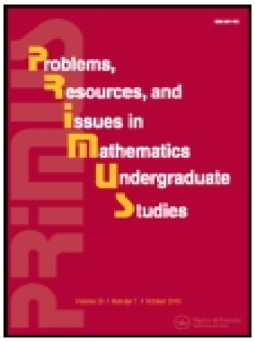

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Developmental Math, Flipped and Self-Paced

Pangyen Weng

Abstract: This article describes a developmental math course design that uses flipped instruction and self-paced learning. The design was created and taught at Metropolitan State University, where most students are returning adult students with little preparation in mathematics. The author argues that this design suits the students well: the learning outcome is better than traditional classes and student satisfaction is high. This article contains three parts: a description of the procedures of the course, learning outcomes with comparison to traditional classes, and analysis and outlooks for future development.

Keywords: Developmental mathematics, flipped instruction, self-paced learning, differentiated teaching.

1. INTRODUCTION

Many students begin their college career with insufficient preparation in mathematics. In the United States, more than 60% of students entering 2-year institutions are required to take at least one developmental math course before they are allowed to take college-level math courses. The lack of math readiness is a major road block to academic success in college: 70% of students taking developmental math do not complete their developmental mathematics courses, and are unable to continue their pursuit of higher learning [1, 2].

Developmental math, once called *remedial math,* is not a new invention in higher education. For decades, colleges and universities have been providing remediation for students before entering college-level math. In recent years, many innovative methods of instruction have been adopted by institutions nationwide, such as blending traditional and online instruction, enhancing student support services, and aligning expectations across education sectors [4].

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At Metropolitan State University, students take a one-semester developmental math course instead of a multiple-semester sequence. For most students, this required course is MATH 98: Introduction to Mathematical Thinking. This course is based on a concise curriculum that focuses only on topics and skills essential to college algebra. Since the content material has varied levels of difficulty and the students have varied levels of competency, it is challenging for instructors to engage all the students and make the most out of class time. This is where flipped instruction and self-paced learning come into the big picture.

Flipped instruction is a concept introduced in the early 2000s and is quickly becoming popular in modern math classrooms [8]. Although there is no universal definition of flipped instruction, flipping the classroom usually means interchanging the function of classroom and home by having students watch video lessons and obtain content information at home, and by conducting in-depth discussion and practices in class. Technology has made it easy to conduct flipped instruction: there are many video lessons on YouTube, and instructors can easily create their own lessons using interactive whiteboard software such as *Educreations* and *ScreenChomp*.

Self-paced learning is natural for mathematics teaching and has been considered by many educators and researchers. Also known as individualized learning or differentiated teaching, self-paced learning is more common at the K–12 levels than in higher education. In self-paced learning, students learn and make progress at their own pace. This approach is believed to be effective in engaging all students in the same class [6, 7]. Different students have different challenges at different times, and a class cannot be truly effective if everyone is forced to sit through the same lecture and learn at a pace dictated by the instructor. With the aid of modern learning technology, advanced students should have the opportunity to learn the material quicker. Students who have difficulties at a certain point should also have the opportunity to work their way through the difficulties and catch up with the class without being rushed.

In the next sections, the author will describe the procedures of his flipped and self-paced course, discuss the learning outcomes in comparison with traditional classes, analyze the strengths and weaknesses, and discuss possible ways of future implementations.

2. A FLIPPED AND SELF-PACED DESIGN

2.1. Background

Like many other universities and colleges in the United States, Metropolitan State University requires that students pass a placement test to enter college-level mathematics courses. Students who are not placed at college-level must pass a developmental math course. Most students take MATH 98: Introduction to Mathematical Thinking.

MATH 98 was created in 2009 to replace a long-time developmental math course MATH 101: Exploring Functions. In 2012 MATH 98 was revised, and it immediately produced impressive outcomes: 68% of students passed MATH 98 in the Fall of 2012, and among the passing students enrolled in subsequent college-level math courses in the spring of 2013, 79% passed at their first attempt.

