Investigating the Effects of Motivational Pedagogical Agents on Student Learning and Choice Making in an Adaptive Learning System

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Abstract. The use of pedagogical agents (PAs) in interactive learning environments holds promise for improving learning outcomes, yet their impact on strategic choice making remains underexplored. This study investigated how motivational pedagogical agents influence students' conceptual learning and choice-making behaviors, such as whether to engage in metacognitive tasks that are optional, when using an adaptive algebra learning technology. In an experiment, 49 high school students were assigned to either an Agent condition, featuring motivational prompts delivered by PAs, or a Non-Agent condition without PAs nor prompts. Although the motivational prompts by PAs did not significantly improve overall learning gains or reduce error rates compared to the Non-Agent condition, younger students (Grade 9) demonstrated modestly higher improvements, suggesting differential benefits based on students' prior knowledge. Additionally, older students (Grade 10) in the Agent condition showed higher engagement with optional tasks over time. These findings highlight the potential of motivational PAs to support strategic choice-making and indicate the need for future adaptive systems to offer context-sensitive prompts that guide learners in making productive choices aligned with their learning goals and self-regulation needs.

Keywords: Pedagogical Agents, Choice Making, Adaptive Learning System.

1 Introduction

Developing students' capacity for strategic and adaptive choice-making is critical for fostering effective self-regulated learning (SRL) in educational contexts [7, 10]. Within SRL, choice-making reflects learners' cognitive and metacognitive processes, influencing how effectively they select tasks and strategies aligned with their learning goals [1, 8]. Effective choice-making enables students to navigate their learning paths autonomously, thereby promoting engagement, persistence, and adaptive expertise, which is the ability to flexibly apply knowledge across diverse contexts [4, 7].

However, strategic choice-making is complex, as learners' decisions vary significantly based on contextual factors such as prior knowledge, motivation, and perceived task difficulty [3, 2]. Not all students are equally skilled in making beneficial choices;

some tend to avoid challenging tasks or neglect additional learning opportunities critical for skill development [9]. Consequently, instructional support within adaptive learning systems is needed not only to permit student autonomy but also to explicitly encourage and scaffold strategic choice-making.

This study addresses this gap by exploring how motivational PAs affect students' choice-making behaviors across different task scenarios and grade levels. We aim to explore the following research questions:

RQ1: What impact do pedagogical agents with motivational prompts have on students' conceptual understanding in algebra?

RQ2: How do motivational pedagogical agents influence students' choice-making behaviors in an adaptive learning system over time?

2 The Learning Environment

With a high-school math teacher, we co-developed AlgeSPACE, an adaptive learning system that leverages pedagogical agents (PAs) to scaffold students' algebra learning, aiming not only to enhance procedural and conceptual understanding [6] but also to promote strategic choice-making behaviors [5]. It includes 28 exercises for solving systems of linear equations with two unknown variables. Fig. 1 demonstrates the main steps involved in the *Efficiency* type of exercises with different choice-making scenarios.

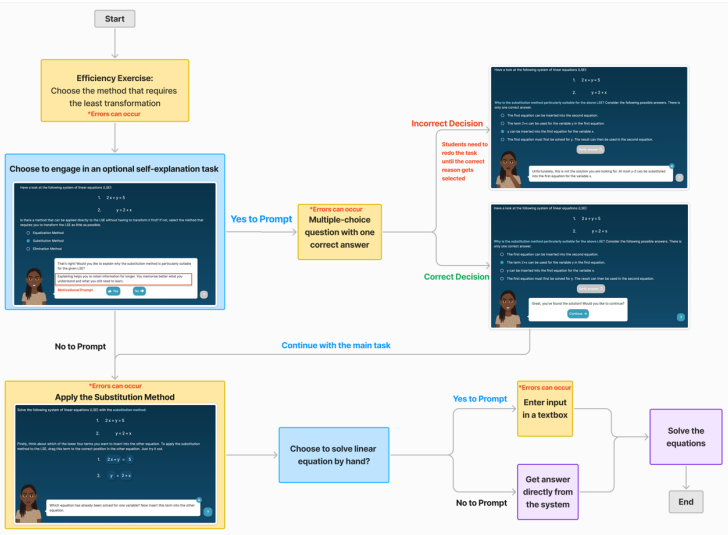


Fig. 1. Steps illustration for an efficiency exercise with optional tasks.

