The Effects of Self-Regulated Learning on Students' Performance Trajectory in the Flipped Math Classroom

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Abstract: The flipped classroom is a unique instructional model with in-class activities being heavily dependent on pre-class learning engagement. Practitioners and researchers have well recognized the critical role of the pre-class learning on students' performance in the flipped class. However, little research has investigated how students learn in the pre-class setting and what factors can help students improve their pre-class learning. Based upon the self-regulated learning theory, this study used both survey research and learning analytics methods to uncover students' performance trajectories of a semester in two flipped undergraduate math courses and examined whether the three key self-regulated learning factors – self-efficacy, the use of metacognitive strategy, and self-regulatory behaviors – were significantly different across different performance trajectories. The results revealed six different performance trajectories among students and found significant differences across these trajectories in terms of the three self-regulatory factors.

Keywords: self-regulated learning, flipped classroom, learning analytics, survey-based research

Introduction

The flipped classroom model has attracted ever-growth attention since its inception in 2007. It is an emerging instructional model that commonly consists of two parts: pre-class Internet-based individual learning and in-class group-based collaborative learning (Bishop & Verleger, 2013). In a flipped class, students normally learn content materials through online instructional videos and text readings on their own pace and schedule prior to the class. Then they gather together in person and apply learned knowledge through group-based collaborative activities in a classroom (Bergmann& Sams, 2012; Herreid & Schiller, 2013). The in-class activities are oftentimes designed to be highly associated with the pre-class learning materials. Thus, the success of in-class learning is heavily relied on students' preparation in pre-class. In the practice of flipped classroom model, teachers have observed the critical influence of the pre-class preparation on the in-class performance (Schell, 2013). Research also empirically demonstrated the significantly positive relationship between the pre-class and in-class achievement (Sun, 2015). Given the important role of the pre-class learning in the flipped classroom, how do students learn in the pre-class and what factors can help students improve their pre-class learning have been continuous questions among flipped classroom teachers.

The pre-class online learning emphasizes a student-centered learning environment, in which students take control of their own learning process (Flipped Learning Network, 2014). For example, students are provided with various learning resources, and they navigate through the materials and learn the content at flexible time, pace, and space (Fulton, 2012). To ensure that they are prepared for the in-class group activities, students are oftentimes required to watch the associated lecture videos and complete the assigned homework prior to class. However, this student-centered way of learning has been a well-known challenge for both students and teachers. Students complain the workload ahead, and teachers lack awareness and confidence that students would spend enough time and efforts on the lectures and be prepared for the in-class activities (Acedo, 2013). To overcome this challenge, researchers suggest that a new or advanced student-centered skill set is demanded to support such the student-centered way of learning (Estes, Ingram, & Liu, 2014). That means, students are expected to be proactive, inquire, and obtain foundational knowledge in a self-directed manner to succeed in the pre-class learning (Talbert, 2014). They are also desired to be active in the setting and pursuit of learning goals, use certain learning strategies to solve problems, monitor their behaviors, and reflect on the performance. In essence, the student-centered environment promotes self-regulated learning as a critical and helpful skill set for the enhancement of students' pre-class learning performance (Connor, Newman, & Deyoe, 2013).

Self-regulated learning is an integrated learning process that regulates students' motivation, behaviors, and metacognitive activities to pursue the planned and adapted personal goals (Schunk, 2001). The self-regulated learning research has suggested three factors that are significant in the self-regulation process, which are *self-efficacy* (Bandura, 1997; Pintrich & Zusho, 2007), *the use of metacognitive strategy* (Duncan & McKeachie, 2005; Winne, 2001), and *the regulation of behaviors* (Hadwin et al., 2007; Winne & Hadwin, 2008). Self-efficacy denotes as “people’s judgments of their capabilities to organize and execute courses of action required to attain designated types of performances” (Bandura, 1986, p.391). Research has demonstrated its robust predicting effect on academic performance (Crede & Philips, 2011) and also suggested its fundamental role in the self-regulated learning process (Winne & Hadwin, 1998, 2008). According to the self-regulated learning model proposed by Winne and Hadwin (1998), while giving a learning task, students normally first define the task such as an easy or a hard task based on their own cognitive factors, and such the definition of the task will guide their following self-regulatory behaviors, for example the regulation of learning time and efforts. Self-efficacy, as one of the cognitive factors, helps students to first generate the task definition and then leads them to regulate their behaviors to complete the task. For example, if a student holds higher-level self-efficacy towards a task, he or she would feel more confident to perform the task, devote more time and efforts in the task, and persist longer while meeting obstacles during the task.