In addition to great efforts from the instructors and excellent tutoring service provided by the university's math center, two factors were crucial to the success of the revised MATH 98: (i) a concise curriculum with a mastery-driven teaching approach, and (ii) the utilization of web-based learning technology.

The curriculum: The revised MATH 98 focused solely on important math skills necessary for college-level math. A relatively small set of topics was adopted, and instructors were asked to focus on these topics with high expectations. Instead of trying to make up all the math they should have known before college, students would work towards mastery of important math skills by working with teachers, tutors, and classmates, and by practicing relentlessly and repeatedly. The topics of MATH 98 can be found in the Appendix.

Web-based learning technology: During the 2012 revision, a web-based learning technology called *MyMathLab*[1] was adopted by all sections of MATH 98. A generic online *MyMathLab* course was used by all instructors, and assignments of at least 40 to 60 problems were given to students on a weekly basis. Students responded positively towards *MyMathLab*: they liked its immediate feedback and real-time learning aids, and they could keep trying difficult problems until they got the right answers.

As the coordinator of MATH 98, the author envisioned an even more effective MATH 98, which could be accomplished by improving some aspects of the course. First, not all students learn math at the same pace. Students come to developmental math classes with widely divergent skills and motivations. Advanced students who find the pace slow would show little interest, lose focus, start skipping classes, or waste time while waiting for other students to make progress. In the meantime those who struggle with mathematics do not have sufficient time to learn thoroughly or find help. Students routinely comment on these issues in the university's course evaluations.

Second, students rely too much on lectures in class. They need to learn to preview content materials before class and practice hard on arithmetic skills and problem-solving after class.

To address these learning issues of MATH 98, the author created a course design that has the following features:

[1]*MyMathLab* is a product of Pearson Education Services.

1. Flipped instruction. Students view custom-made video lessons before class meetings. Classroom time is designated for discussions and problem-solving exercises.
2. Self-paced learning. The course is divided into multiple modules. Students can move to the next module as soon as they complete a module.
3. High expectations. The passing grade is 80% for all homework assignments, quizzes, and tests.

Some ideas of this design came from Preparation for College Mathematics Program (PCMP) at Ramapo College of New Jersey, a project the author co-created with Drs. G. Viglino and K. Potocka [5]. However these two courses are fundamentally different: PCMP is completely online, whereas the flipped MATH 98 is taught and monitored by an instructor.

2.2. The Course Design

The main concept of this course design is that students study the content knowledge before class, meet for discussions and exercises in class, and then continue learning by using web-based resources. Students obtain content knowledge from video lessons and build skills by doing *MyMathLab* assignments at their own pace, under the supervision of the instructor. The instructor plays an important role in this class: instead of lecturing, the instructor helps students by coaching their math skills, monitoring their progress, and offering help when needed.

This class meets twice a week, each time for 100 minutes. One of the meetings is in the classroom, where the instructor briefly presents material, answers questions, and conducts discussions and exercises. The other meeting is in a computer lab, where students take online tests or do homework on *MyMathLab* with one-on-one assistance from the instructor.

The content of the course is divided into six modules. Each module contains a homework assignment, a quiz, and a module test. Students must pass the homework to enter the quiz and must pass the quiz to enter the test. A module is completed when a student passes the module test. Students must complete a module before moving on to the next module. Students also need to pass a gateway test to be eligible for the final exam. The procedure is illustrated in Figure 1.

Here are descriptions of the components of this course.

Self-paced Learning: Although this course is self-paced, it is offered in the 15-week time frame of a semester. A tentative schedule is recommended to students to prevent them from falling too far behind. In the tentative schedule, Module 1 takes three weeks, Modules 2 to 5 each take two weeks, and Module

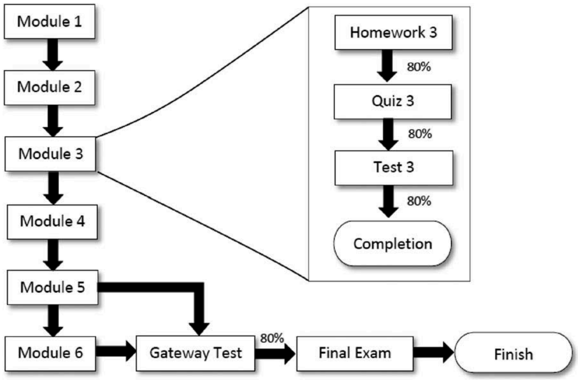

Figure 1. MATH 98 flowchart.

