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Active Learners: Redesigning an Intelligent Tutoring System to Support Self-Regulated Learning

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Abstract. Supporting students' self-regulated learning (SRL) is an important topic in the learning sciences. Two critical processes involved in SRL are self-assessment and study choice. Intelligent tutoring systems (ITSs) have been shown to be effective in supporting students' domain-level learning through guided problem-solving practice, but it is an open question how they can support SRL processes effectively, while maintaining or even enhancing their effectiveness at the domain level. We used a combination of user-centered design techniques and experimental classroom research to redesign and evaluate an ITS for linear equation solving so it supports self-assessment and study choice. We added three features to the tutor' Open Learner Model (OLM) that may scaffold students' self-assessment (self-assessment prompts, delaying the update of students' progress bars, and providing progress information on the problem type level). We also designed a problem selection screen with shared student/system control and game-like features. We went through two iterations of design and conducted two controlled experiments with 160 local middle school students to evaluate the effectiveness of the new features. The evaluations reveal that the new OLM with self-assessment support facilitates students' learning processes, and enhances their learning outcomes significantly. However, we did not find significant learning gains due to the problem selection feature. This work informs the design of future ITS that supports SRL.

Keywords: Self-assessment, study choice, intelligent tutoring system, open learner model, user-centered design, classroom evaluations

1 Introduction

Intelligent tutoring systems (ITSs) typically focus on supporting domain-level learning and have been illustrated to be effective at doing so [5]. Researchers are now more interested in how ITS can be designed to foster self-regulated learning (SRL), while maintaining or even enhancing their effectiveness in supporting domain-level learning. Self-assessment and study choice are two critical processes involved in SRL. Self-assessment refers to monitoring and evaluating how well you are learning/have learned. Study choice means the learner selects what s/he will work on next during the learning process. Feyzi-Behnagh and colleagues [2] found that the metacognitive prompts and feedback provided by the pedagogical agents in MetaTutor could enhance students' self-assessment accuracy and learning efficiency (but not the learning effectiveness) [2]. However, with such promising results from previous work, it is still an open question how we can design specific features of the ITSs to support self-assessment and study choice effectively, while maintaining or even enhancing their effectiveness at the domain level. Recently, ITS researchers have pointed out the potential of using Open Learner Models (OLMs) to support students' self-assessment and study choice [1]. OLM is one component of ITS that displays students' learning progress using different forms of visualizations. In the current work, we explore new designs of an ITS (especially the OLM) to identify the features that can effectively scaffold SRL processes (especially self-assessment and study choice), which will also lead to improved domain-level learning outcomes. We went through design and evaluation stages including paper prototyping, high fidelity prototyping, building redesigned tutor version 1, classroom experiment 1, building redesigned tutor version 2 and classroom experiment 2. Throughout the whole design process, we combined different research approaches, including HCI/user-centered design techniques, experimental educational research and educational data mining. We describe the methods and results used at each stage of the design process to articulate the rationales for our designs, and discuss insights for future work.

2 Design Process, Methods and Results

2.1 Paper Prototyping & High Fidelity Prototyping

We used a tutor for solving linear equations as the platform for this study. The tutor is an example-tracing tutor built with Cognitive Tutor Authoring Tools [5]. It provides practice for five types of linear equations. The example-tracing tutors have built-in OLMs (the Skillometer), which shows students' progress in the form of skill meters.

As the first step in user-centered design, in order to find out the needs of the users, we conducted an interview study with 44 high school students. The interviews revealed that the students inspected the OLM frequently to see their progress, but thought the design of the OLM was too simple to convey much progress information. They did not actively reflect or self-assess in the tutor either. Besides, the students expressed strong interests in selecting their own problems in the tutor. Based on the results from this study, we decided to redesign the Skillometer and create a separate screen for problem selection. We built both paper and high fidelity digital prototypes that show different screens and alternative designs. We conducted two rounds of user testing through one-on-one think aloud sessions with 7 middle school students. The main features of the new designs aimed to 1) facilitate self-assessment; 2) provide more complete/multi-level progress information to the students; and 3) give them control over problem selection. We gathered three primary design recommendations:

1) Facilitate self-assessment using explicit prompts. During the think alouds, the students did not actively initiate any self-assessment activities. To facilitate self-assessment in the tutor, we need to add explicit self-assessment prompts/questions.

2) Gamify by creating levels. We tried to provide more complete progress information by showing students' overall progress on the five different levels (problem types) in addition to the skill bars, which also adds elements of gamification to the system. The students really liked this game-like feature. The participants also expressed that displaying the progress of each problem type on the same screen where they have to select the next problem was helpful for them to make decisions.

