Yixue Adaptive Learning System and Its Promise on Improving Student Learning

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Abstract: Adaptive learning systems offer personalized learning experience to students' characteristics and abilities. Studies have shown these systems can be effective learning tools. Many schools in the United States have adopted adaptive learning systems. Yet development of such systems is still in the early stage in China, and little empirical evidence exists on their efficacy. This paper describes an adaptive learning system, YiXue, and presents two studies that were conducted in China to establish the promise of YiXue adaptive learning platform and two comparison learning platforms used in an after-school English language arts course. The results were promising: student learning efficiency was significantly higher with YiXue than with the comparison platforms. Survey responses suggested that students in the treatment group felt more positive about their learning experience.

1 INTRODUCTION

Through machine learning algorithms and data analytics techniques, adaptive learning systems offer personalized learning experience to students' characteristics and abilities. The intent is to determine what a student really knows and to accurately, logically move the student through a sequential path to prescribed learning outcomes and skill mastery. Many learning products with adaptive features have been developed, such as Cognitive Tutor, i-Ready, DreamBox Learning, Achieve3000, and ALEKS. Such systems constantly collect and analyze students' learning and behaviour data and update learner profiles. As students spend more time in it, the system knows their ability better, and can personalize the course to best fit their talents (Triantallou, Pomportsis, & Demetriadis, 2003; van Seters et al., 2012).

In schools, adaptive systems help close performance gaps, introduce variety into the classroom, provide real-time data on individual students' needs, and free instructors' time for individualized intervention. Studies have shown these systems can be effective learning tools (VanLehn, 2011) and can promote student engagement. An analysis of learning data from 6,400 courses, 1,600 of which were adaptive, revealed that the adaptive courses were more effective in improving student performance than the 4,800 non-adaptive courses (Bomash & Kish, 2015).

Given these advantages, many schools in the United States have adopted adaptive learning systems. Yet development of such systems is still in the early stage in China, and little empirical evidence exists on their promise. This paper presents two studies that were conducted in China to establish the promise and evaluate the efficacy of an adaptive learning platform YiXue when being used in an after-school English language arts (ELA) course. The results were promising: Student learning gain was marginally significantly higher when YiXue system was used and student learning efficiency was significantly higher with YiXue than with the comparison platforms. Survey responses suggested that students in the treatment group felt more positive about their learning experience than their peers in the comparison group.

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2 YIXUE ADAPTIVE LEARNING SYSTEM

Online education has developed rapidly in China in recent years. According to the China Internet Network Information Center (2017), the number of online education users in China had reached 138 million, accounting for 19% of total Internet users, by December 2016. YiXue Inc. was one of the first organizations to develop an adaptive learning system in China. Its system provides instructions and supports for K–12 students and has the following features:

- Fine-grained knowledge map in which knowledge components were organized hierarchically based on learning progression relationship;
- Adaptive diagnostic pre-assessment;
- Automated differentiated instruction;
- Rich, high-quality learning repository of various types of learning content;
- Immediate feedback and explanations to students;
- In-class support and intervention by teachers.

Supported by psychometric measurement models and artificial intelligence, the system implements mastery-based learning and tracks students' mastery of knowledge over time. In mastery learning, students only advance to a new learning objective when they demonstrate proficiency with the current one. Mastery learning programs lead to higher student achievement than more traditional forms of teaching (Anderson, 2000; Gusky & Gates, 1986; Koedinger & Aleven, 2007). A meta-analysis (Kulik, Kulik, & Bangert-Drowns, 1990) of 103 studies of mastery learning reported a mean effect size of 0.52 standard deviation. When students are learning in YiXue, they are first given a pre-assessment that diagnose which knowledge components the students have mastered, and which ones they haven't, according to the predefined hierarchical knowledge structure map. Then the students will enter a learning-by-doing stage. The knowledge that they demonstrate mastery on during the pre-assessment are skipped during the instructional phrase, while weak knowledge was arranged in an optimal order for learning. The most suitable content such as instructional videos, lecture notes, worked examples, embedded practice problems, and tests is delivered based on the student's ability which is estimated in real time by an item response theory (IRT) model (van der Linden, 2016).