6 takes up to four weeks. The instructor monitors the progress based on the schedule and intervenes when students do not make adequate progress.

Students who are ahead of the tentative schedule are excused from classroom discussions but are required to attend the lab sessions. Other students must attend the discussions and the lab sessions. There is no penalty for falling behind the schedule for less than a week. Students who are behind within three weeks are contacted and invited to meet with the instructor for help. Students who are behind the schedule by more than three weeks are dropped from the class. If they meet with the instructor for consultation, they may receive special permission to remain in the class.

Textbook and calculators: The textbook used in this course is a custom edition of *Elementary and Intermediate Algebra: Graphs and Models,* fourth edition, by Bittinger et al. Only chapters 1 to 4, 10 and 11 are included in the Metro State custom edition. A *MyMathLab* student access kit is bundled with the textbook. Calculators are not required for this course and are not allowed in proctored exams.

Video Lessons: Educreations is an app for iPads that allows instructors to record videos lessons on a whiteboard-like environment. Students view the videos on Educreations.com. Educreations organizes the videos in an online class and records the viewing activities of students. The author created more than 30 videos lessons that are between 10 and 20 minutes long. These lessons cover concepts and problems in specific modules, and are accompanied by student worksheets. Students are reminded that if they do not watch video lessons before class then no credit is given for viewing the videos.

Homework assignments: Each homework assignment contains at 60 to 80 problems. Students must score 80% or higher to pass a homework assignment.

Quizzes: When a student passes a homework assignment, he/she is eligible to take a quiz. Students take quizzes online and on their own. Each quiz has 10 problems, and must be completed within 15 minutes. Quizzes can be considered practices for module tests, as the format and the problems in the quizzes are similar to those in the module tests. Students are allowed to retake quizzes as many times as necessary. The passing score for a quiz is 80%.

Module tests: When a student passes a quiz, he/she is eligible to take a module test. Module tests are proctored by the instructor at the computer lab. For module tests, students must complete 10 problems in 15 minutes and the passing score is 80%. Students are allowed to retake a test until they pass it.

Discussions and written group work: The instructor runs discussion sessions based on a tentative class schedule. He answers questions about the video lessons, demonstrates examples, and makes the class solve similar problems. Students practice problem-solving in groups, but each submits his/her own work. Students who are excused from discussions can instead submit written work on problems in the online quiz. Written work is graded for credit.

Attendance: Students are excused from discussions if they are ahead of the tentative class schedule. All students are required to attend the lab.

Final exam: Students must: (i) complete at least the first five modules; and (ii) pass a gateway test to be eligible for the final exam. Module 6 is not required to be eligible for the final exam. It would be inequitable to require it because many students in traditional classes would struggle with the same material but still manage to take the final exam and sometimes pass it. However, the final exam does contain material from Module 6 and students are expected to learn as much as possible.

The gateway test consists of 10 problems and includes topics such as fraction operations, the distributive property, functions, and linear equations. Students are given 15 minutes for the gateway test, and are allowed to retake it until they pass it. The passing score is 80%.

The final exam is a 90-minute 24-problem exam. Students cannot retake the final exam. Students may take the final exam whenever they are eligible for it. In the experiment, six students were eligible to take the finals early, and two students did, in fact, do so.

Grading policy: Out of 100 points, students earn 10 points for completing each module on-time, or eight points for completing a module past the due date. They also earn up to 10 points for graded written group work. The final exam is worth 30 points. Table 1 shows the grading scale without shaded grades.

Table 1. Grading scale

	Points				
	[0, 50)	[50, 70)	[70, 80)	[80, 90)	[90, 100]
Grade	F	D	C	B	A

3. LEARNING OUTCOMES AND STUDENT FEEDBACK

In the Fall of 2013, the author taught two classes of MATH 98 with the flipped design. Students were not aware before the first day of class that they would be taking a flipped class; they were subsequently offered to opportunity to switch to a traditional class.