3) Share control over problem selection between student and system. All participants admitted that they might keep selecting easy problems if they were completely free to select problems by themselves. Therefore, to prevent such suboptimal problem selection decisions, also to maintain the effectiveness of mastery learning in the system, we decided that once the system deems that the student has reached mastery for a certain level, they can no longer select new problems from that level. Such joint control with the system grants students freedom but prevents them from abusing the system.

2.2 Redesigned Tutor Version 1 & Classroom Experiment 1

We then implemented a fully-functional version of the tutor with support for self-assessment and study choice, based on our prototypes. This redesigned tutor has four key new features:

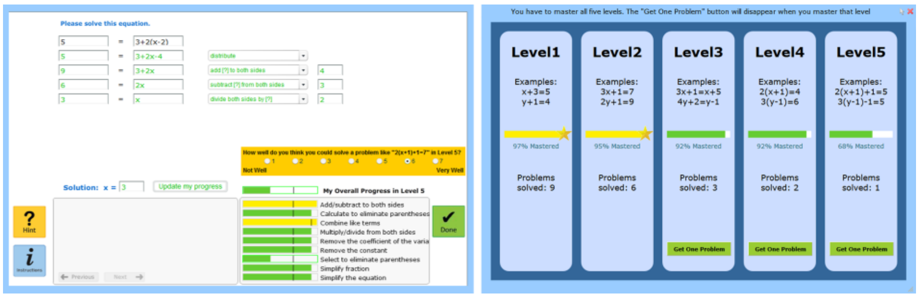

Fig. 1. The redesigned problem solving screen (left) and the problem selection screen (right)

1) Delaying the update of the progress bars. Instead of updating the bars while the student is in the midst of solving a problem, the new tutor updates the bars only when the student is done with the problem, so as to make it easier for students to focus their attention on the changing of the bars. The "Update my progress" button appears after the student finishes solving the problem. When the student clicks on it, the tutor updates the bars (i.e., the bars move to their new positions, based on the students' performance on the problem they just completed). The black lines marked on the bars allow a before/after comparison to further emphasize the change of progress.

2) Self-assessment prompt. The self-assessment prompt ("How well do you think you can solve a problem like "" in level x") appears after the bars stop updating (shown in orange on the left in Figure 1). Answering this self-assessment question may help students become better at self-assessing and self-assess more actively. Also, given the self-assessment prompt comes just prior to the problem selection screen, answering it may help them make better problem selection decisions.

3) Showing progress on the problem type level. Showing both the detailed progress on the skill level and the overall progress on the problem type level gives students more complete information regarding their learning and may further support useful reflection and self-assessment.

4) Selecting the next problem. As shown on the right in Figure 1, on the problem selection screen students can view and compare their progress on different levels, which can aid them in deciding which level they want to work on next. Once they click any "Get One Problem" button, they are directed to a new problem solving screen with a problem from the chosen level. Students can only select problems from unmastered levels, which prevents one type of suboptimal problem selection decision students might make (selecting problems that are too easy), while still giving them some freedom and control over their own learning.

Experimental design, participants and procedure of Classroom Experiment 1. To empirically evaluate the effectiveness of the new tutor, we decided to conduct a controlled experiment instead of a traditional HCI user study. We believe the controlled experiment can provide rigorous evidence as to whether/how our new designs make a difference in student learning. We conducted a 2x2 experiment with independent factors OLM (whether or not the OLM (both skill-level and problem type-level of progress information) are shown to the students) and PS (whether or not students could select their next problem from an unfinished level) at a local public middle school. 98 8^{th} grade students were randomly assigned to one of the four conditions. This is an ablation experiment and we modified the interfaces accordingly to match the manipulation. All participants completed a paper pre-test on solving the five types of linear equations, worked with the tutor for three class periods, and completed a paper post-test that was in the same format as the pre-test.

Results. There were no statistically significant differences among the four conditions either on the pre-test or the post-test. Also, no significant improvements from pre- to post-tests were found for the students. However, analysis of the process measures from tutor log data reveals some promising benefits of having access to an OLM during learning in the tutor. Students who learned with an OLM needed fewer problems to reach mastery on each level ($F(1, 435) = 4.450$, $p = .035$, $\eta^2 = .010$), made fewer incorrect attempts when solving each problem ($F(1, 435) = 4.922$, $p = .027$, $\eta^2 = .011$), and needed less help in the tutor (based on the average assistance score ((hints + incorrect attempts) / total steps) per problem, $F(1, 435) = 6.557$, $p = .011$, $\eta^2 = .015$). On the other hand, the students who had the freedom of problem selection asked for more hints than students who did not have problem selection ($F(1, 435) = 5.642$, $p = .018$, $\eta^2 = .013$).