Fundamental to the YiXue design is provision of feedback and reports to students and teachers. Research has shown that frequent feedback increases student learning (Hattie & Timperley, 2007; Kluger & deNisi, 1996). After students enter solution to problems, YiXue system provides immediate feedback, and presents step-by-step explanations of how the correct answer is obtained.

The system automatically collects student responses to questions. At the end of each session, the system presents students with reports on how they performed. The system uses student response data in real time to update estimates of student ability on related knowledge components and adjusts subsequent contents accordingly. In YiXue, data and feedback are continuously available to teachers to use in making appropriate instructional decisions, hence enabling formative assessment, another practice with a strong research basis (Black & Wiliam, 1998a, 1998b; Roediger & Karpicke, 2006; Speece, Molloy, & Case, 2003; Heritage & Popham, 2013).

Further, YiXue implemented a differentiated instruction model in which students who progress at different rates receive different supports (Subban, 2006; Tomlinson & McTighe, 2006). Students who progress quickly through the basic level of a topic are given more challenging problems to accelerate their preparation for advanced topics. A student who experiences difficulties with a topic first gets a computer-based tutorial, recommendations on review of prerequisites, and finally help from teachers.

A YiXue classroom appears different from a typical classroom because students are expected to spend much of their time independently solving problems on a computer, with frequent feedback, instructional support, and remote tutoring, and using features unique to the delivery of instruction on a computer (e.g., animations, %correct) that are designed to keep their level of engagement high throughout the instructional period. In addition, teachers have important and defined roles in the Yixue classroom including the traditional role of leading periodic classroom discussions on key subject topics. However, teachers also receive easy-to-read reports on classrooms' and students' individual progress, and they are expected to use the data to identify individual students who might be struggling and what they are struggling, and provide them with targeted support during class time. When teaching with YiXue, teachers are expected to spend 1/6 of a session to work with students face-to-face for individualized instructions while the others continue working with YiXue digital content. In this way, YiXue supports a synergistic blending of the