The central design principle in our choice architecture is to allow students to proceed to the next step of the task regardless of the choice they make. As shown in Fig. 1, a motivational prompt was presented when students were given the opportunity to engage in an optional self-explanation task. Similarly, these motivational prompts appeared across different choice-making scenarios as illustrated in Table 1.

Table 1. Pedagogical agents' motivational prompts for different choice scenarios.

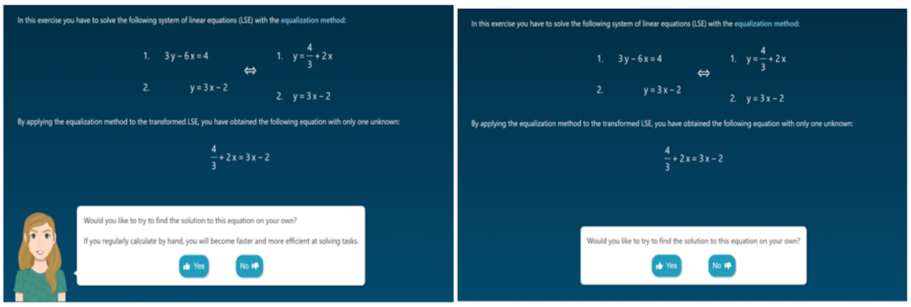
Scenario	Definition	Motivational Prompt
S1_WorkEx	Engagement with pre-solved worked examples	"This helps you to remember the topics you have learnt and to solve upcoming tasks more efficiently"
S2_Self-Expl	Explaining solution strategy by selecting the most appropriate explanation statement from multiple options	"When explaining, you think about the best solutions, which strengthens your problem- solving skills"
S3_Comp	Comparing solution methods with fictional peers	"Comparing different methods deepens your understanding of mathematical concepts and how they are related"

Note. WorkEx = worked examples, Self-Expl = self-explanations, Comp = comparisons.

3 Methods

3.1 Participants and Procedure

We conducted an experiment with 54 German high school students randomly assigned to two conditions: the Agent condition where students interacted with a version of the tool that featured PAs with motivational prompts (Fig. 2a) and, the Non-Agent condition where students used the same tool without motivational PAs (Fig. 2b).



(a) Agent Condition (b) Non-Agent Condition

Fig. 2. Two versions of the tool used in the study.

The study was conducted in a university classroom setting, lasting one hour. Students first completed a 10-minute paper-based pretest. After receiving an interactive tutorial of the tool, students engaged in a 25-minute learning session using either version of the tool. Students were provided with a tablet and used the tool in German. Upon completion, students took a paper-based posttest for 10 minutes. Finally, they filled out a questionnaire. Written guardian consent and ethical approval were obtained prior to the study.

3.2 Measures

Pre-posttests. Conceptual understanding of the systems of linear equations was assessed through counterbalanced pre- and posttests. Each exercise followed a three-part format, scored as 1, 2, and 3 points respectively (max 18 points per test).

Error rates. Conceptual understanding was also evaluated by investigating students' performance in the system, especially from the errors they made in content-specific choices and performing solution steps. Error rates were calculated by dividing total errors by the number of completed or started exercises.

Choice-making frequency. Choice-making behaviors were analyzed by tracking students' engagement frequency in optional tasks. Choice-making frequency was the proportion of "Yes" responses to total choice-making opportunities (range: 0-1).

4 Results

4.1 Conceptual Understanding (RQ1)

Results showed that students in both conditions improved significantly from pretest to posttest (Agent: $t = 3.76$, $p < .001$, Non-Agent: $t = 2.35$, $p = .023$). To address RQ1, we compared pre- and posttest scores, learning gains, and error rates between the conditions (Table 2). Descriptively, the Agent condition exhibited greater learning gains (M = 5.27, SD = 4.07) and slightly lower error rates (M = 1.29, SD = .97) than those in the Non-Agent condition (learning gains: M = 3.22, SD = 4.45; error rates: M = 1.32, SD = 1.14).

However, results from ANOVA analysis revealed that the difference on the learning gains between conditions was not statistically significant ($F = 2.83$, $p = .099$). While controlling for pretest scores, ANCOVAs did not reveal significant differences regarding posttest performance ($F = 1.78$, $p = .189$) or error rates ($F = 0.19$, $p = .668$).

