A Suite of Adaptive Games for Self-Directed Literacy and Numeracy Education

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Introduction

Cheap, plentiful tablets have potential for scaling up the distribution of adaptive educational games and intelligent tutoring systems to children worldwide. However, many existing games do not follow evidence-based design principles. Here we introduce egoTeach, a suite of adaptive educational games built upon principles of cognitive and educational psychology. The software enables active learning, allowing the learner to choose, explore games presenting different material, thus motivating and engaging the learner. Using an adaptive algorithm and sets of stimuli shared across games, the software adapts the sequence of material given to the student while continuously probing their knowledge, re-prioritizing content based on correct and incorrect responses, based on distributed practice effects in memory studies. The games use universal nature themes, and are designed to be learned via active exploration, with mechanics based on the to-be-learned concepts. Combined with continuous positive and negative feedback that is shared across the nine games, the combined spaced repetition and scaffolding algorithm helps children induce and bootstrap core literacy and numeracy concepts.

Self-directed Learning

Numeracy Games

Pilot Participants: 23 2nd-year elementary school students (ages 6-9) in Dar Es Salaam, Tanzania. Eleven students said they had never used a tablet, computer, or smart phone.

Adaptive Algorithm

• Each game uses a simple staircasing function to adjust the difficulty of the game mechanics (e.g., the pace/duration of a trial and/or the number of distractors) as well as the difficulty of the next stimulus presented.
• Stimuli are letters, numbers, and the 1,000 most frequent words in Kiswahili (with translations to English, Nepali, Dutch, German, and French), with voice recordings.
• Stimuli stored in priority queues, with each game adjusting the priority of a given stimulus after each trial based on RT and accuracy.

Numerals and Counting in the ladybug game (see below), learners hear a number and must identify the correct number from several options. Learners then tap the target ladybug the correct number of times, receiving audiovisual feedback and learning the link between numerals and quantity. Incorrect actions slow the bugs’ movements, result in fewer options on the next round, and increase the probability of seeing that number again sooner, while successful interactions do the opposite. Over time, the game proceeds to counting by 2, 3, etc.

Addition and Subtraction In the strategic ant rescue game, learners hear a target number and attempt to move the correct number of ants to the large lilypad, where they find their food. They learn addition, including the standard notation, shown after each subproblem is completed. The game implicitly teaches commutativity of addition: any lilypad can be the source or the destination. It is self-directed in that learners choose their own path, and there is no time pressure. Correct and incorrect responses adjust the estimates of their knowledge. Game dynamics adjust with responses: incorrect responses decrease the maximum number of distractor lilypads; correct responses increase them. Subtraction problems are introduced and appear more often based on correct responses.

Multiplication In the nest building game, a quantity of eggs appear, and learners need to draw a nest to hold that number of eggs. Small numbers (e.g., 2, 3) and prime numbers help children learn the mechanic, which teaches the geometric interpretation of multiplication. Commutativity is clear: length and width are interchangeable. As always, responses are used to adjust the difficulty. Pilot tests found that this game is initially challenging, but that children persevere because they enjoy retrieving all of the eggs when successful—further reinforcing the link between number and quantity.

Spelling Words A version of the bee game (above right), unlocked after the alphabet is learned, is used to teach spelling: a word is spoken, and the bee is directed to pick up the correct letters. Practice starts with common, short words, and gradually increases complexity.

Letter Identification In the bee game (top left), a letter is named and the bee races them to the flower with the named letter. A straight path is good for initial learning, but in later stages the bee’s path wanders. The bee speeds up or slows down depending on accuracy, and more or fewer distractors are shown. Upper and lowercase letters are given.

Results

• Children figured out the dynamics of each game within minutes, enjoyed teaching (and distracting) each other; some switched games often, while others persisted
• >21,000 trials completed by the 23 children over 5 days, who paired up on 10 tablets (due to shipping problems).
• 5 hours (maximum) time spent on tablets over 5 days by children in, with some stratification due to sporadic absences.
• 5,000 trials completed by 12 of the children in the control condition on the final day (after their post-tests were completed).