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Using "First Principles of Instruction" to Design Secondary School Mathematics Flipped Classroom: The Findings of Two Exploratory Studies

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ABSTRACT

Flipping the classroom is a current pedagogical innovation in many schools and universities. Although interest in flipped classroom (or Inverted Classroom) continues to grow, its implementation so far has been driven more by teachers' intuitive beliefs, rather than empirically-based principles. Many studies merely replace in-class instructions with videos and use class time for group discussions. But what instructional design framework should we use in planning the overall flipped classroom approach? This paper attempts to answer this question through two exploratory studies conducted in a Hong Kong secondary school. In Study 1, a flipped classroom Mathematics remedial approach was offered for underperforming students (n = 13) in Form 6 (Grade 12). In Study 2, high ability students (n = 24) in Form 6 participated in another flipped classroom Mathematics training approach. Both flipped classroom approaches utilized the *First Principles of Instruction* design theory. Paired t-test results indicated significant learning gains in both groups of students. Based on the suggestions of students and teacher as well as the existing literature, several recommendations for course planning, out-of-class learning, and in-class learning of flipped classroom are proposed.

Keywords

Flipped classroom, Inverted classroom, First principles of instruction, Mathematics, Pedagogy

Introduction

Flipped Classroom is a technology-supported pedagogical innovation which has become popular in recent years. According to Bishop and Verleger (2013), flipped classroom consists of two components: (1) Direct computer-based individual instruction outside the classroom, and (2) Interactive group learning activities inside the classroom. In the out-of-class learning component, students watch instructional videos prepared by teachers. Students thus acquire some basic information before the face-to-face lesson. The in-class time is then freed up for more interactive learning activities such as collaborative problem solving and receiving teacher's individual assistance.

Hamdan, McKnight, McKnight, and Arfstrom (2013) argue that flipped classroom is a feasible strategy which caters to the needs of diverse learners. For example, if students do not understand the materials presented in the video lectures, they can pause or replay the instruction videos for revision. At the same time, high ability students can skip certain parts of the video lectures to save their learning time. As for the face-to-face lessons, since the in-class time is no longer occupied by direct teaching, more time can be spent on the teacher's one-to-one assistance and small-group tutoring for the less capable students (Bergmann & Sams, 2009), or problem-based learning and small-group learning activities which are suitable for high ability students (Matthews & Dai, 2014). However, Hamdan et al. (2013) lament that there is a lack of empirical study that investigates the use of flipped classroom for diverse learners. In fact, most of the existing studies of flipped classroom focused on flipping a particular course (see Bishop & Verleger, 2013; Giannakos, Krogstie, & Chrisochoides, 2014; O'Flaherty & Phillips, 2015 for a review) rather than explicitly examining whether flipped classroom can benefit underperforming or high ability students.

Besides the lack of studies that examines how flipped classroom may help diverse students, there are two other limitations of previous flipped classroom research. First, a majority of studies had been conducted in Western higher education sector (see Bishop & Verleger, 2013; Giannakos et al., 2014; O'Flaherty & Phillips, 2015 for a review). Very few published studies have hitherto focused on the Asian secondary school settings. Contrary to the popularity in the West, Subramaniam (2008) suggested that contemporary education approaches such as online education may not necessarily capture Asian learners' interest and engagement. Some Chinese learners' preference for teacher-centered learning, and classroom learning may adversely affect the efficacy of flipped classroom. In a traditional class, students typically learn about the subject matter through a teacher-led lecture, followed by a teacher-led activity during class time. However, students in a flipped class are required to take more responsibility for their own learning such as watching the video lectures before class, and participating in group problem-solving activities during in-class lessons. Some Asian secondary school students, being typically passive during in-class sessions, barely interacted with other students; they merely sat quietly and waited for the teacher to approach them (Nawi et al., 2015). This therefore raises several intriguing questions: How would students in a Hong Kong secondary school perceive the use of flipped classroom? Would they find the flipped classroom approach more engaging than the traditional classroom instruction method? Our present study aims to address these very questions.

Second, many studies discussed what benefits can be expected from flipping the class (e.g., Fulton, 2012; Gannod, Burge, & Helmick, 2008), but fell short of defining and examining the design principles of flipped classroom (Kim, Kim, Khera, & Getman, 2014) or utilizing a conceptual framework that could guide the design of flipped classroom (O'Flaherty & Phillips, 2015). Currently, the design of flipped classroom has often been limited to the practice of merely replacing in-class instruction with video-recorded lectures and using class time for homework (Kim et al., 2014). But what instructional design framework should we use in planning the overall flipped classroom approach?

The present study aims to extend our collective understanding of flipped classroom in three ways. First, we tested the feasibility of using an instructional design theory – Merrill's (2002) *First Principles of Instruction* to implement flipped classroom. The effectiveness of the "First Principles of Instruction" had been examined in a study undertook by Thompson/Netg, a company that offers learning solutions for individuals, businesses and institutions (Thomson, 2002). Using a three-group experimental design, the investigators found that the group which received instruction developed based on the "First Principles" scored the highest scores than the other two groups. All differences were statistically significant. Further, the "First Principles" group managed to complete three course activities in the shortest time (29 minutes), compared to the group that received the existing commercial version of the company's course (49 minutes), while most of the control group failed to finish the tasks. Studies done by other researchers (e.g., Frick, Chadha, Watson, & Zlatkovska, 2010) have also suggested that the use of First Principles of Instruction can improve students' motivation and learning when compared with other forms of instruction. The First Principles of Instruction design theory therefore provides us with a unique theoretical framework to implement our flipped classroom approach. Second, we extended our study to a Hong Kong secondary school context; more specifically to the teaching and learning of Form 6 (Grade 12) Mathematics. Third, we designed and offered two flipped classroom for underperforming students and high ability students correspondingly. The effectiveness, student perceptions, and teacher's experiences of the two Flipped Classrooms could thus be compared.

