Learning by Guiding a Teachable Agent to Play an Educational Game

Lena PARETO\(^a,b\), Daniel L. SCHWARTZ\(^b\) and Lars SVENSSON\(^a\)
\(^a\)Media production and Informatics Departments, University West, Sweden
\(^b\)School of Education, Stanford University, Stanford CA 94305

Abstract. Teachable agents are used to support transfer of game playing knowledge to domain knowledge for an educational, arithmetic game. A pre-posttest experiment study show promising learning effects for low ability students.

Keywords. Teachable agent, Educational game, CSCL, Early Mathematics

Introduction

Providing intelligent computer based support to educational games is valuable but challenging; it requires careful trade-offs between fostering learning and maintaining engagement [4]. Educational content must be represented in appropriate form, be closely intertwined with game play, and feedback must be provided [3]. Our educational game [6] is based on a metaphor for arithmetic - a model where numbers are graphical objects (colored squares and square boxes) and arithmetic operations are animated actions on these objects (placement and removing squares on a game board). Any arithmetic computation can be represented in the graphical model – arithmetic rules and properties are built in – insuring valid mathematical computations. The purpose is for students to discover and explore computational behavior of arithmetic, rather than to perform symbolic computations.

To motivate usage and exploration of the model, it is used in several 2-player board games, intertwining game play with learning content. Each player receives a hand of cards visible to both players. The game proceeds by turn taking to lay a card on the common game board. The arithmetic effect of laying a card varies depending on the specific game. In figure 1, both players are “playing” addition and the left player has added a card 44, yielding the result 0+44=44 on the game board (4 orange tens, 4 red ones). The right player has the choice of cards 84, 56, 35, and 78. In this game, the goal is to get as many carry-overs as possible, where 44+84 will yield one carry-over (the tens), 56 and 78 two carry-overs (ones and tens) and 35 no carry-over. The strategy comes from choosing the best card, which in this case is 44+56=100 since

\(^1\) Corresponding Author
it gives maximum points (2 carry-overs) and also leaves the opponent with the worse possible situation (no 2-digit number will yield carry-over when added to 100). Feedback (received points) is given immediately on successful choices. The games have different goals but a common purpose to understand the model, and are designed to be playable and train aspects of arithmetic. The pedagogical goal is a deep understanding of the number system and to discover effective computation strategies.

Numerous game play observations and previous studies show that most children quickly become strategic game players, but our research concern is whether such tacit game playing knowledge can transfer to articulated, explicit knowledge in symbol-based arithmetic.

1. The study

Our hypothesis is that such transfer needs support, and for that purpose we use Teachable Agents [1],[2]. To help children connect their tacit game playing experience with articulated explicit formulations, we use a novel teaching model inspired by apprenticeship, where the player teaches the agent by example and the agent asks for multiple-choice explanations formulated in symbol-based arithmetic. This way, the child shows how to play or guides the agent’s choice by corrective feedback, rather than by direct instruction as in [2]. This makes it easier for young children to teach, and we shift the difficult task of formulating general arithmetic explanations to the agent. The hope is that the child will reflect on and self-explain her playing behavior, which are known to have positive effects on learning [5].

The agent learns from observed playing behavior and chosen explanations. The likelihood of a child’s action being a conscious act of understanding is estimated. We cannot know if a choice is a guess, but over time the likelihood that successful choices are made by chance decreases. Correct explanations indicate conscious and appropriate knowledge. The child’s accumulative teaching behavior is analyzed and reflected in a barometer used as the agent’s acquired knowledge.

The study consisted of measuring learning effects on computational strategies for two different treatments: game play only (condition 1) and teachable agent play (condition 2) by means of a pre-post test in symbol-based arithmetic (figure 2). The experiment enrolled 21 4th-grade students in Sweden during 5 days: 1st day for pre-test and introduction of the game, 3 days of game play for 1 hour, and last day for post-test. The paper-pencil tests contained 67 small addition problems in 4 categories: computing sums and three game-like problem sets (e.g., without computing the sums, determine if a sum is an even hundreds, or determine which of two sums is the largest) at a level difficult to perform without effective computational strategies for the age group. The test was scored by giving one point for each correct answer. The children were divided in the two conditions by stratified random sampling, based on pretest results, and matched up in pairs based on ranking. For the three game play sessions, the agent condition played the game for one round and then taught their agents for two sessions, whereas the game condition only played themselves all three sessions. The posttest was identical to the pretest, except for using different numbers.
2. Results and discussions

Pre-posttest analysis: 16 of 21 performed better on post test (M_{gain} = 18.6 points), and 5 of 21 performed slightly worse (M_{loss} = 1.8 points). These 5 were very high at pretest. The left panel of Fig. 3 shows the overall change of results from pre- to posttest, and is divided into low and high ability groups (above and below grand mean of pretest performance), since the improvement was much clearer for the low ability group. The right panel shows treatment effect for the low ability group for the two conditions (high ability group difference was insignificant).

The primary effect was for the low ability group, which suggests that the game format may reach children missed by standard instruction. The agent condition helped low ability students more than the game alone. The lack of learning effect for the high ability may be due to the relatively simple content in the study. Despite significant effects, the sample sizes are too small to reach strong conclusions. The evidence is promising and indicates that game play can have learning effects that go beyond the game itself. The added effect gained by the teachable agent, is yet too early to make strong claims about. A larger study is currently underway.

References