Discussion. We had a ceiling effect on pre-test with the sample in this experiment, and did not find any significant learning gains due to the tutor. However, the analysis of the tutor log data shows some benefits of having access to an OLM with support for self-assessment. The students who had the OLM needed fewer problems to reach mastery, made fewer incorrect attempts, and needed less assistance in the tutor. These results suggest that the OLM with self-assessment support facilitated reflection and self-assessment during learning, which led to more efficient learning process. Nevertheless, given the small effect sizes (η^2 is around .01) of these log data analysis, it is reasonable to strengthen the scaffolding for self-assessment to foster stronger effects. Therefore, we further improved our design of the OLM and conducted a new controlled experiment with younger students (7th grade).

2.3 Redesigned Tutor Version 2 & Classroom Experiment 2

We kept the four new features in version 1, but further revised the design of the OLM on the problem solving screen, aiming to strengthen the scaffolding for self-assessment and reflection, so that students can achieve better learning outcomes.

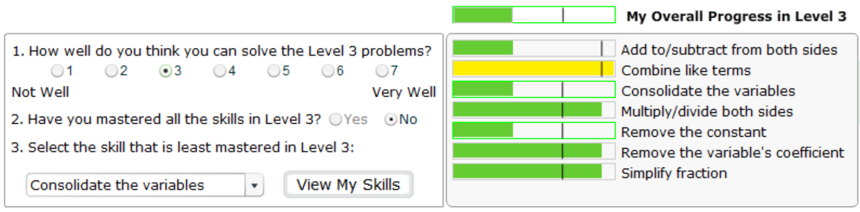

Fig. 2. The new OLM view on the problem solving screen

1) Add more specific self-assessment prompts. We further guide students' self-assessment by adding two more specific self-assessment prompts that are tied directly to their skills. The two new prompts are "Have you mastered all the skills in Level x" and then asking the students to select the least mastered skill in that level from a drop-down menu (as illustrated on the left side in Figure 2).

2) Hide the progress information until the self-assessment questions are answered. In the redesigned tutor version 1, the students answered the self-assessment prompt after the progress bars had been updated to reflect performance on the last problem. It is possible that students answered the prompts based just on what their bars look like, without much reflection. Possibly, students would reflect more strongly on their skills if they self-assess before the skill bars are updated and shown to them. Therefore, we updated the problem solving screen so the bars are hidden until after the student has worked through the self-assessment prompts (the three questions shown on the left in Figure 2; the progress bars on the right in Figure 2 are initially hidden). After students answered all three self-assessment prompts, the "View My Skills" button appears. Once students click the "View My Skills" button, the level and skill bars are shown and start updating after 1 second. In this way, the updating of the skill bars serves as a form of instant feedback on students' self-assessment.

The problem selection screen remained unchanged. With the revised tutor version, we conducted a new controlled experiment with 62 7th grade students at another local public school. The experimental design, procedure and measurements were the same as experiment 1. The results of this experiment have been reported in another paper [4]. To summarize, we found that all students' knowledge of solving linear equations improved significantly from pre- to post-tests, affirming the effectiveness of the tutor.

More interestingly, we found that having access to an OLM resulted in better performance on the post-test, which was also supported by log data analysis. However, we did not find significant effects of the PS factor. The results from the new study affirm the effectiveness of the OLM on students' domain level learning, while the effects of problem selection still need further investigation.

3 Conclusions and Future Work

This paper documents and describes the iterative process we went through to redesign a linear equation tutor so it supports self-assessment and study choice, key processes in self-regulated learning. By scaffolding these processes, we seek to improve students' domain-level learning (and did so for supporting self-assessment). Through this design process, we identified three key features of the OLM that could scaffold students' self-assessment and reflection: self-assessment prompts, delaying the update of the progress bars and providing progress information on the problem type level. In reflection, we believe that the combination of HCI techniques and quantitative educational research methods is an effective way of exploring open-ended design questions in educational technologies. The two approaches weave together and work well in generating design ideas, iteratively improving the designs, and rigorously evaluating the design products. We plan to extend this work by exploring designs to support other SRL processes in the tutor, such as goal setting. Eventually, we hope to help students become better self-regulated learners, who are active and efficient in planning, monitoring and evaluating their learning.

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