Two exploratory studies were conducted: Study 1 investigated a flipped classroom remedial approach for underperforming students, and Study 2 examined the effects of a flipped classroom approach for high ability students. The following research questions were addressed:

- To what extent does the use of flipped classroom have an impact on underperforming and high ability students' Mathematics learning?
- How do the teacher and students perceive the use of flipped classroom?
- How can the design and implementation of flipped classroom be improved?

Flipped classroom design

The two studies reported in this paper were distinct in terms of student cohorts but taught by the same teacher. Study 1 was designed for underperforming students while Study 2 was for high ability students. Despite the different student cohorts, both Studies shared certain similarities in terms of the overall design of the flipped classroom approach, the data sources, and the statistical analyses used. Each flipped classroom approach was designed based on Merrill's (2002) First Principles of Instruction design theory. Malone (1985) explains that unlike explanatory theory ("Y because of X"), design theories emphasize how to achieve goals ("In order to achieve Y, do X"). The *First Principles of Instruction* (see Figure 1 and Table 1) are largely context-free, and are derived from a review of several instructional design theories and models such as the Vanderbilt Learning Technology Center's Star Legacy (Schwartz, Lin, Brophy, & Bransford, 1999), Constructivist Learning Environment model (Jonassen, 1999), the Four Component Instructional Design model (van Merriënboer, 1997), and Learning by Doing model (Schank, Berman, & Macperson, 1999).

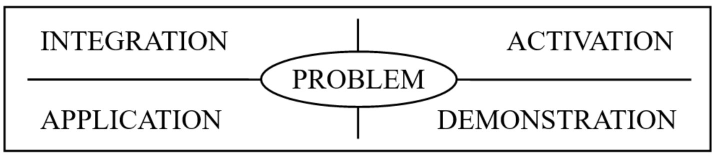


Figure 1. Merrill's (2002) First Principles of Instruction

Table 1. First Principles of Instruction (summarized from Merrill, 2002, p. 45-50)

Instructional principles	Description
Learning is promoted when learners are engaged in solving problems that can be found in the real world [Problem-centric]	*Show task*: Learning is promoted when learners are shown the task that they will be able to do or the problem they will be able to solve as a result of completing a module or course. *Problem progression*: Learning is promoted when learners solve a progression of problems that are comparable to one another.
Learning is promoted when existing knowledge is activated as a foundation for new knowledge [Activation]	*Previous experience*: Learning is promoted when learners are directed to recall, or relate knowledge from relevant past experience that can be used as a foundation for the new knowledge.
Learning is promoted when new knowledge is demonstrated to the learner [Demonstration]	*Demonstration*: Learning is promoted when the teacher demonstrates the appropriate procedures to solve the problems.
Learning is promoted when new knowledge is applied by the learner [Application]	*Practice*: Learning is promoted when the activities and the tests are consistent with the stated learning objectives. *Varied problems*: Learning is promoted when learners are required to solve a set of varied problems.
Learning is promoted when new knowledge is integrated into the learner's world [Integration]	*Creation*: Learning is promoted when learners can use their new knowledge or skill to solve more advanced problems.