Metacognitive strategy refers to the self-evaluation strategy that guides students’ planning, monitoring, and modifying their cognition and behavior (Pintrich & De Groot, 1990). The use of this strategy is believed to be the hallmark of self-regulating one’s learning process because by using this strategy, students compare their current profiles of task performance with the standards they set previously for satisfactory task performances, create a list of matches and mismatches between the current profiles and the standards, and regulate their motivation, cognition, and behavior in the following learning activities (Winne, 2001). Research has revealed that the use of metacognitive strategy plays an important role in students’ learning and, in general, is positively related with academic performance (Pintrich, 2004). In particular, the use of metacognitive strategy has been quite critical in the hypermedia or computer-supported learning environment (Azevedo, 2005). Because such the learning environment provides students with dynamic and nonlinear access to a wide range of information represented as texts, graphs, and videos, without deploying the metacognitive strategy, students are unable to monitor their performances and easily lost in the great amount of information (Azevedo & Cromely, 2004). The pre-class learning setting is the environment that supports students’ learning mainly by computers, which shares the same feature in the students’ self-directed learning with the hypermedia learning environment. Therefore, the use of metacognitive strategy is believed to be a significant part of the self-regulated learning in the pre-class setting.

The regulation of behaviors in general means the management one’s behaviors in ways to achieve set goals (Carlson & Moses, 2001). Pintrich and his colleagues (1993) attempted to summarize the essential self-regulatory learning behaviors into four categories in the Motivated Strategies for Learning Questionnaire, which are time/study environmental management, effort regulation, peer learning, and help seeking. They believed that to achieve certain learning goals, self-regulated learners tend to find a specific time and place that they can concentrate on the learning task, spend more time on doing the task and persist longer while meeting obstacles, identify peers in the class who are capable of answering questions, and feel unafraid to seek help from others if needed. Both research and theory suggest that self-regulatory behaviors students enacted during learning have a positive effect on their achievement (Winne & Hadwin, 2008).

The majority of research explored the effects of these three self-regulatory factors on students’ one-time achievement such as a post-test score or a final exam score (Azevedo & Cromely, 2004; Crede & Philips, 2011). Since the self-regulated learning is a process, it is valuable to explore the effects of such the self-regulatory process on a performance trajectory or trend, for example a performance trend in an entire semester. Because compared to the one-time achievement, the analysis of the performance trend is able to provide more detailed look on students’ learning process during a semester and identify potential linkage between changes in the performance and the self-regulatory factors.

In this paper, we first identify students’ performance trajectories based on four major exam scores obtained during a semester in two flipped undergraduate math courses, and then investigate whether there are significant mean differences across different performance trajectory groups in terms of the three key self-regulated learning factors – math self-efficacy, the use of metacognitive strategy, and self-regulatory behaviors. We use both survey research and learning analytics methods to uncover students’ self-regulated learning process in the pre-class learning setting. These methods allow us to examine both students’ psychological perceptions and their detailed learning behaviors during the pre-class learning. Two major research questions guide the design of this study, which are as follows:

1. What are students’ performance trajectories in a semester in the flipped undergraduate math courses?
2. Are there any mean differences across different performance trajectories in terms of math self-efficacy, the use of metacognitive strategy, and self-regulatory behaviors?

Methods

Participants

A total of 151 undergraduate students from Calculus I and II courses in a large Midwestern university in the United States participated in the study. There were 50.3% female and 49% male. The majority of participants were White students (68.9%), followed by Asian students (25.2%), and the rest from other ethnical backgrounds. Over 84% of students were freshmen and sophomore.

Study context and procedure

The study included 16 flipped sessions of Calculus I and II. Every Tuesday and Thursday, students attended 55 minutes recitation sessions either in person or through online web-conferencing tool. During the recitation session, students applied newly learned knowledge from the pre-class learning through problem-based and group-based work. To effectively learn in the recitation session, students were required to complete the associated pre-class lectures before attending the recitation session. An online lecture commonly consisted of lecture videos, information slides, embedded quizzes, formative feedback for the quizzes, and associated homework at the end of the online lecture. To obtain the insight of students' perceptions of their self-regulated learning, two online surveys were sent to consented students at the 3rd and 10th week of the semester.

