Sequencing Content in an Adaptive Testing System: The Role of Choice

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ABSTRACT
The effect of choice on student achievement and engagement has been an extensively researched area of learning analytics. Current research findings suggest a positive relationship between choice and varied outcome measures, but little has been reported to indicate whether these findings hold in the context of Intelligent Tutoring Systems (ITS). In this paper, we report the results of a randomized controlled experiment in which we investigate the effect of student choice on assignment completion and future achievement in an ITS. The experimental design uses three conditions to observe the effect of choice. In the first condition, students are able to choose the order in which to complete assignments, while in the second condition, students are prescribed an intuitive order in which to complete assignments. Those in the third condition were prescribed a counter-intuitive order in which to complete assignments. Results indicate that allowing students to choose the order in which to work on assignments leads to higher completion rates and better achievement at posttest. A post-hoc analysis also revealed that even considering students with similar completion rates, those given choice had higher posttest scores than those observed in any other condition. These results seem to support the many theories of the positive effect of choice on student achievement.

CCS Concepts
• **General and reference~Empirical studies** • **General and reference~Experimentation**.

Keywords
Mastery Learning; Student Choice; PLACEments; ASSISTments; Remediation Assignments.

1. INTRODUCTION
The concept of mastery learning is based on a philosophy that states that "all students have the ability to learn anything" and that this ability is a function of time. In other words, given a new topic, it is merely a matter of time and practice before one can reach a state of understanding. It has also been suggested that mastery learning is purely teacher-paced, where teachers determine the order in which students must learn specific knowledge components or skills.

An opposing philosophy to mastery learning is known as the personalized system of instruction (PSI), in which students decide on their pace and the amount of content they learn. [2] Ritter, Yudelson, Fancsali, and Berman conducted a study in which mastery learning of content in the Cognitive Tutor was compared to teachers' prescriptions of the order in which to present content. [10] It was found in this work that the system's determination of ordering caused significant improvements in student learning. Their findings suggested that using ITS to prescribe the order in which students were presented a set of knowledge components or skills was a better approach to learning than allowing teachers to determine or prescribe content order. From a different perspective, these results seemed to show that choice, at least at the teacher level, did not cause learning gains.

The effect of choice on various aspects of human life has been studied for many decades. Watanabe & Sturmey performed a meta-analysis of publications in the area of metacognition and the effect of choice on student performance and found that, particularly for students with disability, allowing choice has many benefits. [13] Choice was shown to improve student engagement on tasks as well as propensity of completion. Additionally, it has been shown that intrinsic motivation to carry out general tasks can be improved when students are given choice. [3] Other researchers have observed the positive effect of choice on outcome measures in a number of varied activities. [6, 9, 14] Wang & Stiles showed that students completed more tasks when asked to choose when and how to complete the tasks. [12] This phenomenon is evident in preschoolers [1], high-schoolers [11], and college undergraduates [14]. Across ages, the primary contributing factor causing the increase in performance and rate of completion has been attributed to the motivational effects of choice.

The extent of the effects of choice are sometimes conflicting across different studies. Flowerday and Schraw [4], for example, show that choice had a positive effect on attitude and effort, however the effect on cognitive engagement was minimal or non-existent. While not unanimous across all domains and studies, there is compelling argument to pursue the study of choice for its potential benefits in learning. Understanding how the positive aspects of choice can best be implemented to improve students' learning experiences is a topic still in need of research.

Despite the many benefits that seem to be derived from choice, ITSs rarely offer features that allow students to make choices

regarding what they learn, and when and how to remediate content that they may be lacking. Ostrow & Heffernan conducted a randomized controlled experiment in which they investigated allowing students to choose the type of feedback received while working on an assignment and its effect on assignment completion and future performance. [8] They compared students who were given the choice to decide on the type of feedback received with those who randomly received a particular type of feedback. They found that students given choice had significantly better achievement than those in the control group, lending credence to the notion that choice has a positive impact on student performance within an ITS.

In this study our goal is to investigate the effect of choice on student assignment completion and learning gains when given the opportunity to choose the order in which to complete assignment tasks. We report on a randomized controlled experiment in which students were placed into three conditions. In one condition, students were asked to choose the order in which to complete the assignments, whereas students in the other two conditions followed different prescribed content orders. We also report a post-hoc analysis of the study in which we find that, for students with similar assignment completion rates, those in the choice group performed better at posttest than those in either prescribed condition.