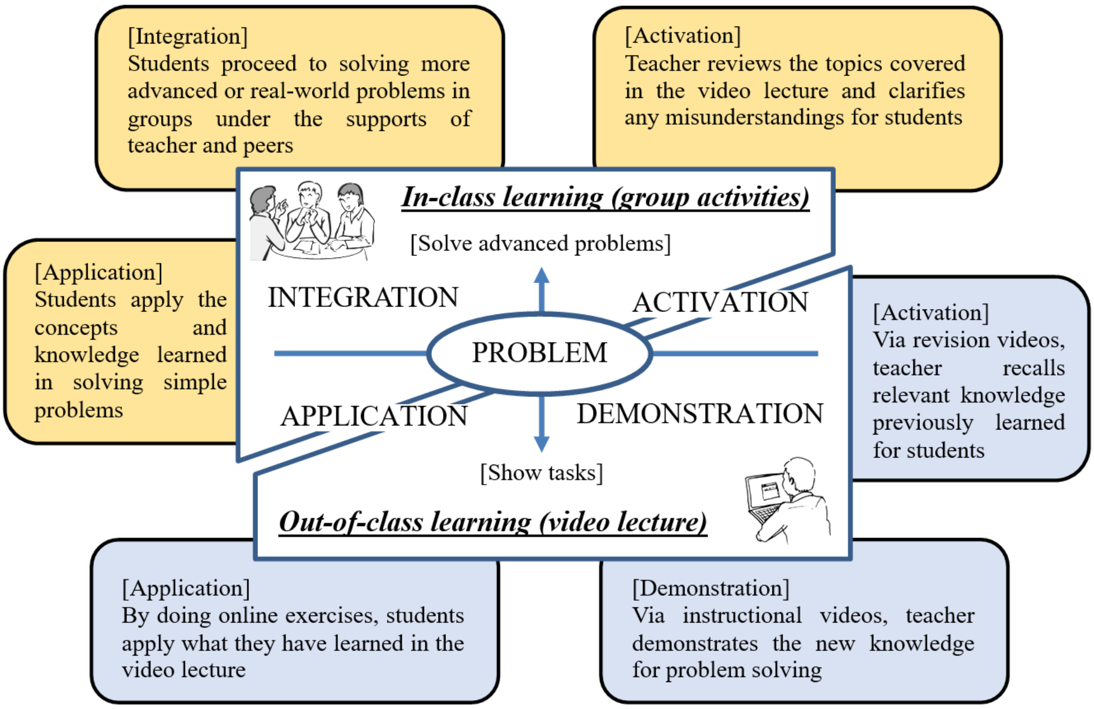


Figure 2. Overarching design framework of flipped classroom

The First Principles of Instruction design theory provides us with a unique theoretical framework to implement our flipped classroom approach (see Figure 2). Specifically, in our flipped classroom approach used in both Studies, we delivered the activation phase, demonstration phase, and application phase outside classroom via video lectures. Students first watched several instructional videos, as mini-lectures, for a particular topic (e.g., mid-point formula in coordinate geometry) at home. In each mini-lecture, the teacher would first show the task that students were able to handle after the completion of the mini-lecture [*problem-centric – show task*]. The teacher then activated students' prior knowledge by recalling relevant concepts or knowledge previously learned [*activation phase*]. Next the teacher demonstrated the new knowledge, strategy, or procedure for solving the problem [*demonstration phase*]. The mini-lectures could be paused at any time or be played back repeatedly so that students could learn at their own pace. After viewing the mini-lectures, students would answer some simple online quizzes by applying what they had learned in the video lecture to promote learning [*application phase*]. The online quizzes helped teachers check the students' learning by analyzing their responses to the questions.

During face-to-face class sessions, we delivered the activation phase, application phase, and integration phase inside the classroom. The teacher would first review the topics covered in the video lecture, and clarify any misunderstandings [*activation phase*]. Students would then apply the concepts learned in solving some simple problems either individually or in pairs [*application phase*]. Students were also asked to apply their knowledge in solving more advanced or real-world problems in groups under the supports of teacher and peers [*integration phase*]. The use of group discussion could deepen students' understanding and help them integrate the new knowledge into real-world contexts (Warter-Perez & Dong, 2012). Figure 3 shows the flow of teaching and learning activities in each session.

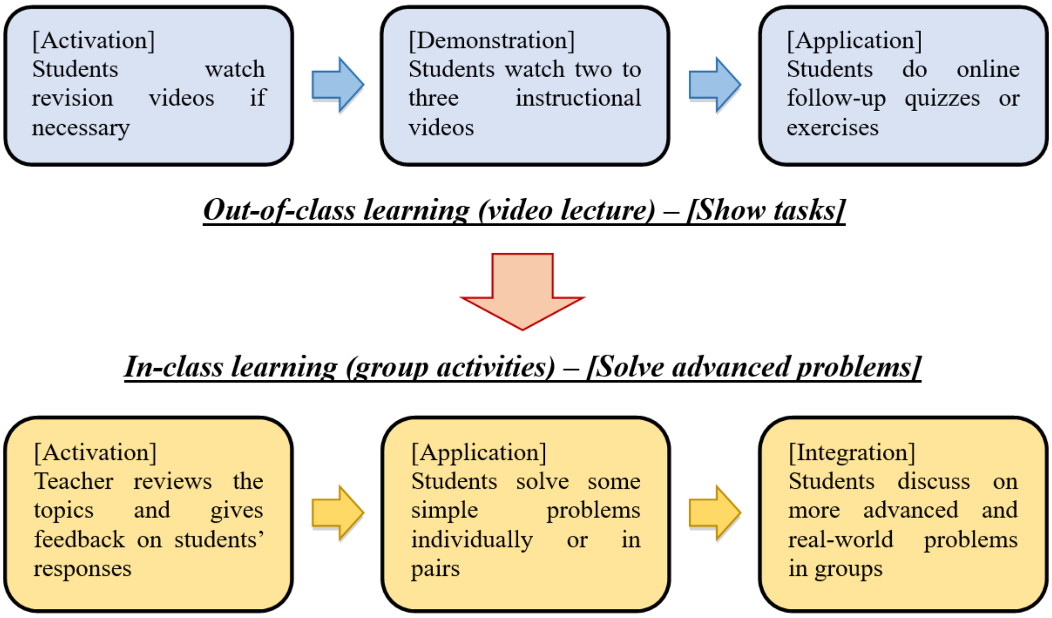


Figure 3. The flow of teaching and learning activities in each session

The design of instructional videos

The design of our video lectures was informed by evidence-based findings. First, we limited the length of our instructional videos to less than six minutes. Videos shorter than six minutes were found to be most engaging to students (Guo, Kim, & Rubin, 2014). Second, we followed the guidelines pertaining to the cognitive theory of multimedia learning (Mayer, 2014). For example, it is suggested that learning is enhanced when extraneous material are excluded (i.e., coherence effect), when cues are provided to highlight essential materials (i.e., signaling effect), and when words are spoken in conversational style (uses *I* and *you* as in an informal conversation with the learner) rather than non-personalized style in which the teacher speaks in a third-person formal monologue (i.e., personalized effect) (Mayer, 2014). Third, we mainly employed Khan-style tutorial style (i.e., a teacher drawing on a digital tablet) since the natural motion of human handwriting can be more engaging than static computer-generated fonts (Cross, Bayyapunedi, Cutrell, Agarwal, & Thies, 2013). Figure 4 shows a screen-shot of a video lecture used in Study 1.

