Board 80: Integrating Adaptive Learning Lessons in a Flipped STEM Course: Development, Learning Gains, and Data Analytics

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Nicholas Abate attended the University of South Florida where he obtained a Bachelor's degree in Mechanical Engineering, graduating Summa Cum Laude. During his time at USF, he was an active member of the Society of Aeronautics and Rocketry, as well as the Society of Automotive Engineers. In his final year of academia, Nicholas worked with Professor Kaw as an undergraduate research and learning assistant for a numerical methods course to study the effectiveness of flipped classrooms with adaptive learning.

Integrating adaptive learning lessons in a flipped STEM course: development, outcomes, and data analytics

Introduction

The flipped classroom is currently a popular pedagogy [1] as it is believed to improve student engagement, create self-regulation of learning, and establish habits for life-long learning [2]. In addition, the increased amount of in-class active learning created by the implementation of this pedagogy is meant to improve student performance. This increase is evident from a meta-study of Freeman, et al. [3] where a medium effect size (Cohen's d=0.47) was observed for active learning classes over traditional classes via assessments such as final examinations and concept inventories.

The modern flipped classroom typically involves more than watching video lectures at home and doing homework in the classroom [1]. In addition to watching lecture videos or doing textbook readings, students often take online quizzes before class or at the beginning of class time. These quizzes are conducted to ensure that students come prepared to class so they can actively participate in the classroom activities. However, this approach does not differ based on the needs of the students as everyone gets the same pre-class assignment. This aspect can be monotonous to some students who may readily understand and are able to implement the content while leaving others frustrated if they have some gaps in the understanding of the pre-requisite material. This frustration can result in student resistance when incorporating the flipped classroom [4].

A solution to the pre-class learning issue, which we implemented in a numerical methods course for engineering students, is to implement adaptive lessons through an adaptive learning platform (ALP) such as Smart Sparrow [5]. Smart Sparrow adaptive lessons pace and direct students through pre-requisite and new content and assess their knowledge and understanding as they go. Performance and behavior-based metrics, such as the number of attempts to complete a lesson, lesson score, and time spent per lesson, are automatically collected by the ALP for analysis by the instructor.

Development

As part of an NSF grant between 2013 and 2016, instructors at three universities, University of South Florida, Arizona State University, and Alabama A & M University, taught a course in Numerical Methods for engineering students using both a flipped and blended modality. Cognitive and affective learning outcomes were compared between the two modalities through a final examination, surveys, and focus groups. No statistically-significant differences between these two modalities were observed, and the effect sizes (illustrating the practical significance of the differences) were small [6]. However, during the focus groups and surveys, students as well as instructors mentioned the benefits of solving problems in the flipped classrooms. These benefits included the discussion with their peers, the immediate help available through the teaching assistants and the instructor, the preparation engendered, and the resulting engagement. A follow up *exploratory* NSF-funded study [7] was therefore conducted at the University of South Florida to improve the flipped classroom by implementing the pre-class learning assignments as adaptive lessons. It is the pre-class assignments in the flipped classroom where student resistance is most expected [4], [8].

We prepared 17 adaptive lessons that covered half of the topics of the Numerical Methods course at the University of South Florida. The ALP allowed the combining of videos, textbook content, simulations, and quizzes. The quizzes consisted of multiple-choice, fill-in-the-blank, and algorithmic questions which provided students with immediate feedback on their errors. Based on how the students responded to the questions on the quiz, they were directed along personalized paths.

To give an example of the adaptive lessons, the development of lessons for the Gaussian elimination method of solving simultaneous linear equations will be discussed. Matrix algebra used to be a required course in the engineering curriculum at the University of South Florida, but now a concept of matrix algebra is taught when needed and hence all students are not equally prepared in the fundamentals. With 36% of students being community college transfers and having students at different levels of course completion at USF (36% of students are over-traditional age), adaptive lessons for the pre-requisite knowledge served to develop uniform competency amongst students. Students who already know the content could breeze through the lessons, while others would get a critically needed review of the material. The four pre-requisite lessons for the Gaussian elimination topic included the definition of matrices, binary operations on matrices, setting up of simultaneous linear equations in matrix form, and finding the inverse of a matrix. Example lesson content from the nonlinear regression topic is shown in Figure 1.