In this section the author compares the outcomes of the two flipped classes with two traditional classes the author taught during 2012 and 2013 with the same curriculum and expectations. In both flipped and traditional classes, students must meet certain requirements to become eligible for the final exam. See Table 2 for the comparison.

3.1. Comparison of Course Grade

The students in flipped classes earned higher grades and had a higher passing rate. The grade distributions of the two groups are shown in Table 3. Note that the grading schemes are different between flipped and traditional classes.

Table 2. Enrollment and retention

Class type	Enrolled	Minus withdrawals	Eligible for final
Flipped	62	56	45
Traditional	63	59	42

Table 3. The Grade distributions of the course grades

Class type	Number	A (%)	B (%)	C (%)	D (%)	F (%)	W/I
Flipped	56	41	21	14	–	5	18
Traditional	59	17	22	10	8	22	20

3.2. Comparison of Final Exam Results

Students in the flipped classes were given final exams equivalent to those given in traditional classes. Compared with traditional classes, the flipped classes have a similar percentage of A grades in the final exam, but a higher percentage of B and C grades (see Table 4).

3.3. On-Time Completion Rates

For the self-pacing aspect of this design, the percentages of students completing each module, on-time or past the due date, are listed in Table 5. Note that Module 6 is not required in order to enter entering the final exam, and its deadline is the day of the final exam.

3.4. Student Survey

A survey of 13 questions and open-ended student comments was given to students at the end of the semester. A total of 39 students took the survey, and the results are summarized in Table 6. Notable outcomes include:

- 79% of students were learning at their own pace (instead of the scheduled pace);
- 72% of students have a lower anxiety about maths after taking this class;

Table 4. Distribution of final exam results

Class type	Number	A (%)	B (%)	C (%)	D (%)	F (%)
Flipped	45	20	24	24	24	7
Traditional	42	21	12	17	33	17

Table 5. On-time completion rates

Module	Number	On-time (%)	Past due date (%)
1	58	91	9
2	54	56	44
3	54	74	26
4	53	66	34
5	45	58	42
6	25	100	–

Table 6. Survey results

Statement	SA (%)	A (%)	N (%)	D (%)	SD (%)
The online learning resources are adequate	51	33	10	5	–
The support from the instructor is adequate	59	33	8	–	–
I have enough opportunity to develop my math skills	46	38	8	8	–
I am able to learn at my own pace	51	28	10	10	–
Tests on *MyMathLab* helps me learn better	51	21	23	5	–
Assignments and quizzes on *MyMathLab* helps me learn better	44	36	18	–	3
Instructor's online video lessons help me learn better	41	26	31	3	–
Class discussions help me learn better	54	31	13	3	–
I have less math anxiety compared to the beginning of this class	41	31	18	8	–
I am confident in taking my next math class	44	28	26	3	–
I have learned a lot of math in this class	46	35	14	5	–
The format of this class suits me better than lectures in a traditional math class	59	24	11	3	3
I would recommend this class to others	65	14	19	–	3

Note: SA = Strongly agree; A = Agree; N = Neutral; D = Disagree; SD = Strongly disagree.

- 83% of students think that the flipped format suits them better than lectures in a traditional classroom;
- 79% of students would recommend this class to others.

Student comments on this course were mostly positive. Here are some excerpts:

- (I like) the videos the teacher made. (I like) *MyMathLab* view-an-example tab.
- (I like) the online component. I couldn't do what I was able to do if this were a traditional lecture.
- I like the amount of opportunity to learn at your own pace - I like how the computer breaks down everything for me. If I don't understand, my instructor is always there to help.
- The questions I had were answered by our prof during lab testing.
- I liked being able to take my time with each lesson. It helped me learn better. Also the reviewing in class helped me a lot.
- Like learning at my own pace and I also liked having all the online resources available to me whenever I needed them.
- I really appreciated being able to learn at my own pace. It worked with my busy school schedule very well.
- (I like that) it's both in-class and online.
- I really liked how this class was run. It really helped me with my math knowledge.