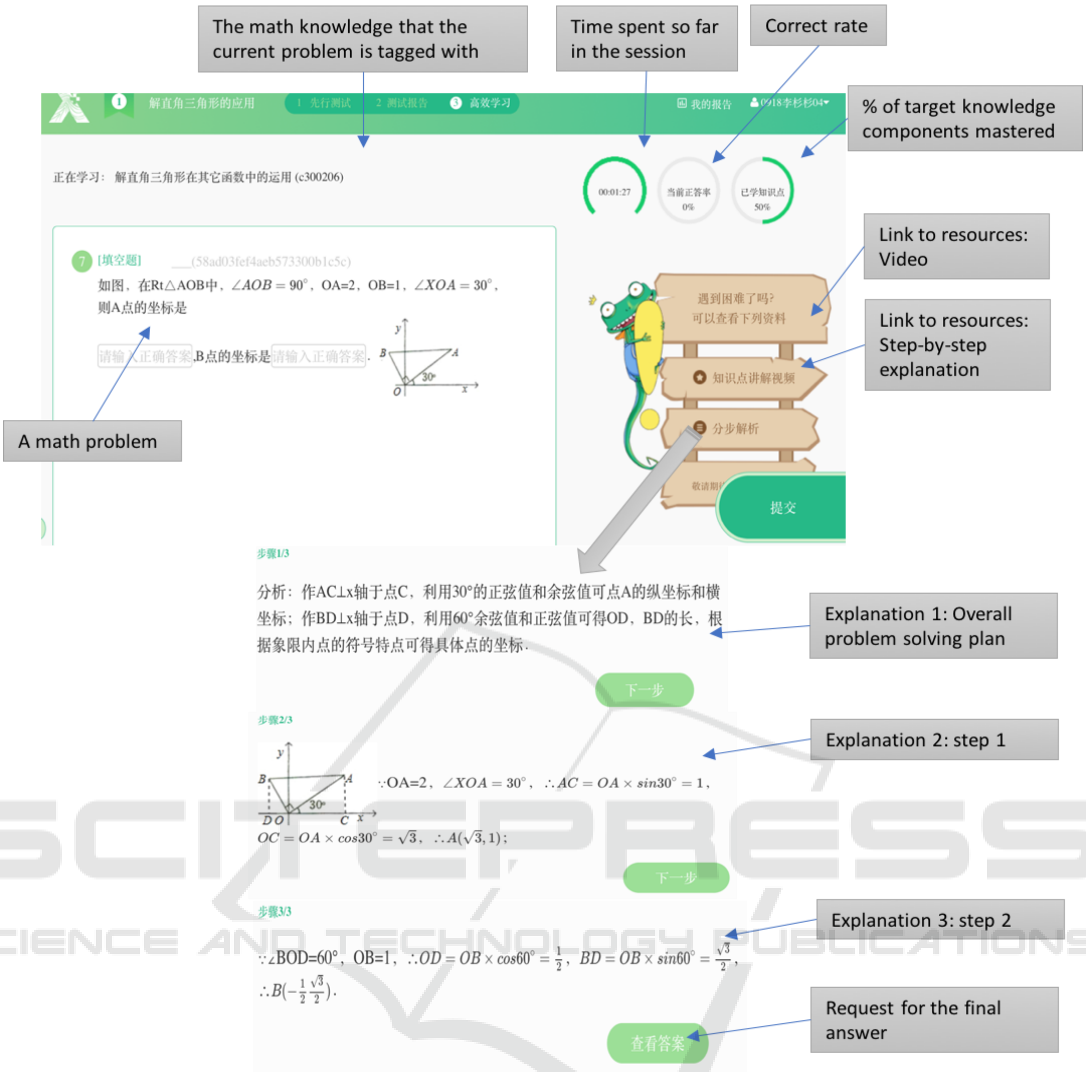

Figure 1: Illustration of a math problem in YiXue and its associated explanations.

teacher's and technology's role in delivering instruction and supports differentiated instruction—characteristics that are unlikely to be found in the average "business-as-usual" classroom.

YiXue Inc. has developed instructional materials for middle school mathematics, English, Physics, Chinese, and Chemistry and is working on expanding content coverage to the whole spectrum of K-12 education settings. In the year of 2017, Yixue has been used by approximately 2,200 students in 17 cities in China, representing a broad range of student populations with respect to socioeconomic status, urbanicity, and performance levels.

Fig. 1 illustrated a math learning-by-doing problem in YiXue system. At the center of the screen is a math problem that the student needs to solve. The top left corner of the screen shows the focal knowledge that the current problem addresses. The top right corner shows measures of practice and progress of the student, including how long a student has been learning within the system, percent correct so far, and, of all the knowledge components that the student is weak on, and what % of them that the student has mastered through learning in Yixue. On the right side of the screen, there are a few buttons that when clicked, will bring up resources the student may refer to if he/she has difficulty solving the problem. The student may request to watch a short video (usually 3-5 minutes) in which a teacher explains the knowledge component and demonstrates how to solve similar problems, or request for step-by-step explanation of the problem. The bottom half of Fig. 1 shows 3 messages. The first one provides a high-level problem-solving plan overall, but doesn't scaffold the problems or show single steps. The purpose of presenting the plan at first is to prompt the students to come up with their own solutions given the overview. If the student still has trouble moving on, he/she can click “next” to request for the explanation 2, which shows the first step to solve the problem, on top of explanation 1. Similarly, explanation is only available upon request by the student, and the student can go back making an attempt at the problem at any moment. In the end, the student can click “show me the answer” button to request the system to show the correct answer. When doing so, the student will be prompted that this problem will be evaluated as “incorrect” if he/she decides to continue.

It is worth mentioning that in order to increase learning efficiency and prevent students from wasting time over-attempting (aka. students take a guess-and-check approach and repeatedly enter incorrect answers), the system will automatically bring up the explanations after 3 failed attempts. Note that even a student provides the correct answer to the problem on the first attempt, the system will still present the full explanation, including explanation #1 to #3, plus all forms of correct answers to prompt the student to compare his/her solution to the one(s) provided by the system to reinforce student’s understanding of the knowledge.