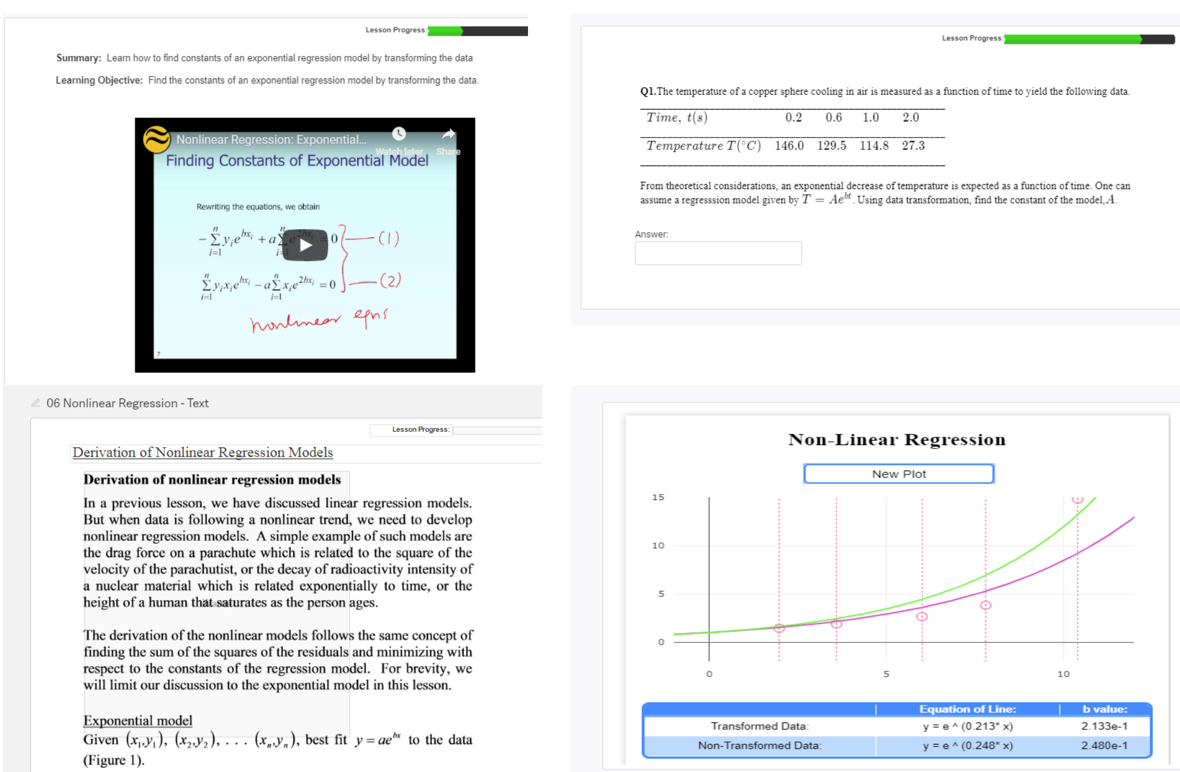

Figure 1. Typical content of an adaptive lesson for nonlinear regression

Implementation

The adaptive lessons were seamlessly presented to the students through the learning management system (LMS) of CANVAS (Figure 2). No additional passwords or new user interfaces were involved. The students could take a lesson as many times as they liked. The highest score out of all attempts was reported automatically to CANVAS.

Figure 2. Typical pre-class assignment via the LMS

The adaptive lessons were assigned online on Thursdays at 5 PM, covering the content for the next week, and were due at 11:30 AM on the following Tuesday. This schedule was chosen because the class meeting times for the two sections of the course were 12:30 PM–1:45 PM and 3:30 PM–4:45 PM on Tuesdays and Thursdays.

The class time was spent on the following:

a) students individually answered three to six conceptual questions followed by peer-to-peer discussion and explanation by the instructor [9] - [11],
b) students worked on as many procedural exercises out of the six assigned per topic, and
c) instructor delivered micro-lectures on topics requiring extra explanation based on what students struggled with in the pre-class assignments.

Only the conceptual questions were graded.

Summary of Results

Results and outcomes based on an analysis of the ALP performance metrics, final examination, surveys, and focus groups were determined and are summarized below.