Measures

Measures of this study include math self-efficacy, the use of metacognitive strategy, behavioral data, and exam scores. Math self-efficacy and the use of metacognitive strategy were measured on seven-point Likert scales at the first and second survey, respectively. The behavioral log data was retrieved at the end of the semester from the learning management system that students used for the flipped courses. The four major exam scores were obtained from the course instructors. Means, standard deviations, Cronbach's alpha of survey scales, and correlation coefficients between all variables are summarized in Table 1.

Math Self-efficacy (MSE): Motivated Strategies for Learning Questionnaire (MSLQ: Pintrich et al., 1991) is a widely used measure in the areas of motivation and self-regulated learning (Anthony & Artino, 2005). Extensive research has provided evidences to show that MSLQ is a reliable and valid instrument (Pintrich et al., 1993; Duncan & McKeachie, 2005). The 5-item self-efficacy subscale of MSLQ was adapted to measure students' math self-efficacy of learning in the flipped math courses. One sample item is "*I'm confident I can understand the basic concepts taught in math.*"

Use of Metacognitive Strategy: The 12-item metacognitive self-regulation learning strategy subscale of MSLQ was adapted to measure students' use of metacognitive strategy while learning in the pre-class online setting of the flipped courses. One sample item is "*When studying the pre-class lecture materials, I try to determine which concepts I don't understand well.*"

Behavioral Data: Three types of behavioral data were retrieved from the learning management system, which include the number of attempts for each online homework, the progress of watching each online lecture (i.e. complete the lecture or not complete), and the time (minutes) spent on each online lecture. These behavioral data were log data that presents detailed information of how students work on each online lecture and homework during the semester.

Exam Scores: Students were tested four times during the semester in the paper-and-pencil exams. The four exams largely evenly spread out in the semester, and each exam was designed to test students' understanding and application of the learned knowledge prior to the exam. There were 16 weeks in the entire semester. Exam 1 was conducted in week 4; exam 2 was in week 9; exam 3 was in week 14; and exam 4 was in week 16. The first three exams were the midterms, and they, in total, accounted for 50% of the final grade. The last exam was the final exam, and it accounted for one third (approximately 33%) of the final grade.

Table 1: Means, standard deviations, Cronbach's alpha, and correlation coefficients of measures

Variable	Mean	SD	Alpha	Zero-order Correlations				
				1	2	3	4	5
1. Math Self-efficacy	4.85	1.48	.93	-				
2. Metacognitive Strategy	3.55	2.29	.89	.175**	-			
3. Attempt	.99	.96	-	-.001	.069**	-		
4. Progress	.39	.49	-	.004	.033**	.566**	-	
5. Time (minus)	90.28	231.27	-	-.048**	.006	.310**	.217**	-

Note: ** *p<.01*

Analysis

Hierarchical cluster analysis

Hierarchical clustering was employed in this study as a learning analytics method to answer the first research question. Hierarchical clustering, compared to other clustering methods, better helps researchers to explore the unknown numbers of latent groups in the dataset based on the similarity of interested variables (Vellido, Castro, & Nebot, 2011). In this study, students took four major exams at the 3rd, 9th, 14th, and 16th week of the semester that assessed their understanding of the content knowledge within a certain period of time. The scores of the four exams were standardized before the analysis. Ward's minimum variance method (Ward, 1963) was used as the criterion to evaluate the similarity by the squared Euclidean distances between groups. Each cluster or group was expected to describe a different performance trajectory of students in the semester.

ANOVA analysis

ANOVA analysis was the primary method that used to answer the second research question. The dependent variables included the three self-regulatory factors – math self-efficacy, the use of metacognitive strategy, and self-regulatory behaviors. The independent variable was the performance trajectory groups generated by cluster analysis. In addition, Tukey's HSD test, a post hoc tests in ANOVA, was conducted to further explore the mean differences of the three self-regulatory factors across different performance trajectory groups at an adjusted alpha level .017 (i.e. .05/3).

Findings

Cluster analysis findings

Agglomeration schedule was examined to determine the number of clusters that could be kept for further analysis. Figure 1 demonstrated the grouping procedure with the distances between clusters in each combining stage. It was noticed that the increase of distance between clusters started to go up from the stage of cluster 7 to the stage of cluster 4. To see which stage caused the highest increase of distance after combining clusters, Figure 2 was plotted. It was shown that the change of distance between clusters increased dramatically after agglomerating cases from six clusters to five clusters. This indicated that six clusters could be an appropriate solution.