3 METHODS

We conducted two small-scale randomized controlled studies to examine the efficacy of YiXue Learning compared with two popular online learning systems, New Oriental Online (www.koolearn.com) and Magic Grid (www.mofangge.com) and to examine the promise of the YiXue platform on improving student learning. These systems were selected because they have similar learning content, format, and intensity as YiXue. They have been popular options for ELA learning in China. In New Oriental Online, an experienced teacher first explains the concepts thoroughly in an online video, and then students practice the in-class quiz problems online.

Students check their understanding through a subject test. Magic Grid helps students improve their knowledge of English through problem practicing, redoing problems that they got wrong, and carefully reviewing lecture notes. Neither systems implement adaptation during the learning phase.

4 EXPERIMENT 1: YIXUE AND NEW ORIENTAL ONLINE

Sample and Random Assignment. In the first experiment, 41 eighth-grade students (ranging from 13 to 15 years old) were recruited from one middle school (School Y) in Shanghai. A pre-study survey was used to collect students’ school grades in English and other background information (such as gender, family socioeconomic status, parent educational level). We then used stratified block randomization (Trochim, Donnelly, & Arora, 2016, p229) to randomly assign the students to either control group or treatment group. Students were first put in blocks of four according to their prior achievement level, and then two students in each block were randomly assigned to the treatment group and the others to the control group.

Research Procedure. On the first day of the study, students in both groups took a paper-based pre-test on the topic they would study, “Passive Tense,” which had not been covered in school. Research staff trained the students on using the technologies and navigating through the systems before the learning sessions began. Students in both groups studied the topic online during two classes periods in one week for a maximum of 100 minutes. The 21 students in the treatment group used YiXue, and the 20 students in the comparison group used New Oriental Online. The experiment was conducted without teachers’ support, and no other instructions outside the systems were provided to the students. The learning schedule for both groups was identical, including the break time between online classes and the number of breaks. At the end of the learning sessions, a paper-based post-test was administrated to both groups. Students were given 25 minutes to finish the pre- and post-tests. All students finished the tests within in the given time, and all 41 participating students completed all steps (pre-test, learning, and post-test) of the experiment.

4.1 Experiment 2: YiXue and Magic Grid

For the second experiment, we recruited a different group of 87 eighth-grade students from School Y in the same age range and with the same English skill and background as those in Experiment 1. Students were randomly assigned to conditions through a similar randomization procedure as in Experiment 1, with 44 students assigned to the control group and 43 to the treatment group. Experiment 2 followed the same procedure as Experiment 1 and students studied for a maximum of 100 minutes except that in this experiment, the comparison group used Magic Grid, instead of New Oriental Online, and the learning topic, “Adjectives and Adverbs,” had been introduced to the students during regular classes. Thus, the online learning sessions were to review this knowledge. Students learning with Magic Grid got exposed to at least 80 problems and their associated solutions and explanations. All but 2 students in the comparison group studied for 100 minutes. Students in the YiXue group learned at their own pace and the amount of instructional video watched and the number of practice problems finished varied, based on student’s proficient level on knowledge points within the designated learning topic. 11 students in the treatment group spent less or equal to 75 minutes on YiXue system while the other 32 students used up all 100 minutes. All students completed all steps, namely, pre-test, learning, and post-test, of the experiment.

4.2 Data Sources

Pre- and Post-tests. The pre- and post-tests were developed for the experiments. The problems in the tests were constructed by an experienced English teacher in the local school and covered the focal learning subjects during the experiments. Two independent, experienced subject matter experts reviewed the pre- and post-tests to ensure that they were comparable in their coverage, overall difficulty, types of items, and alignment with the local middle school English learning standards. The experts also checked to make sure that the test items are not over-aligned with YiXue learning content, or the content being taught by the comparison systems. Each test included 45 multiple-choice, fill-in-the-blank, or sentence transformation questions and the total score on the test was 100.