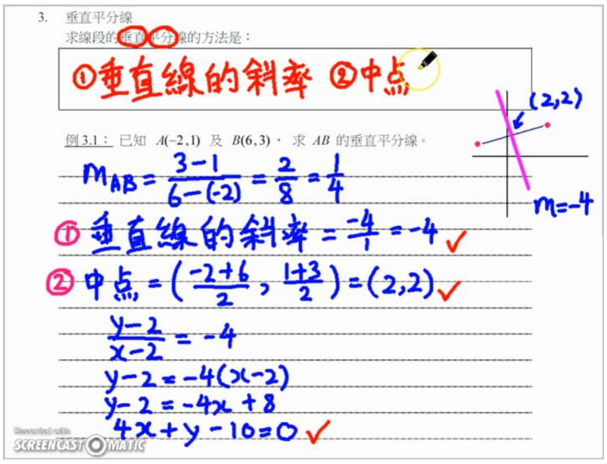


Figure 4. Screen-shot of the digital tablet drawing lecture in Study 1

General method

Overview of the two studies

The two exploratory studies were conducted in a Hong Kong secondary school. Most of the students have minimal experience of using flipped classroom. Table 2 summarizes the contexts of Study 1 and Study 2.

Table 2. Summary of the contexts of Study 1 and Study 2

	Study 1	Study 2
Number of participant	13	24
Level	Form 6 (Grade 12)	Form 6 (Grade 12)
Mathematics ability of participants	Low	High
Course topic	Coordinate geometry	Arithmetic and geometric sequences and their summations
Number of session	Three	Six
Length of each instructional video	≤ 6 minutes (two to three videos per session)	≤ 6 minutes (two to three videos per session)
Time for each face-to-face lesson	50 minutes	One hour
Duration of program	Two weeks	Four weeks

Data collection and analysis

The three research questions were addressed by using four major sources of data, including pre-test and post-test, questionnaire survey (for Study 2 only), student interview, and teacher interview. Table 3 shows each research question and the methods associated.

Table 3. Summary of research questions and data analysis methods

Research question	Data source	Data analysis method
RQ1: To what extent does the use of flipped classroom have an impact on underperforming and high ability students' Mathematics learning?	Pre-test and post-test Questionnaire survey	Paired sample *t*-test Descriptive statistics
RQ2: How do the teacher and students perceive the use of flipped classroom?	Student interview Teacher interview Questionnaire survey	Coded and organized into emerging categories
RQ3: How can the design and implementation of flipped classroom be improved?	Student interview Teacher interview Questionnaire survey	Coded and organized into emerging categories

To answer RQ1, a 15-minute pre-test and 15-minute post-test were conducted to assess students' learning progress. To enhance the reliability and validity, all test questions were adopted and modified from the Mathematics public examinations in Hong Kong. By referring to the annual reports of the public examination, we ensured that the questions in pre-test and post-test were different but similar in terms of scope and difficulty level. To evaluate the effectiveness of the intervention, paired sample *t*-test was used to compare the difference between pre-test mean and post-test mean. Besides the use of tests scores, questionnaire data could also reveal the general impact on student learning.

To answer RQ2 and RQ3, a 15-minute questionnaire and student interview were used to study student perception of flipped classroom. The questionnaire was adopted and modified from Johnson's (2013) survey. The questionnaire survey asked students to rate their general attitude toward the flipped classroom designed. Additional spaces were provided for free text responses. In the student interview, we investigated how students learn through flipped classroom, examined their perceptions and experience, and identified any difficulties encountered. An interview protocol of suggested questions and possible follow-up questions was designed based on Lofland, Snow, Anderson, and Lofland's (2006) guideline on interview. In particular, some of the interview questions were adopted from Zappe, Leicht, Messner, Litzinger, and Lee's (2009) survey of flipped classroom.

During the teacher interview, the teacher was asked to reflect upon his implementation of flipped classroom according to a guiding protocol. The protocol focused on two areas: (1) The perceptions of implementing flipped classroom; and (2) the difficulties encountered in flipped classroom.

Quantitative data from questionnaires provided a general understanding of students' perceptions of flipped classroom. The qualitative data collected from the questionnaires and interviews were thematically analyzed and organized into categories (Corbin & Strauss, 2008).

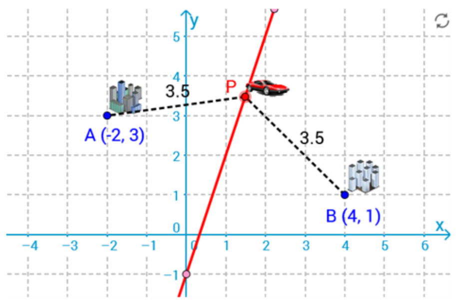
Study 1: Flipped classroom for underperforming students

Participants and procedure

Participants were 13 Form 6 (Grade 12) students. They were invited because of their underachieving performance in coordinate geometry. The remedial program was thus about coordinate geometry. Referring to the curriculum guides of Hong Kong Secondary Mathematics education (CDC & HKEAA, 2014), the class schedule of the remedial program was set (see Table 4). While the video lectures demonstrated some basic information of the topic (e.g., calculating the distance between two points), the in-class time mainly focused on handling the more advanced problems and real-world problems. Figure 5 shows one of the real-world problems used in the program.

Table 4. Overview of the class schedule of the remedial program in Study 1

Session	Video lecture (out-of-class)	Face-to-face lesson
1	Mid-point of two points; Distance between two points; and Slope of straight line	Transformation of point Advanced problems
2	Equation of straight line; *x*- and *y*-intercept of straight line; and Interception point of straight lines	Perpendicular lines Advanced problems
3	Slope of the equation of straight line; Line perpendicular to straight line; and Perpendicular bisector of two points	Concept of locus Real-world problems



City A and City B are two cities separated apart.
A straight road should be built such that every point of the road is equidistant from the two cities (i.e., AP = BP).

(a) Describe the geometric relationship of the road and the two cities.