1.1 Research Question
The following research question is addressed in the present study:

Does allowing students to choose the order in which to remediate skills improve adherence in the form of assignment completion rates, and/or Math achievement?

In other words, does choice matter? What is the relationship between student choice and mastery learning?

2. METHODS
This section describes the methods employed in answering the research questions stated above. We ran the randomized controlled experiment in PLACEments, an adaptive testing system. This system is described briefly in this section. We then present the experimental design, the participants used in the experiment, and the outcome measures of interest.

2.1 An introduction to PLACEments
PLACEments is a computer-aided adaptive testing feature of ASSISTments, an online learning platform powered by Worcester Polytechnic Institute. [5] PLACEments uses a prerequisite skill graph that underlies the system, created based on the Massachusetts Common Core State Standards for Mathematics. [7] All PLACEments tests are teacher-driven, in that teachers choose what and when to assign. These tests are composed of an initial set of skills selected by the teacher, and once assigned, students are tested on questions related to the initial skills. If a student performs poorly on any of the initial skills, the system traverses the skill graph to select questions from the immediate prerequisite skills of the incorrect items. These items are then included on the test, and the graph traversal for item selection continues until the system determines that there are no further prerequisite skills to be shown or the traversal reaches a predefined end point in the graph; the predefined end-point is set at test creation time. In this manner, the system can isolate and map the depth of gaps in students' knowledge, while providing opportunity for remediation.

2.1.1 Progressing through the Test
For the sake of simplicity, we use the hypothetical graph shown in Figure 1 to explain how the test proceeds. The nodes in the graph represent skills or knowledge components. The arrows between skills represent the order in which students need to learn these skills/concepts in order to succeed in the subsequent skills. They therefore show the prerequisite relationships between skills (thus, skill 'D' is one of the prerequisites of skill 'A'). The correctness indicators attached to each node in the graph are a representation of a given student's performance during the test. In this configuration, the student is assigned 'A', 'B', and 'C' as initial skills in the test. The system presents the student with questions from these skills, and since the student performs poorly on skill A (as shown in the graph), the student is further tested on skills D, E, and then subsequently H since the student did not demonstrate mastery of skills E and H respectively.
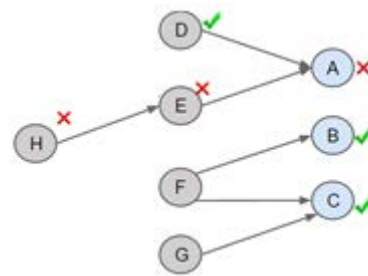

Figure 1 A sample skill graph and a sample student's response configuration

Generally, the tests are meant to identify students' lack of specific skill knowledge and to find which prerequisite skills to blame for that missing knowledge.

2.1.2 Remediation Assignment Creation and Release
Once the knowledge gaps are determined from the test, PLACEments attempts to help students close that gap. Once the test is completed, students are assigned remedial practice questions on the skills in which they performed poorly. The release of these assignments is staggered and is based on the underlying prerequisite skill graph that PLACEments depends upon, and the number of these "remediation" assignments given is dependent on the student's performance during the test. The remediation assignments of the lowest grade level skills on which the students performed poorly are released first and, once completed, subsequent post-requisite skill remediation assignments follow. In the configuration depicted in Figure 1, the remediation assignment for skill H is released and completed before the assignment for E is released. The assignment for skill A will be held back until the student completes skill E. All remediations are mastery-based assignments referred to as "skill builders," in which students are given similar skill-based items until a predefined threshold of understanding is reached; this threshold is usually met by answering three consecutive items correctly.

2.2 Experiment Design
We ran a randomized controlled trial in PLACEments in which we experimented with the order in which remediation assignments were released. Figure 2 illustrates the experimental design for this study.

As shown in Figure 2, each participant is given a predefined PLACEments test which has various initial skills. These

assignments are teacher-assigned and may have varying degrees of difficulty. After the tests, students are randomly placed in one of three conditions. In the first condition, "Prerequisite to Postrequisite," participants are assigned remediation skill builder assignments beginning with the skills of the lowest grade level and the graph is traversed in the pre-to-post direction. Participants are required to complete all released remediation assignments for a given test before the subsequent post-requisite skill related assignments are released. This condition typifies the current graph traversal direction for remediation assignments that are released in PLACEments (See section 2.1.2 for more details).
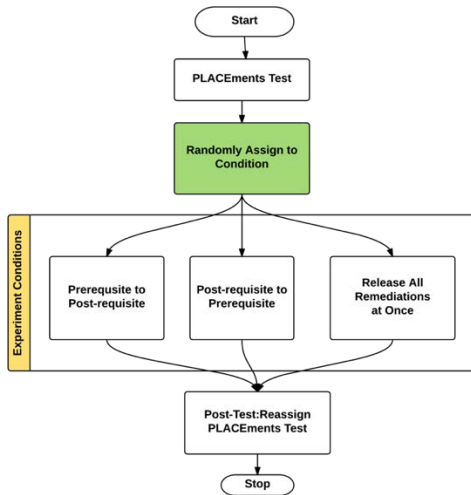