Student Surveys. Two student surveys were administered during each experiment. Students were asked to complete an information survey about themselves and their families’ educational background on the first day of the study and to respond to a post-study survey of their online learning experience after the post-test was finished. In the post-study survey, students were asked to reflect on their online learning experience from three aspects: learning efficiency, ease of use, and satisfaction with the system. Each aspect included a few Likert scale questions ranking from from *completely disagree* (1 point) to *neutral* (3 points) to *completely agree* (5 points).

5 RESULTS

5.1 Learning Outcome

The first step we did was to check baseline equivalence of the control and treatment groups in their prior knowledge. *t*-test results showed that for both experiments, as expected given the randomiza tion featured in the research design, analyses found no difference between the treatment and control groups in their pre-test scores ($p > .05$).

However, in Experiment 1 the average post-test score of the control group was lower than the average pre-test score, and scores for a few outlier students dropped significantly from pre-test to post-test. We are still examining the possible reasons for this unexpected drop. Thus, we report learning results only from Experiment 2.

We used multiple linear regression in *R* (*lm* function) to model the mean differences in post-test scores between students in the treatment and comparison groups, controlling for their pre-test scores. The result showed that after controlling for their pre-test scores, students who used YiXue scored 3.8 points higher on average on the post-test, comparing to students who used Magic Grid and the difference is marginally significant ($F(2, 84) = 104.6$, $p = .09$, $r^2 = 0.71$).

We then calculated *learning efficiency*, which was defined as the gain score divided by the total number of minutes that a student spent on online learning (Table 1). We noticed that for Experiment 2, student’s pre- and post-test scores was highly correlated ($r = .84$). Across all students in both conditions, pre-test average score was 52 points, and post-test average score was 61 points. We first calculated gain score for each individual student by subtracting his/her pre-test score from the post-test score, and then divided each student’s gain score by the amount of time they spent learning in the systems (YiXue or Magic Grid depending on their conditions) to compute learning efficiency for each student. Results from linear regression modelling suggested that learning efficiency was significantly higher in the YiXue group ($p = .01$).

5.2 Survey Results

32 students in Experiment 1 and 76 students in Experiment 2 responded to the post-study survey. Both groups had positive feedback about their online learning experience (scores higher than 3 points) compared with traditional in-class learning. Students felt that they were more active and had more flexibility.

Table 1: Learning Efficiency Results from Experiment 2.

Condition	Mean gain score from pre-test to post-test	Mean time spent in system (minutes)	Mean learning efficiency (gain score per minute)
YiXue	10.56	90.19	0.13
Magic Grid	6.5	98.86	0.06