The student-level ALP metrics included the number of attempts to complete a lesson, the raw score (based on all attempts made), the lesson score (based on the maximum score for the various attempts), the time spent on a lesson and the number of hours before the deadline that a lesson was completed. Lesson-level metrics included the percentage of students who completed the lesson and percentage of adaptive feedback in use. This latter percentage was based on the number of custom states or states with adaptive feedback that were triggered and seen by at least one student.

In assessing the relationship between final examination performance and ALP use, the correlations between the final examination results and most of the lesson metrics were not sizable or statistically significant. For example, there was almost no relationship between the final examination score and the total hours spent on the lesson ($r = -0.003$, $p=0.972$). Since most students received high lesson scores because they could pursue multiple attempts, we sought to differentiate the lesser performing from the better-performing students. This differentiation was evident in the relationship between the final examination score and the raw score, which was based on all attempts, where we measured a correlation of $r=0.35$ ($p<0.0005$). This demonstrated that students who answered the questions correctly on the initial attempt achieved better performance on the final examination, suggesting that stronger preparation or due diligence may contribute to better exam performance.

To assess the impact of the adaptive lessons on cognitive outcomes, identical two-hour-long final examinations were given for the two teaching modalities –flipped instruction with adaptive learning and flipped instruction without adaptive learning. The final examination consisted of two parts – 14 multiple-choice questions and 4 free-response questions. Both parts were weighted equally. There was no statistically-significant difference in the students' average performance across the two treatments ($p=0.547$), but the higher mean was achieved by students in the flipped classroom with adaptive learning ($d=0.12$). Students' pre-requisite-course GPA was used as a control variable in comparing the means using an analysis of covariance (ANCOVA).

To determine if adaptive lessons were associated with enhanced affective outcomes, the College and University Classroom Environment Inventory (CUCEI) was used [12]. This inventory measures seven psychosocial dimensions of the classroom:

1. cohesiveness (the extent to which students know and help one another),
2. individualization (the extent to which students are treated individually and differentially),
3. innovation (the extent to which new class activities or teaching techniques are used),
4. task orientation (the extent to which class activities are well organized)
5. involvement (the extent to which students participate in class activities),
6. personalization (the extent to which interaction takes place with instructor), and
7. satisfaction (the extent to which classes are enjoyed by students).

The classroom environment was rated higher for the flipped classroom with adaptive learning with medium effect size and significant differences at $p<0.05$ for three of the seven dimensions. One of these three dimensions was Individualization ($d=0.43$), which measures individual or differential treatment and is a primary goal of adaptive instruction. Personalization ($d=0.6$) and task orientation ($d=0.53$) were the other two dimensions for which there were statistically significant differences.

Focus groups were conducted to learn about student perspectives on the adaptive learning, and the groups were based on student demographics: 1) white males, as they formed the majority of students in the population studied, and 2) those who were not white males. The latter group was more supportive of and positive about the adaptive lessons. The advantages pointed out by both groups included having

1) all content available in one place via the adaptive software,
2) been held accountable for the learning of the content,

3) control over the pace of the learning,
4) reinforcement via quizzes, and
5) the ability to learn through multiple forms of content and unlimited attempts.

Specifically, for those who were *not* white males, lecture preparation, content understanding, and enhanced accountability for the material was the adaptive-learning feature that was most-frequently explained as helpful to their learning. This was followed by the presence of quiz questions, whereby they could confirm, reinforce, or gain understanding. In discussing their satisfaction and engagement, this group discussed the convenience of the guided approach with the adaptive platform, including the availability of all resources from the same website, the ability to work at one's own pace, and the capability to re-watch videos and re-work questions as many times as needed or desired. The quiz questions also aided their engagement.

Based on the positive results of this exploratory study of using adaptive lessons to improve pre-class learning in flipped classrooms, we believe that the study should be extended to gain additional insights by developing adaptive lessons for all the topics of the Numerical Methods course and implementing and assessing them at multiple universities to obtain a diverse student population. A proposal for this was submitted to the National Science Foundation in December 2018 with the goal and hope of continuing this needed research in the area of adaptive learning in the university STEM classroom. Two journals papers [13-14], one in print, and another submitted for review provide extensive details of what is summarized in this paper.

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