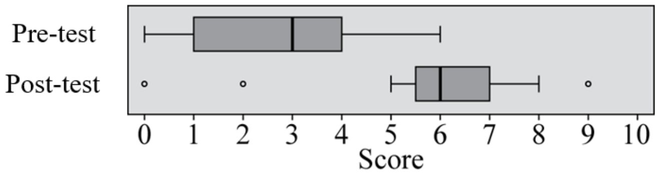
(b) Find the equation of (a).

Figure 5. Sample question of the real-world problems of coordinate geometry (see Chik, 2014)

Results

Pre-test and post-test

The total score of pre-test and post-test was both 10. The questions in the two tests were different but similar in terms of scope and difficulty level. A paired *t*-test showed a significant difference between the pre-test mean (n = 13, M = 2.77, SD = 1.79) and the post-test mean (n = 13, M = 5.85, SD = 2.41), $t(12) = 6.50$, $p < .0001$. The Cohen's d value was 1.80, indicating a large effect size. Figure 6 shows the box plot and the results of the pre-test and post-test scores.



	Mean	Std. deviation
Pre-test	2.77	1.79
Post-test	5.85	2.41

Figure 6. Box plot and the summary of the pre-test and post-test results of the remedial program in Study 1

Students' perceptions of flipped classroom

Student interview data was thematically analyzed and organized into several categories, namely course content and design, collaboration with peers, and teacher's supports. Some direct quotations from the interview findings are reported for illustration.

Course content and design. Almost all students supported the use of flipped classroom and perceived that this instructional approach facilitated their learning. Most of the students reported that they could review the materials anytime and anywhere: "We can review the videos when necessary" (Student 1). However, a few students reported that they could not handle some of the advanced problems and real-world problems. They requested more basic exercises to help them acquire the new knowledge and skills: "The final problem (real-life problem) is very difficult. … I need to do more exercises. In this way, I can master the skills better" (Student 2).

Collaboration with peers. Almost all students engaged in small-group learning activities. A few students explained that they could support each other by discussing problems, explaining concepts, and checking answers or steps of problem solving: "I find learning in groups better since my classmate can answer my questions immediately when I don't understand" (Student 7).

Teacher's supports. The most commonly mentioned issue concerned the support of out-of-class learning. A number of students expressed that they could not receive help during the video lectures. Some of them suggested the teacher provide explanations or solutions to the online exercises: "we cannot ask question immediately while watching videos" (Student 5); "Please provide a full solution and explanation of the online exercises, especially the harder one" (Student 8).

Study 2: Flipped classroom for high ability students

Participants and procedure

There were 117 students in the Form 6 non-science classes. Based on their latest Mathematics examination score, the top 25% of the students were invited on a voluntary basis. A total of 24 students participated in this training program. The course was about arithmetic and geometric sequences and their summations. Referring to the curriculum guides of Hong Kong Secondary Mathematics education (CDC & HKEAA, 2014), the class schedule of the training program was set (Table 5). The video lectures handled the basic parts of the topic (e.g., evaluating the summation of an arithmetic sequence). As for the face-to-face lessons, some advanced application problems and real-world problems were discussed, such as counting the number of seats in a theatre (a problem of arithmetic sequences), and calculating the amount of revenue of a firm (a problem of geometric sequences).

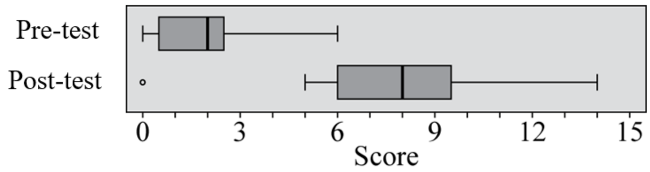
Table 5. Overview of the class schedule of the training program in Study 2

Session	Video lecture (out-of-class)	Face-to-face lesson
1	Review on sequences; and Introduction to arithmetic sequences	Advanced problems
2	Introduction to geometric sequences	Advanced problems
3	Distinguishing between arithmetic sequences and geometric sequences; and Introduction to summation of sequence	Real-world problems
4	Summation of an arithmetic sequence	Real-world problems
5	Sum of the first *n* terms of a geometric sequence	Real-world problems
6	Sum to infinity of a geometric sequence	Real-world problems

Results

Pre-post test

The total score of pre-test and post-test was both 15. The questions in the two tests were different but similar in terms of scope and difficulty level. A paired t-test showed a significant difference between the pre-test mean (n = 24, M = 2.00, SD = 1.77) and the post-test mean (n = 24, M = 8.08, SD = 3.03), $t(23) = 9.43$, $p < .0001$. The Cohen's d value was 1.92, indicating a large effect size. Figure 7 shows the box plot and the results of the pre-test and post-test scores.



	Mean	Std. deviation
Pre-test	2.00	1.77
Post-test	8.08	3.03

Figure 7. Box plot and the summary of the pre-test and post-test results of the training program in Study 2

Students' perceptions of flipped classroom

Table 6 shows the questionnaire results of Study 2. Overall, most of the students (87.5%) found that flipped classroom was more engaging than traditional classroom, and preferred learning at their own pace. Also, many students (70.8%) liked watching instructional videos, and recognized that flipped classroom provided more chances for peer communication.

Table 6. Questionnaire results in Study 2 (n = 24)

Item	Score on the 5-point Likert Scale (% Respondents)					
	5	4	3	2	1	Mean(*SD*)
1 The flipped classroom is more engaging than traditional classroom instruction	54.2	33.3	12.5	0	0	4.42 (.72)
2 I like watching the lessons on video	41.7	29.2	29.2	0	0	4.13 (.85)
3 I prefer a video-recording of the lesson to a traditional teacher-led lesson	45.8	25.0	29.2	0	0	4.17 (.87)
4 I like to self-pace myself through the course	50.0	37.5	12.5	0	0	4.38 (.71)
5 I like taking my quizzes online by using online learning platform	45.8	20.8	29.2	4.2	0	4.08 (.97)
6 The flipped classroom gives me more chances to communicate with other students.	33.3	37.5	29.2	0	0	4.04 (.81)
7 I am more motivated to learn in the Flipped Classroom	41.7	37.5	20.8	0	0	4.21 (.78)
8 The flipped classroom has improved my learning of Mathematics	41.7	45.8	12.5	0	0	4.29 (.69)

Note. 5 = strongly agree to 1 = strongly disagree.