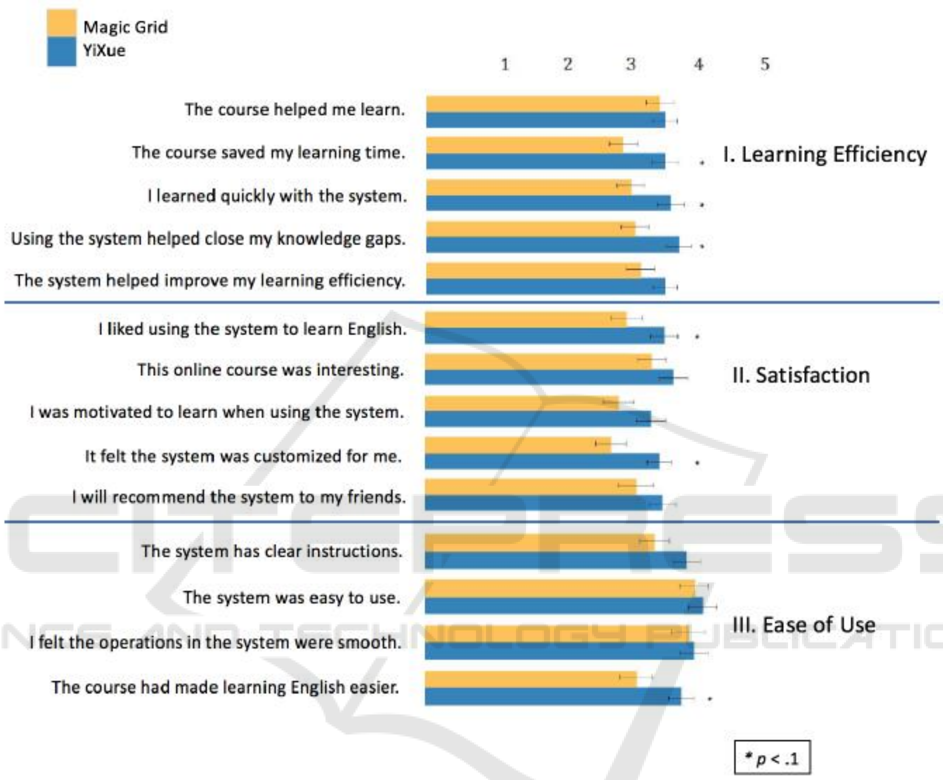

Figure 2: Survey Results from Experiment 2.

Scores for YiXue were higher than for New Oriental Online on 15 of the 17 survey questions, especially regarding "ease of use" and "learning efficiency." Students in the treatment group felt that learning, along with practice quizzes and explanations of common mistakes, was very effective because they were always aware of what knowledge they had mastered and what they needed to strengthen. The control group students felt that most of the time they were only watching online videos repeatedly, without practicing.

Moving from Experiment 1 to Experiment 2, we removed 3 redundant questions in the post-survey as students' responses to the questions were not differentiated from to their responses to other similar questions. Thus, the survey was reduced to 14 questions. As shown in Figure 2, in the Experiment 2, scores for YiXue Learning were higher than for Magic Grid on all 14 questions and significantly higher on questions on "learning efficiency" and "satisfaction with the system." During the post-study interview, students in the control group stated that they felt bored because they kept "practicing problems without knowing why" and that they "never understood why they made mistakes when solving problems."

6 CONCLUSION

In this paper, we introduce an adaptive learning system, YiXue, and its features, and described two small-scale randomized controlled experiments that aimed at establishing the promise of the YiXue system. Overall, the results of the experiments suggest that the YiXue adaptive learning system has promise for improving student learning outcomes effectively and efficiently. The studies did have limitations; the sample sizes were small, the duration was short, the focus was on only selected ELA topics, and we were not able to use an external standardized outcome measure. Thus, further research is warranted to examine the efficacy of the YiXue adaptive learning system. We are in the process of examining the features of the systems used in the studies and student's learning activities during the experiment to better understand what might have led to the difference in learning outcomes and how the learning outcome differs across students of different incoming knowledge, or students of different self-efficacy in math (a question in the student survey). We are analysing student learning log data to investigate the relationship between learning process and the learning outcome, as well as how YiXue can be improved to better facilitate learning. For instance, analysis is being conducted to see if higher learning gains in YiXue is associated with longer learning time, better performance within the system, or longer engagement time with videos. We are also planning on more randomized controlled experiments with larger sample size, longer duration to further evaluate the efficacy of YiXue in other subjects, including mathematics and physics. In the meantime, the development team at YiXue is focusing on enhancing the system's adaptivity and effectiveness through profiling students (Bouchet et al., 2013), attending to student engagement level (Baker & Ocumpaugh, 2015) and cognitive styles (Yang et al., 2013), and more accurately tracking student's progress on fine-grained knowledge points using state-of-art algorithms and data-intensive modelling approaches.

As stated above, many randomized trials and other sound studies of adaptive learning systems have been conducted in the United States, but very few rigorous experimental studies have been done in China. With many schools in China introducing online learning systems, there is broad interest in how to select and use such systems and whether they lead to improvement. With these studies, we have the opportunity to contribute to much-needed knowledge about online learning and adaptive learning in K–12 instruction, esp. in China. We expect the results of the studies reported here to be meaningful to teachers, educators, and parents.

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