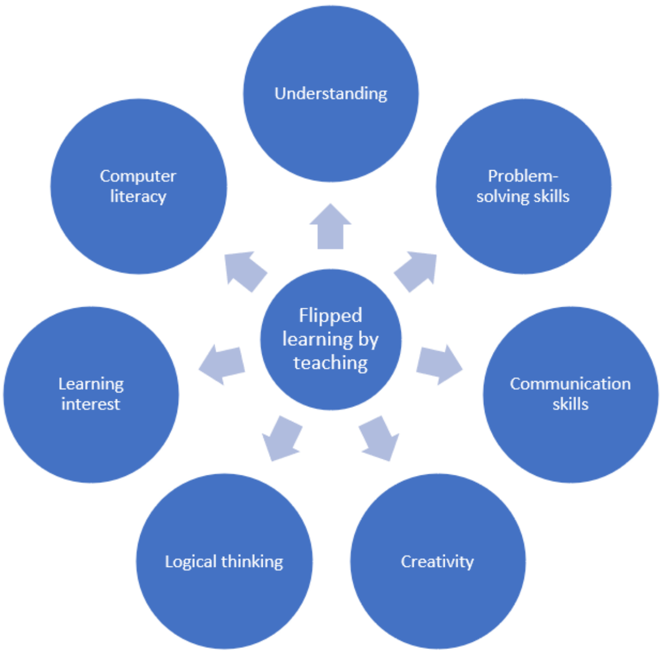

Figure 1. Seven benefits of using flipped learning by teaching (Source: Authors' own elaboration)

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 answer 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 low EQ and inadequate communication skills may just be stunned and freeze at that moment (student A).

In the meantime, since computer software (such as PPT) was used as the teaching instrument, the process of teaching is indeed a practice of using computer tools for effective communication. As a result, students' communication skills and computer literacy could be improved due to the enriched teaching section in flipped teaching by learning.

Flipped Learning by Teaching Fosters Students' Learning Interest

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

DISCUSSION

Metacognition Development in the Creation of the Teaching Material May Be the Key to Success

Aligning with a systematic review conducted by Lachner et al. (2022), this study suggested that the preparation of lessons may be one of the main factors for the improvement of understanding and higher-order thinking skills in learning by teaching. A recent meta-analysis conducted by Ribosa and Duran (2022) further confirmed this idea. A significant improvement was found (ρ=.013) among students who created teaching materials compared to those with business-as-usual interventions. As revealed by this study, the development of the material could help students clear their blind spots, facilitate their organization of content materials, and widen their possible methods to reach solutions. As a consequence, planning (one of the main components of metacognition) is enhanced, and thus better performance could be expected (Fung, 2019).

May Metacognition Be Related to Creativity?

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

Good Medicine for Health Tastes Bitter

Echoing studies conducted in the past (e.g., Aslan, 2015; Fung, 2019; Hutagaol-Martowidjoyo & Adiningrum, 2019), results in this study also reveal that teaching by learning is a very time-consuming strategy from students' perspective. Teachers may also encounter confusion and misunderstanding during the teaching section. However, participants did provide interesting comments as they believed the time spent is the 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. On the contrary, these steps are already embedded in learning by teaching. For instance, the in-class teaching, and the Q&A section are useful for clearing students' misconception and misunderstanding and thus they are equivalent to checking answers and doing revisions after-class. Although it seems to be more time-consuming, the time spent may indeed be a necessity for the process of learning. In light of these facts, whether learning by teaching is more time-consuming remains inconclusive.

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 and the participants in this study are considered to be familiar with both CHC and western culture, the sample size is relatively small, which could undermine the generalization 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 research, especially those with different measuring instruments, are essential for providing additional evidence in this topic.

CONCLUSION & IMPACTS TO SOCIETY

Throughout past decades, there has been a significant growth in the emphasis on STEM related subjects. Educators have been experimenting with pedagogies that assist in the problem-solving and exploratory learning among students. Learning by teaching seems to be a promising candidate that fuels students' success across a variety of tasks and disciplines. However, the 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 become much better critical thinkers, innovators, and analyzers.

By using seven-12 minute pre-class video followed by 40-minute in-class sections, result revealed that flipped learning by teaching could foster STEM education through the improvement of students' understanding and memory. Meanwhile, flipped learning by teaching is an effective STEM teaching and learning approach as it could develop students' problem skills, creativity, communication skills, computer literacy as well as students' learning interest. Although teaching by learning seems to be time-consuming, the time spent may indeed be a necessity for the process of learning.

