What Young Children Need to Learn About Numbers

Differences in learning style and response to error correction in pre-kindergarten and kindergarten students using an adaptive iPad based learning game

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Introduction

While children have a general number sense, some things that are obvious to adults are not so obvious to children. For example, to adults, it is obvious that you should give more objects to someone who asks for six than to someone who asks for four. Many preschoolers, however, do not find this obvious at all – even preschoolers who can count from one to ten flawlessly (Le Corre & Carey, 2007; 2008). Likewise, adults see it as obvious that seven must be larger than five, because seven comes after five when counting from one to ten. Yet many children who can count from one to ten have no idea which of any two numbers in that range is larger (Okamoto & Case, 1996; Ramani & Siegler, 2008).

To overcome these limitations on their number knowledge, children must learn to connect groups of objects or events to symbolically expressed numbers. For instance, a child must learn to connect 12 dots with the spoken number name "twelve" and to connect seven tolls of a bell with the written numeral "7." Making these connections is one of the most important mathematical competencies children are asked to acquire during the preschool and early elementary school years. One of the most common learning tasks given young children is to determine the number of objects in a set, either by visual recognition (subitizing) or by counting (Gelman & Gallistel, 1978; Trick & Pylyshyn, 2003). Other important challenges during the early school years include acquiring skills relevant to cardinality, such as recognizing and generating the number symbols that accompany sets of a particular size, and skills relevant to ordinality, such as identifying the larger of two numbers.

Beyond learning number names and counting routines, research has shown that verbal representations of numbers are linked to spatial representations, and that this linkage plays an important role in numerical understanding (Ansari, 2008; Hubbard, Piazza, Pinel, & Dehaene, 2005; Siegler & Ramani, 2009). At the neural level, a circuit connecting the prefrontal cortex and an area in the parietal lobe known as the horizontal intraparietal sulcus (HIPS) has been found to be crucial for these linked representations (Nieder & Dehaene, 2009; Dehaene et al., 2004; Hubbard & McCandliss, 2011). At the behavioral level, how precisely the verbal and spatial representations of number are linked is related to both preschool and elementary school children's arithmetic skills, and to elementary school children's overall math achievement test scores (Booth & Siegler, 2006; 2008; Geary, et al., 2007). For early learners, their approximate number sense, early number competencies, and executive functions such as set shifting, inhibitory control and working memory all provide predictive value for later mathematical achievement (Clark et al., 2010, Jordan et al., 2009, 2010Mazzocco et al., 2011). Children arrive in first grade with widely variable numerical and executive function skills, it is also noteworthy that high achieving students exhibit a strong visuospatial working memory, a strong number sense and frequent use of memory-based processes to solve math problems (Geary et al., 2009). A program that can track an individual child's initial abilities and augment her/his school experience could help a child with less preparation catch up to his/her peers.

Our goal was to evaluate the age-appropriateness and learning trajectories of pre-school and kindergarten children on a new cognitive exercise designed to help young children strengthen their number representations as well as strengthen executive function skills.

Materials & Methods

We developed an adaptive iPad-based game for preschool children that works on basic numeracy skills in conjunction with working memory skills. The game begins with simple counting of sets of objects and matching sets to numerals. At first, the learner is presented with a set of objects arranged like the dots on a domino, and asked to select the matching numeral (numbers 1-6, Figure 1). Next, the learner is presented with several sets of objects arranged in a 10-frame, and asked to select the correct set associated with a given numeral (numbers 3-10, Figure 2). In the next higher levels of the game, the learner is presented with an array of numerals and sets. The sets are represented as spots on a ladybug (numbers 1-6, domino pattern) or on a caterpillar (numbers 1-10, 10-frame pattern). The learners is asked to match all the numerals to the appropriate sets when both numerals and sets are visible until matched (Figure 3). In the highest levels of the game the bugs and numerals are hidden under leaves and can only be exposed one at a time Figure 4). In this condition accurate matching of numerals to number counts requires working memory recall of the visual-spatial locations of the matching items, as well as counting and numeral identification. Interstitial activities, such as a sound counting task (Figure 5) and a finger counting task (Figure 6), are interspersed throughout the prgression, providing a variety of numerical activities.

Figure 1. Level 1 - Count the balloons and then select the dog with the matching numeral on its tag.

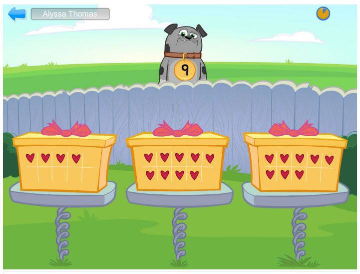

Figure 2. Level 2 - Count the designs on the gifts and then select the one that matches the numeral on the dog's tag.