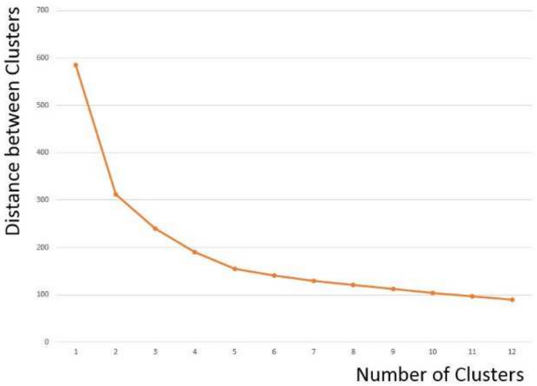

Figure 1. Distance between clusters.

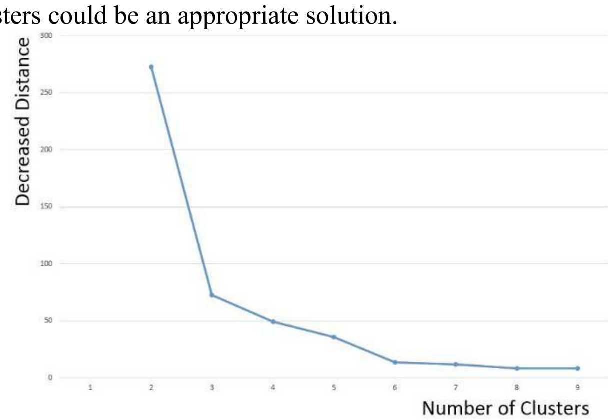

Figure 2. Distance change between clusters.

Figure 3 below demonstrates a six-group solution. Based on the performance trend, we interpret these six groups as follows:

1. *Group 1 – High performance group*: Students in group 1 started above the standard mean of the exam and ended also above the standard mean of the exam. There was a slightly increasing trend of the performance during the semester.
2. *Group 2 – Decreasing performance group*: Students in group 2 started at a high level, around one standard deviation above the standard mean of the exam, but ended around the standard mean of the exam. There was a clearly decreasing trend of the performance during the semester.
3. *Group 3 – Increasing performance group*: Students in group 3 started below the standard mean of the exam but ended above the standard mean of the exam. There was a clearly increasing trend of the performance during the semester.

4. *Group 4 – Decreasing performance group*: Students in group 4 started above the standard mean of the exam but ended below the standard mean of the exam. There was a clearly decreasing trend of the performance during the semester.
5. *Group 5 – Increasing performance group*: Although students in group 5 started below the standard mean of the exam and also ended below the standard mean, there was a slightly increasing trend of the performance during the semester.
6. *Group 6 – Low performance group*: Students in group 6 started below the standard mean of the exam and decreased to even lower grade at the end of the semester.

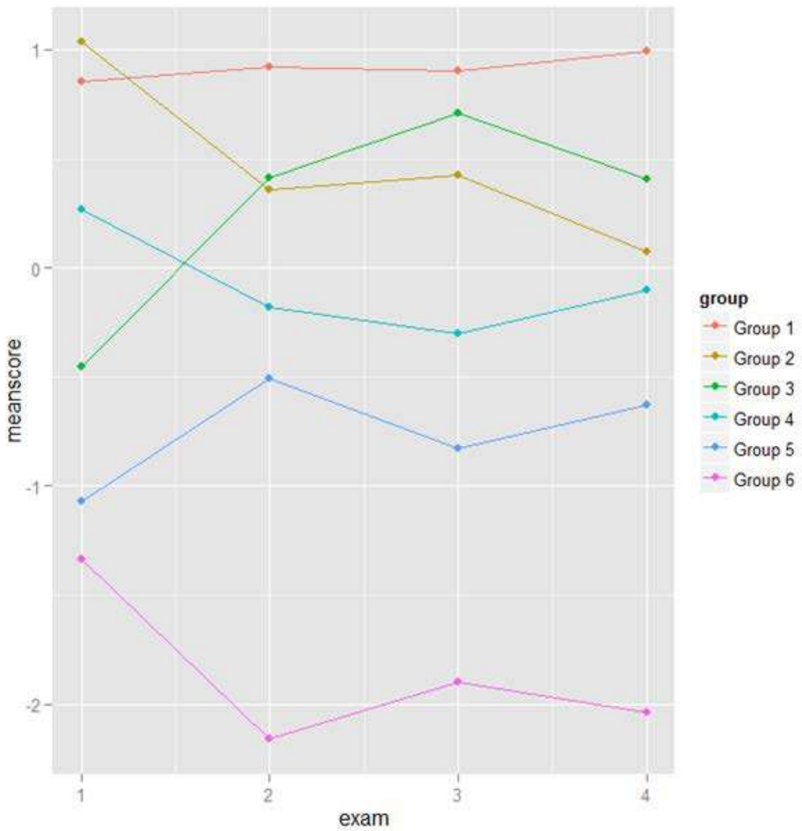

Figure 3. Students' performance trajectories in a semester.