4. ANALYSIS AND FUTURE DEVELOPMENT

4.1. Strengths of the Design

Learning outcomes and student feedback of the flipped classes suggest that the flipped design has met or exceeded all initial expectations. To be specific, the flipped classes have the following advantages.

1. *Improved learning outcomes*. The combination of flipped teaching and self-paced learning significantly improves student learning outcomes. One indicator is the final exam that measures student competency at the end of the course. When compared with traditional classes, flipped classes have similar percentages of A grades (20% versus 21%), but higher percentages of B grades (24% versus 12%) and C grades (24% versus 17%). (See Table 4.)

   Students in flipped classes receive much higher grades than those in traditional classes (see Table 3). In addition to improved learning, students benefit from a favorable grading scheme that rewards them with a full credit for completing a module. The author thinks this encourages students to make a consistent effort in learning. Under this scheme, students who are on pace with the class schedule usually earn either an A or B grade provided they perform reasonably in the final exam.
2. *Excellent teaching and learning experiences*. Students respond well to flipped instruction because it allows them to access information and learn mathematics anytime they want. They are more engaged in their own learning: instead of coming to a lecture not knowing what to expect, they come to class for a higher level of learning, where questions are answered, important concepts are reinforced, and more problem-solving is practiced.

   Self-paced learning reduces stress and increases productivity. Although it is not unusual for students to fall behind the schedule in traditional or flipped classes, students in flipped classes usually manage to catch up without seriously hurting their progress or grades. They also feel less stress because they are in control of their own pace and progress.

   The author enjoyed teaching this course. He was able to be a guide at their side, not a sage on the stage. Although students were doing hands-on learning, the instructor could target difficult course material and provide individualized assistance anytime to anyone who needed it. Students liked the fact that their instructor guided them through the course instead of lecturing them on the course content and later judging them via testing and grading them.
3. *Improved academic skills*. Students in MATH 98 need to be taught not only the content but also how to learn it. In the flipped class, students preview before class meeting, discuss with classmates in groups, keep trying until getting correct answers, solve problems in timed online tests, meet with

instructor or tutors for help, and monitor their progress regularly. These learning activities improve their academic skills and make them better learners.

4. *Easy management of withdrawals and incompletes*. At Metropolitan State University, students who fail or withdraw from a class have to retake it and start all over again. Students who receive an incomplete can get their grades converted if they fulfill an *individualized completion plan* under the supervision of the instructor in the following semester. In reality, incompletes seldom get converted because an individualized completion plan is hard to manage when the student and instructors are occupied with other courses in a new semester.

   For flipped classes, if a student fails or withdraws from the class, they would continue their work when they enroll again. An incomplete is only granted to a student who has completed at least four modules, and the completion plan is simple: The student will complete the rest of the work. A students with an incomplete has full access to the computer lab, the university's testing and tutoring services, and the instructor's office hours.

4.2. Things to Improve

1. *Unlimited retakes were counterproductive*. Students who fail a particular test multiple times often resort to memorizing formulas and patterns of solutions instead of trying to better comprehend the problems. Since the problems in tests are similar and there are unlimited retakes, some students might eventually pass them without fully achieving the desired learning objectives. A possible solution is to limit the number of retakes and require students to put in extra work or consult with the instructor before trying the tests again.
2. *The number of custom-made video lessons viewed was sometimes lower than expected.* This happened at the beginning of the semester when students were still expecting traditional lectures, and during the semester when the materials were easier. Some students also seemed to have a habit of starting homework right away, and viewing video lessons or using *MyMathLab* learning resources only when needed. Viewing video lessons is important for the flipped classroom, and in the future the author would consider making video lessons prerequisites of homework assignments.

4.3. Future Development

This design can be used in developing new pedagogy and instruction practices to provide better learning experience to more students. The author is particularly interested in exploring in the following directions.