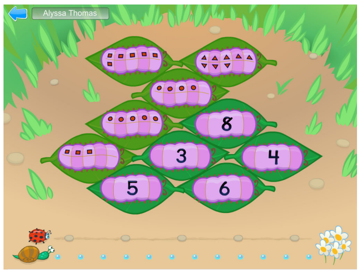

Figure 3. Level 3 - Given a limited number of turns, match bugs showing the same number, when the bugs are all visible.

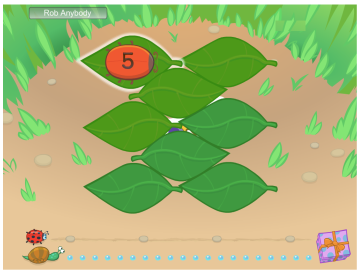

Figure 4. Level 4 - Given a limited number of turns, match bugs showing the same number, when only one bug at a time is visible.

Figure 5. Interstitial 1 - Count the dog barks (1-5) and then select the tag with the matching numeral.

Figure 6. Interstitial 2 - Count the fingers (1-10) that the dog is holding up and then select the tag with the matching numeral.

At two public schools, 65 students (48 pre-kindergarten students and 17 kindergarten students) worked with our iPad-based number game for an average of 15 days, spending roughly 10 minutes each day on the number game. For pre-kindergarten students the average total number of trials was 805, while for kindergarten students the average number of trials was 1484. Feedback was provided on each error in the form of both computer provided verbal and visual information indicating when an error was made. The software provided students with feedback after every trial indicating whether the response was correct or incorrect. Simple feedback was provided by the animated dog characters (e.g. shaking head, smiling), while more complex feedback was provided by the narrator (e.g., "Try counting the ballons.")

Results

Major performance differences were seen between pre-kindergarten students and kindergarten students, with a much larger percentage of the kindergarten students advancing to higher completion levels (Figure 7).

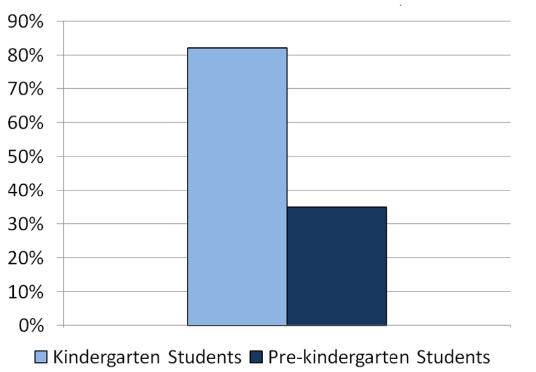

Figure 7. Percentage of students who completed all levels, by grade.

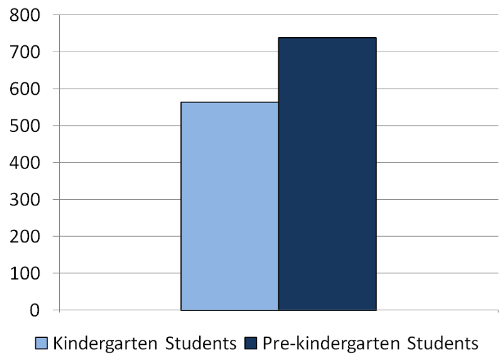

Figure 8. Number of trials to complete all levels, by grade.

On average, the pre-kindergarten students required 738 learning trials to pass the highest stage, whereas the kindergarten students required only 563 learning trials (Figure 8).

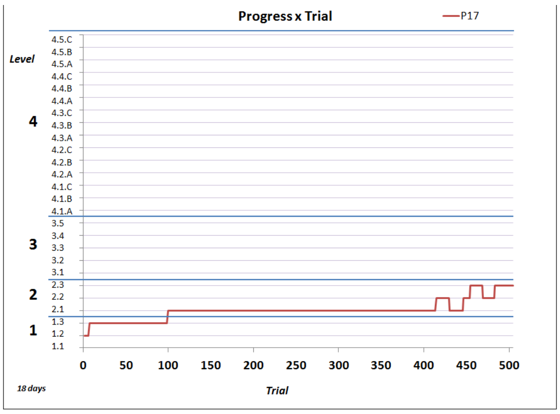

Figure 9. Pre-kindergarten student stuck in level 2.

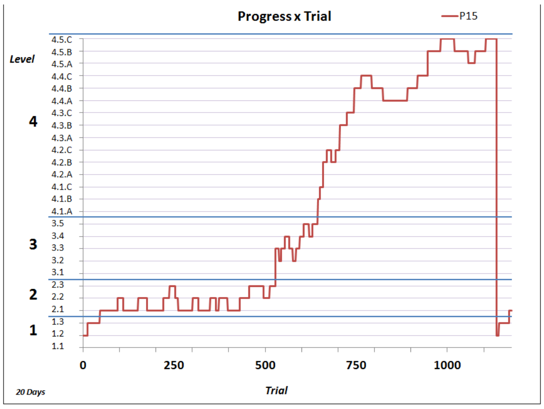

Figure 10. Pre-kindergarten student stuck in level 2, who subsequently completed all levels.