ANOVA analysis findings

ANOVA analysis results showed that there were significant mean differences among the six performance trajectory groups in terms of math self-efficacy [$F(5,145)=10.493$, $p<.001$], the use of metacognitive strategy [$F(5,108)=3.959$, $p=.002$], the number of attempts for each online homework [$F(5,9666)=7.248$, $p<.001$], and the progress of watching each online lecture [$F(5,9676)=13.463$, $p<.001$]. No significant difference was found on the time spent on each online lecture across the six groups. The detailed descriptive statistics of each group including number of cases, mean, and standard deviation of each self-regulatory factor were summarized in Table 2.

In addition, Tukey's HSD post hoc test revealed more detailed information regarding the mean differences across six groups by pairwise comparison. Specifically, with respect to math self-efficacy, perceived math self-efficacy in group 1 was significantly higher than the rest groups and followed by the order: group 2, group 3 or 4, group 5, and group 6. No significant difference was detected between group 3 and 4. This result indicates that students in group 1 hold the highest level of confidence in their capabilities of learning math, while students in group 6 have the lowest level of confidence, and students in group 2 are more confident than those in group 3 and 4. Based on Figure 3, we can see the mean of math self-efficacy in each group roughly correlates with its first exam score, with a higher level math self-efficacy leading to a higher score in the first exam. But no such relationship is observed between the math self-efficacy and students' final exam score.

With respect to the use of metacognitive strategy, students in group 3, 1 and 5 were using significantly more metacognitive strategy than those in group 4, 2 and 6. Especially, students in group 3 reported to use the metacognitive strategy most frequently, and students in group 2 reported to use at a very low frequency. It is interesting to notice in Figure 3 that the performance trajectory of group 3, 1 and 5 all presents an increasing trend, while the performance trajectory of group 4, 2, 6 all presents a decreasing trend. It seems that the performance trajectory may be positively related with the use of metacognitive strategy. The more frequency of the use of metacognitive strategy, the more likely the performance would be improved throughout the semester.

With respect to the two self-regulatory behaviors – attempts and progress, students in group 6 always ranked lowest among six groups on these two behaviors, indicating they enacted significantly less self-regulatory behaviors during the pre-class online learning than students in other groups. No significant differences were found among the rest groups in these two behaviors. Figure 4 demonstrates detailed weekly-self-regulatory behaviors of the six groups. As we can see in Figure 4, students in group 6 basically attempted least on the online homework in each week and also had the lowest complete view of the online lectures in each week. Based upon the performance trajectory in Figure 3, the results indicate that the lack of self-regulation on learning behaviors in the pre-class learning setting may lead to the failure of the course.

Table 2: Descriptive statistics of three self-regulatory factors in six performance trajectory groups

	Group 1 (n=38)		Group 2 (n=15)		Group 3 (n=25)		Group 4 (n=34)		Group 5 (n=24)		Group 6 (n=15)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
MSE	5.87	.89	5.40	1.02	4.63	1.17	4.74	1.41	4.10	1.66	3.36	1.29
Metacog	4.35	2.24	2.05	2.24	4.38	1.87	3.23	2.10	3.69	2.10	1.96	2.10
Attempt	1.04	.94	.96	.91	.97	1.03	.99	.96	1.03	.96	.83	.89
Progress	.43	.50	.41	.49	.42	.49	.36	.48	.40	.49	.30	.46
Time	82.29	191.51	83.81	201.80	96.20	247.84	88.45	238.71	104.37	157.23	89.29	261.83