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APPENDIX A

Table A1. Summary of observation in chronological order

Date	Participant	Event
5 days before day 1	All	1. Recruitment of the participants completed. 2. A 15-minute 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 & Student D	1. Students would like to get video earlier so that they could have more time for preparation. 2. Videos were thus given one day before original plan.
Day 1	Student D	1. Student asked about the priority among the 21st century skills. Does innovation have the least importance? What is the definition of creativity? Is ability to extend & link content to other topics or daily life a kind of creativity?
Day 4	All	*In-class teaching*
		1. 12:24-In 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 is just a constant." Student A asked again "so, what constant is it and what's the magnitude?" With this unexpected question, student C did not answer directly & tried to find answer from his notes. Finally, student C did not give an exact answer to question & told audience students this is homework for you to figure out what this constant after this class is (communication skills). 2. 27:00-Student B used two approaches to derive the equation of kinetic energy (creativity). For demonstration of deriving KE equation, researcher & student A pointed out a mistake of formula transformation. Student B paid close attention to this feedback (communication [active listening]) & tried to find source of mistake by reassessing derivation process (problem-solving [resilience]). Finally, student B realized his misunderstanding of concepts, & gave a response saying himself is not circumspect enough when solving questions (communication). 3. 30:14-To show the relationships between the force exerted cross-sectional area & pressure with pressure formula learned, student A used two examples computing pressures: fixed cross-sectional with different force & fixed force with different cross-sectional area. Calculations show that with the same area of 1 m, pressure is larger for a force of 200 N than a force of 100 N; with the same force of 100 N pressure is smaller for an area of 2 m^2 than an area of 1 m^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 equations of pressure, student A used equations to solve two sample questions. When solving questions, student A first identified problems. Specifically, how many & what variables need to be computed in a question. Then, she gathered given information (known variables) in questions, followed by applying equations learned to calculate answers (problem-solving [analytical skills]). 5. All students used PowerPoints to present. They highlighted key terminologies, definitions, & equations by different font sizes & colours. Graphics & 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 researcher & expressed that other participants may not be very familiar with STEM.
Day 7	Student A	1. Student texted researcher & expressed that some participants went off topics during meeting. 2. Student believed that other participants may not be very familiar with the 21st century skills such as problem-solving, creativity, etc.
Day 8	Student C	1. Student texted researcher to add supplementary information to clarify his point made in focus meeting.

APPENDIX B

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 are the pros and cons of this learning method compared to traditional direct lecture-based teaching?
7. What are the difficulties of using this approach?

APPENDIX C

Table C1. Detail of the pre-class, in-class, and focus group meeting for each student

	Student A	Student B	Student C	Student D	Student 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 an 8-minute lecture	Being as audience	Being as audience	Being as audience	Being as audience
	Being as audience	Conducting an 8-minute lecture	Being as audience	Being as audience	Being as audience
	Being as audience	Being as audience	Conducting an 8-minute lecture	Being as audience	Being as audience
	Being as audience	Being as audience	Being as audience	Conducting an 8-minute lecture	Being as audience
	Being as audience	Being as audience	Being as audience	Being as audience	Conducting an 8-minute lecture
After intervention (day 5)	~25-minute group interview				

APPENDIX D: 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 do not 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 are 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 five 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 consisting 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 (i) extract the key information, (ii) translate them into language, and (iii) 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 three seconds).

Researcher: I see. Do you think this learning approach is useful in enhancing your learning interest?

Student E & student 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 is 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 consider 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 do not 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 maybe 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 do not 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 do not 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 do not 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 did not 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 do not listen to others' presentations carefully.

Student E: Sensible.

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

All: No.