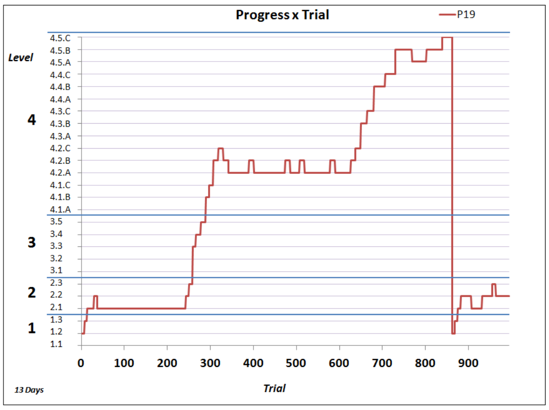

Figure 11. Pre-kindergarten student showing advancement through all levels.

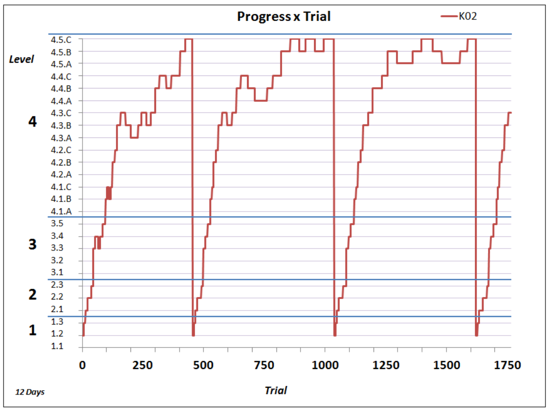

Figure 12. Kindergarten student showing grade-typical performance (student completed all levels and restarted, three times).

Data was collected for each learning trial so that we could track individual students' progress over time. One trend that emerged from this data was that a large number of students, especially those in pre-kindergarten, failed to pregress beyond level 2 (Figure 9). Other students got temporarily stuck in level 2, but were eventually able to pass (Figure 10). Differences were also seen among those students who were able to master the game (17 pre-kindergarten students and 14 kindergarten students), with those in pre-kindergarten typically progressing more slowly (Figure 11) than those in kindergarten (Figure 12). Further analysis confirmed that a substantial proportion of the pre-kindergartners (42%), as well as some kindergartners (18%), were unable to pass level 2 (Figures 13 & 14). In contrast, very few students got stuck on the putatively harder task in level 3.

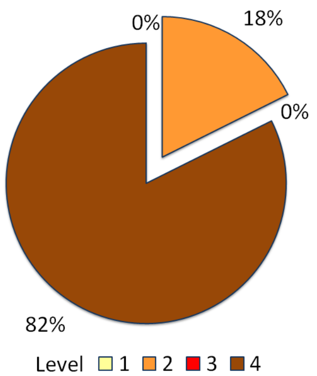

Figure 13. Highest level entered by kindergarten students.

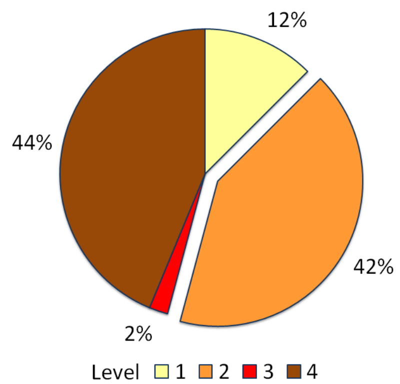

Figure 14. Highest level entered by pre-kindergarten students.

Conclusions

The older (kindergarten) children were developmentally more prepared for this task as presented, while the younger (pre-kindergarten) children needed different forms of scaffolding or feedback. Compared to the older students, the younger students had more difficulty with exercise in general, and especially with exercise level 2 (associating Arabic numerals with sets of countable objects in a ten frame). Pre-kindergarten students often became stuck at level 2 for long trial sequences. We concluded that their difficulties were exacerbated by the type of feedback given after errors: the computer highlighted each set in turn, naming the number of objects in that set. The student then got a second chance to answer the same item (second answers did not count toward passing the level, but this was not obvious to the students).

With this type of feedback, a majority of older but not younger children were able to adopt a successful strategy and master the task. A subsequent version of the software will be tested, using revised error feedback (i.e. not naming the number of objects in the sets) and imposing additional costs for making errors, to determine if these changes will help younger children adopt more productive strategies.

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