Figure 2 Experimental Design

The "Post-requisite to Prerequisite" condition has a similar behavior as the "Prerequisite to Post-requisite" condition with the exception that the graph is traversed in reverse, from the post-requisite to the prerequisite skills, which is counter intuitive to most teachers. In the third condition, graph traversal is not considered. For all participants in this third condition, the release of remediation assignments is not staggered, nor is it based on the prerequisite skill graph. Instead, all remediation assignments are released to the students at once and they get to choose the order in which to complete their assignments.

A month after the initial test, students had the opportunity to retake their initial PLACEments test as a posttest to gauge the amount of learning that had occurred from the remediation assignments and, ultimately, the effect of condition.

We also performed a post-hoc analysis of the data collected from this experiment. In this post-hoc analysis, we investigated the effect of other PLACEments test features and the condition assignment on student's performance gain over the study period.

2.3 Participants
For this experiment, there were 410 student participants, each of whom was assigned the initial PLACEments test as well as the reassignment that served as the outcome measure. All students were 7th and 8th grade users of ASSISTments. The participants had varying levels of math competence and were randomly assigned to one of the three previously described conditions in the study. The "Prerequisite-to-Post-requisite," "Post-requisite-to-Prerequisite," and "Release All" conditions had 129, 145, 136 students respectively. Random assignment to condition was performed after the initial PLACEments test was completed. The results of the tests in no way impacted random assignment.

2.4 Outcome measures
To determine the effectiveness of choice, the following outcome measures were used: *remediation completion rate*, *performance on posttest,* and the *learning gain* from the initial to the reassigned PLACEments tests (i.e., from pre to posttest).

The completion rate, in this context, is the ratio of remediation assignments completed to the number of remediation assignments assigned. This outcome measure was intended to help determine whether the order in which remediation assignments were released had an impact on students' assignment completion rates. Additionally, we use students' performance on the second PLACEments test as a second outcome measure (i.e., posttest). We also considered the gain in PLACEments test performance. This gain was the mathematical difference between the initial test performance (expressed as percent of items answered correctly) and that of the second PLACEments test.

3. RESULTS
In this section, we present an initial intent-to-treat analysis of all the participants in the experiment and further describe an analysis of students who participated in the post-test. We then proceed to answer the proposed research questions using data from students who were actually treated. The dataset for this experiment can be found at http://tiny.cc/palsrct5data.

3.1 Effect of Choice on Remediation Assignment Completion Rate
Though all 410 students in the study were expected to complete the posttest, we found that a high percentage of students did not have the opportunity to do so. In some cases teachers prevented entire classes from completing the posttest, while in other cases, the school year ended before students had the opportunity to take the posttest. In view of this, only one of our research questions can be answered using the entire population of the study.

In regards to the impact of choice on assignment completion**,** Table 1 shows the remediation completion rate for each of the conditions in the study. There was no significant difference in remediation completion rates between conditions (p-value > 0.05). Though students in the counter intuitive condition (i.e. post-to-pre condition) seemed to have a slight edge over students in other conditions, the difference was not significant. The observed difference may be due to the fact that the post-to-pre condition encouraged students to complete more assignments because they presumably navigated from difficult assignments to easier assignments. Generally, there was a low average remediation assignment completion rate of 0.38 across the entire population.

Table 1: Remediation Completion Rates by Condition

Condition	Participants	Mean Completion Rate
Pre-to-post	129	0.38
Post-to-pre	145	0.42
StudentChoice	136	0.35

3.2 Effect of Choice on Post-test Performance
Of the 410 initial students, 70 students completed the post-test. As Table 2 shows, the students were randomly and almost equally distributed across the different conditions. This section describes the effect of choice on performance of these students on the post-test.