1. *Flipping college algebra*. College algebra is considered one of the most difficult courses for average students: nationally, the passing rate of students enrolled in college algebra is 40% [9]. Not only do students struggle with content knowledge, many of them also lack interest and do not enjoy the learning experience. If flipped classes are successful for developmental math, it might also be suitable for college algebra. The nature of college algebra is similar to that of developmental math: it is skill and problem-solving oriented, it requires a lot of practice and coaching, and the benefit of self-paced learning outweighs the benefit of lectures in the classroom.
2. *Collaboration among instructors.* The flipped design makes it easy for instructors to co-teach classes by dividing the duties into discussion sessions and lab sessions. It also allows the math department to best use its instructors by staffing the discussion sessions with more experienced instructors and staffing the lab sessions with less experienced instructors or teaching assistants. Another idea is to team up a group of instructors and create a math learning lab that is accessible to more students.
3. *Rolling enrollment.* Many universities admit students year-round on a rolling basis. It would be fantastic to also enroll students in developmental math on a rolling basis. Students should not wait until the beginning of the upcoming semester to start learning developmental math. With the flipped design, it is possible to create a system that enrolls students as soon as they are admitted, generates individualized study plans for them, and initiates learning right away. Eventually, college algebra and other math courses with self-paced learning designs can also be integrated into the system. These courses would form self-paced math sequences.

   Rolling enrollment might sound like an administrative mess involving faculty resources, student billing, grade registration, etc., but more and more institutions are finding ways to implement it. More than 350 institutions have been offering or are seeking to create self-paced and competency-based programs since 2013, when the U.S. Department of Education began to allow student aid to go into such programs in higher education [3, 10].

5. SUMMARY

In an era when online classes play an increasingly important role in higher education, mathematics remains as one of the rare subjects where many instructors and students still value face-to-face delivery of knowledge. The flipped and self-paced design combines the best of the two worlds of online and classroom instructions: students can learn the course anywhere and anytime by using web-based technology, and they also receive personalized help and in-depth instruction from meeting with the instructor. This design produces better learning outcomes and excellent learning experiences for students. The author recommends this design to instructors of developmental-level and college-level algebra, and to institutions that are interested in creating significant learning experiences via innovative ideas.

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The author thanks the Mathematics Department of Metropolitan State University for supporting his exploration and experimentation on instructional designs of developmental mathematics over the years. The author also thanks Dr. G. Viglino of Ramapo College of New Jersey for being a mentor and for his many visionary ideas of teaching developmental mathematics.

APPENDIX: TOPICS OF MATH 98

The following topics are covered in MATH 98. They are organized in modules for use in the flipped classes. They are based on *Elementary and Intermediate Algebra: Graphs and Models,* fourth edition by Bittinger et al.

- Module 1: 1.1 Introduction to Algebra. 1.2 The Commutative, Associative, and Distributive Laws. 1.3 Fraction Notations. 1.4 Positive and Negative Real Numbers. 1.5 Addition of Real Numbers.
- Module 2: 1.6 Subtraction of Real Numbers. 1.7 Multiplication and Division of Real Numbers. 1.8 Exponential Notation and Order of Operations. 2.1 Solving Equations. 2.2 Using the Principles Together. 2.3 Formulas.
- Module 3: 2.4 Application with Percent. 2.5 Problem-Solving. 2.6 Solving Inequalities. 2.7 Solving Applications with Inequalities.
- Module 4: 3.1 Reading Graphs, Plotting Points, and Scaling Graphs. 3.2 Graphing Equations. 3.3 Linear Equations and Intercepts. 3.4 Rates. 3.5 Slope.
- Module 5: 3.6 Slope-Intercept Form. 3.7 Point-Slope Form; Introduction to Curve Fitting. 3.8 Functions. 10.8 The Complex Numbers.
- Module 6: 11.1 Quadratic Equations. 11.2 The Quadratic Formula. 11.6 Quadratic Functions and Their Graphs.

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BIOGRAPHICAL SKETCH

A native Taiwanese, Pangyen "Ben" Weng came to the United States at the turn of the 21st century, earned his Ph.D. from University of Minnesota, and fell in love with the land of 10,000 lakes. Since joining Metropolitan State University in Saint Paul, Minnesota, Ben has focused mainly on improving its developmental mathematics program. His motto is *anyone can learn math.*