Similar to Study 1, students' responses to the open-ended questions in the questionnaire, and interviews were thematically analyzed and organized into several categories, namely course content and design, collaboration with peers, and teacher's supports.

Course content and design. Students talked about the advantages of flipped classroom, such as being able to learn at their own pace, and having autonomy in learning: "Students are free to choose whether to watch the videos for revision or not" (Student 10), "We can decide our own learning progress" (Student 9). In addition, students' perceptions of flipped classroom were generally positive. Some students even requested the teacher to provide more examples and exercises for them, as well as extend the duration of lessons: "It would be better to provide more examples and advanced application problems" (Student 15); "We can stay even after 5:30pm (end of the lesson)" (Student 20).

Collaboration with peers. Most students stated that the in-class discussion facilitated their learning. They also valued the communication with peers in their learning. For example, "Students mainly discussed the solution in class, which facilitated our communication and learning" (Student 18).

Teacher's supports. While many students appreciated that they could receive more help from teacher during in-class time, a number of students expressed that they could not get immediate assistance in their out-of-class learning. A few students asked for a place for posting questions to the teacher: "We cannot get instant feedback when we encounter problems at home" (Student 17); "You can provide a place for students to ask questions during the out-of-class session" (Student 12).

Teacher's overall opinions of the flipped classroom

The teacher interview data were thematically analyzed and organized into two main categories, namely his experiences of implementing flipped classroom, and the difficulties encountered during its implementation.

Experiences of flipped classroom. The First Principles of Instruction provided a clear guideline for the teacher to design flipped classroom, instead of merely relying on his intuitive beliefs. To facilitate the learning of new content, the teacher affirmed that recalling the relevant pre-requisite knowledge was necessary. By putting some revision videos online, students could do the revision outside the classroom, and more in-class time was thus spent on clarifying misunderstanding or solving more advanced problems. However, in addition to activation outside the classroom, in-class activation was useful for both underperforming and high ability students. This is because the teacher observed that some students might forget what they had learned out-of-class when coming back to the classroom: "They could not recall the knowledge because they had visited the video lecture too early before its corresponding lesson."

While demonstrating the new content via video lectures could free-up more in-class time, the teacher thought that parts of the course were still suitable to deliver inside the classroom, especially for the difficult learning items. This was because the teacher found it difficult to explain the complicated concepts in a short video. Also, teacher could have a better understanding of whether students could follow the presentation in a face-to-face teaching and learning environment: "Students' facial expressions usually give me some hints, telling me which parts are difficult for them and I need to explain further."

Difficulties encountered. The teacher found that the analytics of the online quizzes were useful in lesson preparation. However, he was concerned that some students might complete the online quizzes casually: "Based on the results of the online quizzes, I can figure out whether I need to re-teach or not. But I am not sure whether the students completed these multiple choice questions seriously or not." The teacher also pointed out the importance of engaging in the advanced and real-world problems in Hong Kong secondary education context. At the same time, he admitted that not all students could handle these problems due to their ability and subject interests. He recommended exploring further strategies in flipped classroom to cater to the needs of different students: "In the context of Hong Kong Mathematics education, it is necessary to equip students to solve real-world problems. In public examination, it is not unusual that some questions are related to everyday life. Although the flipped classroom approach provides room for us to handle these problems inside the classroom, it is difficult to satisfy all students due to the time constraint and the large class size."

General discussion

Contrary to many previous published studies, the present study is distinctive in the following two ways. First, it tested the feasibility of using the Merrill's (2002) First Principles of Instruction design theory to implement flipped classroom in a secondary school context. A majority of previous studies did not explicate any specific conceptual framework to help instructors design their flipped classrooms (Bishop & Verleger, 2013; Giannakos et al., 2014). Second, very few previous studies utilized their results to develop design principles for using flipped classroom (O'Flaherty & Phillips, 2015). Our present study proposed several recommendations (Table 7) based on the suggestions of students and teacher, as well as relevant literature. The results are discussed in three main sections: Impact on students' Mathematics learning, the First Principles of Instruction, and a comparison of the two flipped classrooms.

Impact on students' Mathematics learning

From the pre-test and post-test results, there was a significant learning gain in both Studies. Moreover, the effect size of both Studies was large. From the student interviews of Study 1, most of the students reported that flipped classroom facilitated their learning, which confirmed the test results. In Study 2, the test results were also consistent with their self-perceived learning. There were 87.5% of students who agreed or strongly agreed that "The flipped classroom has improved my learning of Mathematics." Also, 79.2% of students agreed or strongly agreed that "I am more motivated to learn in the flipped classroom."

Nevertheless, we do not claim that flipped classroom is better than other instructional approaches in other contexts. In the present study, we could only suggest that the use of flipped classroom may be useful in increasing the Mathematics achievement for both underperforming and high ability students. We could not claim causality effect since no control group (e.g., non-flipped classroom condition) was employed.

Merrill's (2002) First Principles of Instruction

In the following parts, we discuss each of the four phases of First Principles of Instruction, namely activation, demonstration, application, and integration.