Table 2 Completion Rates and Learning Gains

Condition	Number of Participants	Average Completion Rate*	Learning Gain*
Pre-to-post	22	0.457	0.038
Post-to-pre	26	0.476	0.120
Release All/ Student Choice	22	**0.512**	**0.310**
Total	70		

* Significance with p-value <0.05

Among others, Table 2 shows that students in the pre-post condition who completed the posttest also completed far more remediation assignments than those in the other two groups. Additionally, students in the choice condition were not completing as many assignments as those in either prescriptive condition. These results suggest that choice in this setting did not necessarily increase assignment completion rates for these students, as described in section 3.1 above. However, Table 2 suggests that this same group of students performed better on the posttest than students in the two prescriptive conditions. Their gain in achievement from the pre-test to the post-test was more than twice the gain for the counter intuitive group and 10 times that of the intuitive group. This seems to suggest that students in this condition may have recognized the skills they performed poorly on and were therefore able to make intelligent choices regarding which skills required remediation.

We also performed a one-way ANOVA and the results show that there was a significant difference in math achievement for students who had the chance to complete the experiment (p-value < 0.05).

4. ANALYSIS OF RESULTS

4.1 Post-hoc Analyses

Across our population, 32 students had an assignment completion rate of 100%. (see Table 3) We analyzed these 32 participants and found that, first of all, they were equally distributed among the conditions. Secondly, students in the choice condition achieved huge learning gains over those from the other prescriptive conditions. This result seems to suggest that even among students who are consistent in completing their assignments, prescribing the order in which to complete assignments is not ultimately helpful to learning. When there are multiple tasks to be performed by students, it is best to allow them to choose the order in which to work on the assignments, as suggested by our results here. Allowing students to choose the order in which they work on assignments appears to provide better gains than when the systems make the choice for them, especially for students who have high assignment completion rates.

Table 3: Learning Gains among students with comparable assignment completion rates

Condition	Number of Participants	Learning Gain*
Pre-to-post	11	0.056
Post-to-pre	11	0.086
Student Choice	10	**0.333**
Total	32	

* Significance with p-value <0.05

5. DISCUSSION

Student choice has been found to be helpful for encouraging learners to perform well on certain outcome measures of interest. Research has shown that giving students opportunities to make choices regarding the pace and sequence of math content has many positive effects on students. These findings informed our quest to determine whether the phenomenon would hold true in the context of PLACEments, the adaptive testing system that leverages the ASSISTments learning platform.

In the current study, we set out to determine whether the touted benefits of student choice could be replicated in our testing system, and if so, to what degree it mattered. Contrary to the established notion that choice improves assignment completion, the present study showed that assignment completion rates were not significantly different among conditions. These findings reveal that though there were differences in student completion rates, these differences were not significant and their magnitudes were minimal at best. We think this may be the result of several factors, the most prominent of which is the possibility that the lengths of the PLACEments tests in these classes were too short.

However, of the students who completed the posttest, we found that differences in assignment completion were significant. We also found that among those students who completed the experiment, there were significant differences in learning gains. Post-hoc analysis of the results seemed to suggest that choice was very important amongst students with comparable assignment completing behavior. This is an impactful finding, as it suggests that choice increases performance. Of note here, the observed performance boost could not be attributed to students completing more assignments than those in the other groups; the assignment completion rates were not significantly different, and yet the difference in performance remains.

The contributions of this paper support that in every learning analytics study that tries to model students learning and behavior, the effect of choice cannot be ignored. Additionally, designers of ITSs must look for ways to incorporate opportunities for students with comparable abilities and assignment completion rates to make choices in the order in which they complete assignments while using the system. This consideration will contribute to an improved learning experience for students.

6. FUTURE WORK

The study we report in this paper has one clear limitation in that there was a considerably high dropout rate among all experimental conditions. We presume this high attrition may have been caused by a number of possible factors which require further scrutiny. We think that this may be an artifact of the PLACEments system and the size and difficulty of the assignments used in the study. Further investigations into the causes of this high dropout rate are necessary to help rectify the issue in future analyses, and to boost teacher and student fidelity of the PLACEments system.

The current study investigated the effect of choice on the release and completion of remediation assignments. Another feature of the system in which we can implement choice is in the test itself. Additional experiments are being planned to determine how choice can be incorporated in this aspect. An illustrative example of this involves providing choice in completing the initial skills for the test.

We intend to run additional experiments to replicate these findings and improve upon the current results. If the results hold in replication trials, we will modify the PLACEments system to allow students to choose the order in which to complete their

remediation assignments as it is shown here to significantly benefit student learning.

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