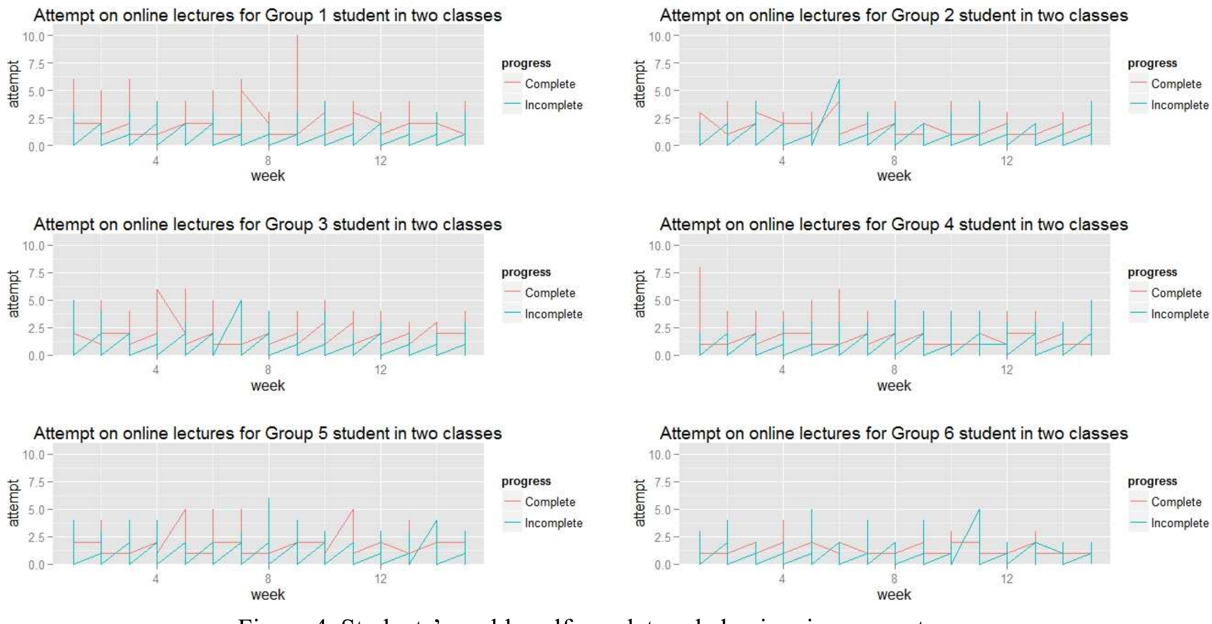

Figure 4. Students' weekly self-regulatory behaviors in a semester.

Conclusions and implications

The present study took an initial step to use both survey research and learning analytics methods to uncover the self-regulated learning process in the pre-class setting of the flipped classroom, and examined the relationship between the self-regulated learning process and students' performance trajectories during a semester in two flipped undergraduate math courses. The cluster analysis revealed six different performance trajectory groups among students. The analysis of survey and behavioral log data demonstrates that students in these six groups are significantly different in the self-regulation process during the pre-class learning. Specifically, math self-efficacy plays a foundational role in the influence of the performance trajectory. Students with higher level math self-efficacy tend to achieve higher in the first exam. However, such the positive relationship does not hold for the rest exams. For example, although students in group 2 perceive higher math self-efficacy than those in group 3, they, however, achieve lower in all exams except the first one than students in group 3. With respect to the use of metacognitive strategy, students who reported as a frequent user of this strategy are more likely to have an increasing performance trajectory during the semester (e.g. students in group 3), while students who reported to rarely use this strategy tend to have a decreasing performance trajectory (e.g. students in group 2). With respect to the regulatory behaviors, students who attempt significantly less on the online homework and only complete a small proportion of the online lecture review (e.g. students in group 6) are very likely to fail in the flipped courses.

The findings from this study have several implications in the field of learning analytics and flipped classroom research. First, in this study, we have shown that learning analytics method offers a great potential to the discovery of behavioral and performance trend, such as the performance trajectory presented in this study. The examination of the trend, rather than a one-time achievement, provides a more detailed look of students' learning process during a semester and makes it possible to identify relationship between the change in the trend and the self-regulated learning process. Second, the findings in this study suggest that teachers in the flipped class should enact tactics to improve or sustain students' perceived math self-efficacy, such as complimenting their growth, attributing the poor performance to the lack of efforts, and encouraging them try harder. They should also pay more attention to students who rarely involve in the pre-class learning and may provide personal feedback to these students during in-class group work. Most importantly, teachers should implement strategies to enhance students' use of metacognitive strategy, such as providing metacognitive feedback to students when they got wrong in the embedded online quizzes, and helping students reflect on their pre-class learning while facilitating group work in class.

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