Activation

The teacher shared that he "would usually have a revision on the background information before teaching some new materials" even in traditional classroom, aiming to "prepare their learning by recalling the relevant knowledge." But in his experience, not every student was engaged in this revision, especially for the high ability students. He explained that "They already have the knowledge in their mind. In-depth revision was not necessary for them but for the less capable students." Therefore he affirmed that it is desirable to shift the revision part outside the classroom. In students' opinion, they can benefit since "Students are free to choose whether to watch the videos for revision or not" and "can review the videos when necessary."

However, we still suggest including a brief review at the beginning of each face-to-face lesson. Based on the teacher's observation, some of the students forgot what they had learned in the video lectures when coming back to the class. But looking at their performances of the online exercises, the teacher believed that these students had prepared for the class seriously. He argued that "They could not recall the knowledge because they had visited the video lecture too early before its corresponding lesson." In this regard, in-class activation on out-of-class learning materials may be useful for both underperforming and high ability students. As Munson and Pierce (2015) recommended, a brief review highlighting the key concepts presented in the video lecture can serve as a starter of class.

Demonstration

In the teacher's opinion, "direct demonstration is still an effective way to deliver new concepts for my students." For the simple learning items, he found that teaching via instructional videos was similar to the direct teaching inside the classroom. But the advantage of using instructional videos is to free-up the in-class time for interactive group learning activities (Bishop & Verleger, 2013). However, a number of students expressed that they could not ask question immediately and get instant feedback when watching the instructional videos or doing the online quizzes. Therefore, we suggest creating a Q & A forum or allowing students to leave comments in the online learning platform. In this way, both teachers and their classmates can provide timely feedback when students post their questions online. Conte et al. (2015) further recommended enabling "real-time question-and-answer interactions and a full archive of all information exchanged" (p. 70).

Application

Online quizzes are useful for students to apply the knowledge. There were 66.7% of the students in Study 2 agreed or strongly agreed that "I like taking my quizzes online by using online learning platform." The analytics of the online quizzes also provided information for teaching preparation (Mok, 2014). He mentioned that "Based on the results of the online quizzes, I can figure out whether I need to re-teach or not." But at the same time, he was "not sure whether the students completed these multiple choice questions seriously or not. It is possible that students submitted their quizzes by randomly clicking an answer." Therefore, he had designed a set of pre-lesson worksheets which required students to write down some content notes of the instructional videos, and display some problem solving steps of several simple exercises. Similar to Clark (2015) and Little (2015), the teacher could assess students' pre-class preparation by checking their worksheets.

In his experience, the teacher noticed that "There is a gap between understanding and applying the concepts." In traditional classroom, students cannot get help immediately from their teacher or peers when doing their homework. In the present study, the homework problems were handled inside the classroom in a small-group learning environment. Similar to Clark's (2015) observation, students in the two Studies "learned from each other by discussing problems, explaining procedures, and confirming answers" (p. 109). Indeed, a number of students pointed out that "The advantage of flipped classroom is having more discussion" inside the classroom.

When solving a set of varied problems during the application phase of flipped classroom, peer-supported learning is especially important because of the highly interactive nature of this instructional approach. On one hand, teachers are able to spend more in-class time for one-to-one assistance and small-group tutoring (Bergmann & Sams, 2009). But on the other hand, teachers are unavailable to help other students when they are occupied by some students in need. Enfield (2013) lamented that "this resulted in students waiting for long periods of time for help" (p. 26). In this regard, the teacher highly encouraged his students to provide feedback for their classmates:

> "Suppose I have answered group 1's question. When group 2 asks the same question, I would direct group 2 to ask group 1. If I am not occupied by other groups, I would listen to group 1 and see how they explain to group 2. In this way, not only group 2 can get help, but also I can check for group 1's actual understanding on the question and clarify their concepts when necessary. Sometime I perceived that their wordings were more understandable among them."

In fact, providing feedback is cognitively engaging (Nicol, Thomson, & Breslin, 2014). Although peers' feedback may be regarded as lacking expertise, Love, Hodge, Grandgenett, and Swift (2014) found in their flipped classroom study that "explaining a problem or idea to their partner helped them to develop a deeper understanding of it" (p. 322). In our present study, a student affirmed that "Learning in groups is better since my classmate can answer my questions immediately when I don't understand." It is thus important for flipped classroom practitioners to develop a routine of peer collaboration (Enfield, 2013).

Integration

To promote student learning, students have to engage in solving more advanced problems and real-world problems (Merrill, 2002). We found that most students were willing to do more advanced application problems. In the words of a student, "The questions were very practical. I perceive that I have learned more when comparing with normal lessons." However, the teacher realized that not all students were able to handle these kinds of problems, particularly the underperforming students. So how can we address the needs of various students?

We provide an example of catering to diverse learners in flipped classroom. Clark (2015) reported a study of a Secondary School Mathematics Flipped Classroom in the United States. Inside the classroom, students had more time to handle various problems with the supports of their teacher and peers. He further illustrated that the teacher would allow the students to join one of the following three main groups (p. 103-104):

- Group 1: Students immediately began working on their independent practice problems without the teacher's assistance;
- Group 2: Students gathered around and reviewed the content with the teacher; and
- Group 3: Students congregated at the back of the room and revisited the instructional videos collaboratively on electronic devices.

In this practice, students were free to choose their learning activities. They can join Group 1 if they are able to handle the advanced problems, Group 2 if they need teacher's assistance and then do more basic exercises to consolidate their knowledge and skills, or Group 3 if they need to re-study with the help of teacher and peers to acquire the out-of-class learning materials. Perhaps each group can be further divided into several sub-groups, and teachers can allow their students to form their own group. According to Self-determination Theory, this practice can satisfy students' need of autonomy which in turn promotes their intrinsic motivation of learning (Deci & Ryan, 2002). We suggest that teachers should first identify the core materials to be completed by all students. Then different levels of tasks and extra exercises should be prepared for each group correspondingly.