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

APPENDIX E

Table E1. Summary of the focus group meeting

Category	Item	R (F[a])	O	Main content/idea	Reference
Which teaching method do student prefer	Prefer traditional method	.50 (2)	A	-Teacher can ensure learning is on the right track & student is teaching it right.	B L5-7
			D	-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. --For example, "when student C mentioned about 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 do not 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 education (fostering 21st century skills)	Flipped learning by teaching approach is helpful to study of STEM, understanding increase	1.0 (4)	A	-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 organizing the points and creating the PPT, the blind-spot could be cleared. -Understanding is enhanced	A L21 & E L21, L23-32, B L52-56, C L76
	Flipped learning by teaching approach is useful in fostering problem-solving skills	1.0 (1)	A	-Answering unexpected questions from others allow us to review content we have learnt. During 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)	A	-During the Q&A, we have to think about how to answer or solve their problems. Our communication skills are improved 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. -Communication skills is enhanced for certain because the whole teaching is (similar to) a discussion. -To teach others the abstract ideas requires communications skills.	A L50-51 A L90-97 D L114-115 B L117-118
	Flipped learning by teaching approach is useful in fostering creativity	.67 (6)	A	-Organizing of lesson is main reason for improvement 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 difference between student & teacher. Such difference would lead to a significant improvement in creativity. -Regarding to STEM, understanding is very important. It is impossible to apply knowledge of these subjects without understanding them in advance. -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. -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, & apply them to our daily life. I think these are all creativity. -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.	B L58-59 A L66-72 A L84-89 C L80-81 D L 100-103, L105 D L106-108

Note. [a]Total number of agreements and disagreements; R: Reliability; F: Frequency; O: Opinion; A: Agree; & D: Disagree

Table E1 (Continued). Summary of the focus group meeting

Category	Item	R (F[a])	O	Main content/idea	Reference
Flipped learning by teaching approach is helpful to STEM education (fostering 21st century skills)			D	-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)	A	-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-teacher have to (i) extract the key information, (ii) translate them into language, and (iii) help students to understand the logics behind the knowledge.	E L60-64 C L77-80
	Flipped learning by teaching approach is useful in fostering learning interest	1.0 (3)	A	-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)	A	-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 approach	Difficulty, very time consuming	.33 (3)	A	-Very time consuming. Listening to teacher in direct teaching, is already enough for students who are with low learning incentive & low motivation.	C L128
			D	-Despite the more time is spent, the elements they are spent are parts of learning process. 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. Quality is the point.	D L132-133 L147-153 A L134
	This approach may be more suitable to able students, with higher degree of discipline	1.0 (5)	A	-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. -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 I mentioned before, if I do not 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.	B L142 L261-263 C L270-273 D L172-176 D L185-186 A L276-280 E L281-283 C L284

Note. [a]Total number of agreements and disagreements; R: Reliability; F: Frequency; O: Opinion; A: Agree; & D: Disagree

Table E1 (Continued). Summary of the focus group meeting

Category	Item	R (F[a])	O	Main content/idea	Reference
Difficulty in using flipped learning by teaching approach	Difficulties competition	1.0 (1)	A	-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 do not 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 financial	1.0 (2)	A	-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.	B L191-194
				-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)	A	-When we are watching the video, we will follow the ideas shown in the video to solve the problem. But if I do not 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
			D	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 evaluation	1.0 (1)	A	I think one of the disadvantages 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.	D L221-225
Suggestions from students	After-teaching evaluation	1.0 (1)	A	It would check and evaluate whether we have really mastered this content knowledge.	D L221-225
	Topics should be relevant	1.0 (1)	A	I think the coverage of topics is relatively large as they include mechanics, electricity etc. I suggest maybe 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)	A	-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.	D L236-239
				-Learning difference can be solved by using student's discussion I mentioned before. Able students can help & direct less able students. As a result, for able students, their knowledge can be consolidated. While for less able students, their problems can be solved, & learning is facilitated.	D L286-289
	Able student can help less able student in group work	.33 (3)	A	-Learning difference can be solved by using student's discussion I mentioned before. Able students can help & direct less able students. As a result, for able students, their knowledge can be consolidated. While for less able students, their problems can be solved, & learning is facilitated.	D L286-289
			D	-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.	C L290-294
				-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.	A L295-298

Note. [a]Total number of agreements and disagreements; R: Reliability; F: Frequency; O: Opinion; A: Agree; & D: Disagree

Table E1 (Continued). Summary of the focus group meeting

Category	Item	R (F[a])	O	Main content/idea	Reference
Suggestions from students	Assistance should be provided in lecture preparation	1.0 (3)	A	-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. 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.	B L243-245, L251-255
				-Immediate assistance could be provided in the next session.	A L258-259
				-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.	D L38, S L39
	The role of teacher should be passive	1.0 (1)	A	-The role of teacher should be passive.	D L37

Note. [a]Total number of agreements and disagreements; R: Reliability; F: Frequency; O: Opinion; A: Agree; & D: Disagree