Table 2. The mean and standard deviation of student learning outcomes.

	Non-Agent			**Agent**		
	Combined (n = 25)	Grade 9 (n = 18)	Grade 10 (n = 7)	Combined (n = 24)	Grade 9 (n = 17)	Grade 10 (n = 7)
Pretest	8.12 (5.15)	6.44 (4.47)	12.43 (4.44)	6.63 (5.46)	4.63 (3.80)	11.46 (6.10)
Posttest	11.34 (4.53)	11.07 (4.79)	12.04 (4.06)	11.90 (4.16)	11.44 (4.00)	13.00 (4.65)
Learning Gains	3.22 (4.45)	4.63 (4.45)	-0.39 (1.46)	5.27 (4.07)	6.81 (3.52)	1.54 (2.73)
Error Rate	1.32 (1.14)	1.28 (0.97)	1.43 (1.58)	1.29 (0.97)	1.39 (1.07)	1.05 (0.68)

4.2 Choice-Making Behaviors (RQ2)

Results showed that, on average, students chose to engage in optional tasks 55% of the time when given the option. A linear regression analysis elucidated how students' engagement with optional tasks evolved across exercises when examining grade level (9th vs. 10th) and condition (Non-Agent vs. Agent), see Fig. 3. For 9th Grade students, both Non-Agent and Agent groups exhibited a generally declining trend in engagement frequency over time, though the decline was slightly less pronounced for those receiving motivational prompts (Agent condition). In contrast, 10th Grade students displayed notably different patterns. Those in the Non-Agent condition similarly showed a decrease in engagement as exercises progressed, whereas students in the Agent condition exhibited an increasing trend in engagement frequency over the course of learning.

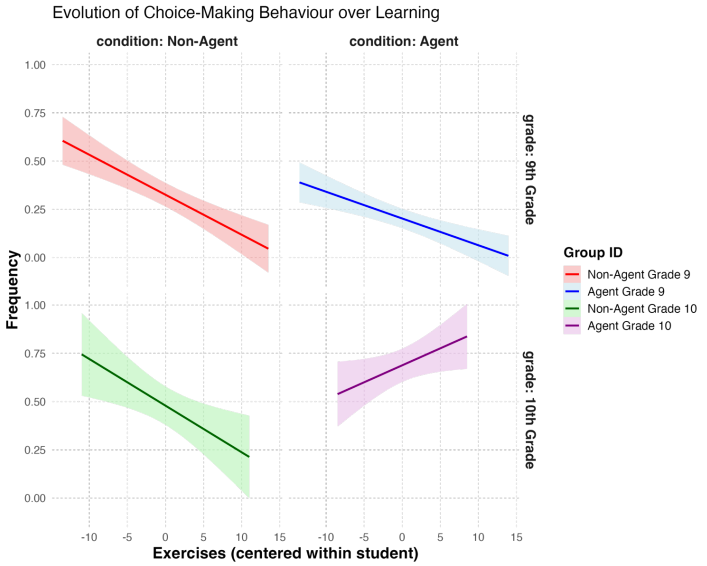


Fig. 3. Frequency of choosing optional tasks over time for each group.

5 Conclusion

This study explored the role of motivational pedagogical agents in enhancing students' conceptual understanding of algebra and their strategic choice-making behaviors within an adaptive learning system. Although motivational prompts with PAs did not yield statistically significant overall learning gains, 9th graders showed more improvements, indicating potential differential effectiveness based on students' prior knowledge. Moreover, older students (10th graders) in the Agent condition showed an increasing trend of choice frequency over time, indicating their better preparedness in strategically selecting problem-solving tasks that foster flexibility and deeper learning.

While we acknowledge the limitations of our small sample size and the brief duration of the intervention, our findings contribute to the field of technology-enhanced learning by highlighting the importance of designing adaptive systems that do more than deliver content; they should also promote strategic choice-making. Specifically, we emphasize the value of incorporating motivational scaffolds that dynamically respond to learners' cognitive profiles and strategic behaviors, such as the decision to engage in optional learning activities. These results suggest that adaptive learning technologies should move toward more personalized, context-sensitive supports that foster metacognitive awareness and encourage productive choice-making in complex learning environments.

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