Comparison of the two flipped classrooms

Most of the findings of Study 1 and Study 2 were similar. For student learning, both underperforming students and high ability students achieved a learning gain with a large effect size using the "First Principles of Instruction" enabled flipped classroom approach. Their perceptions of flipped classroom were also positive. Considering the flow of teaching and learning (Figure 3), students in both Studies pointed out the needs of additional supports (e.g., Q & A forum) in the video lecture. For the in-class learning segment, a brief review was recommended since students, regardless of their ability, might forget what they have learned in the video lecture. Both underperforming students and high ability students recognized that flipped classroom could provide them with a greater chance for peer collaboration. For example, "Students mainly discussed the solution in class, which facilitated our communication." The teacher's and peers' supports outside and inside the classroom are vitally important to support both underperforming students and high ability students in flipped classroom.

Table 7. Summary of the recommendations of the design and implementation of flipped classroom

Component	Recommendations	Supporting resources
Course planning	• Identify and prepare the learning materials for the core part of the course (completed by all students), advanced problems (for the high ability students) and extra basic exercises (for underperforming students)	Teacher's recommendation; students' recommendation; Clark (2015)
Out-of-class learning	• Address the activation, demonstration, and application phases	Teacher's recommendation
	• Limit the duration of instructional videos within six minutes	Guo et al. (2014)
	• Provide revision videos to recall the relevant knowledge for learning new knowledge (especially for underperforming students)	Teacher's recommendation; Merrill (2002)
	• Enable online question-and-answer interactions with the teacher for students to ask questions and receive immediate feedback	Students' recommendation; Conte et al. (2015)
	• Provide pre-lesson worksheets to ensure students' preparation for the class	Teacher's recommendation; Clark (2015); Little (2015)
	• Prepare the face-to-face lesson based on students' performances of the online quizzes	Teacher's recommendation; Mok (2014)
In-class learning	• Address the activation, application, and integration phases	Teacher's recommendation
	• Provide a brief review to highlight the key concepts presented in the video lecture to activate students' prior knowledge	Teacher's recommendation; Munson and Pierce (2015)
	• Facilitate peer-supported learning by teacher's encouragement or guideline for students	Clark (2015); Enfield (2013); Love et al. (2014)
	• Design different levels of problem-solving tasks for students (provide more basic exercises for underperforming students and more advanced problems for high ability students)	Students' recommendation; Clark (2015)
	• Allow students to choose the various learning activities based on their needs (to cater to underperforming students and high ability students)	Clark (2015); Deci and Ryan (2002)

However, students' views on the in-class problem solving activities were different among the underperforming students and the high ability students. In Study 1, the underperforming students wanted to have more basic exercises because they did not feel confident in doing the advanced problems. For example, "The final problem (real-life problem) is very difficult. … I need to do more exercises. In this way, I can master the skills better." Through the lens of Merrill's (2002) First Principles of Instruction, more emphasis should be placed on the application phase before advancing to the integration phase when designing a flipped classroom for underperforming students. In contrast, the high ability students in Study 2 would like to have more advanced and real-world exercises. As suggested by the following student, "It would be better to provide more examples and advanced application problems." In order to engage more advanced problems, they even asked for extending the class time: "We can stay even after 5:30pm." Therefore, flipped classroom practitioners can put emphasis on the integration phase to satisfy the needs of high ability students.

As Niemiec and Ryan (2009) suggested, teachers should provide the learning activities which are suitable and optimally challenging for students. Therefore, if the general ability of students is low, teachers should prepare extra basic exercises to consolidate their learning before approaching the advanced problems in their flipped classroom. As for the high ability classes, teachers can provide more advanced and real-world problems for students after dealing with several warm-up exercises. In other words, flipped classroom is not a one-size-fits-all solution for catering to diverse learners. The difficulty and amount of learning materials provided in flipped classroom should match with the ability and needs of students.

Finally, we organize in Table 7 the recommendations discussed above into three main themes, namely course planning, out-of-class learning, and in-class learning. These recommendations are proposed based on the students' and teacher's suggestions for improvement from the interviews and open-ended responses of questionnaire. Some of the recommendations are also derived from relevant existing literature. Practically, these recommendations may help practitioners design and implement a flipped classroom.

Conclusion

The flipped classroom approach has become very popular in many educational institutes around the world. In this study, we investigated the use of Merrill's (2002) First Principles of Instruction design theory to design flipped classroom for secondary school Mathematics education. Results revealed that this approach can help enhance underperforming and high ability students' Mathematics achievement. Students' qualitative responses also showed that they benefited from the flipped classroom approach. This is congruent with previous research conducted in higher education settings (e.g., Herreid & Schiller, 2013). Yet teachers should design their flipped classroom according to their students' ability.

There are several limitations that affect the generalization of our findings and one should exercise caution in interpreting the results of our study. First, due to logistical issues, we could only employ a one-group pre-and-post-test design. Using a more robust design (e.g., randomized experimental design with separate control and intervention groups) could show the effect of flipped classroom on student achievements more clearly. We therefore urge future research to use experimental or quasi-experimental design to examine the effects of flipped classroom. Second, the study sample consisted of Form 6 (Grade 12) students. Future research should examine this approach involving students of other grade levels. Third, the duration of this study ranged from two to four weeks. Conducting a longitudinal study (e.g., one year) can help determine if students' perceptions of flipped classroom would change over time. Nevertheless, despite these limitations, we believe the findings would benefit other researchers and educators in exploring the use of the First Principles of Instruction to design a flipped classroom teaching and learning approach.

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