Can children enhance their arithmetic competence by playing an especially designed computer game?

Ingemar Holgersson[1], Wolmet Barendregt[2], Elisabeth Rietz-Lepännen[2], Torgny Ottosson[1] and Berner Lindström[2]

[1] Högskolan Kristianstad, Sweden; [2] Göteborgs universitet, Sweden

Abstract
Fingu is a game and a game platform aimed at helping children 4 to 8 years old develop competence and fluency with basic addition combinations. We present results from an eight week intervention, where children, 5-, 6-, and 7 years old, have been allowed to play the game as part of their ordinary pre-school and school activities. Results show significant positive differences between pre- and post-tests in four arithmetic measures with modest to large effect sizes. In contrast most differences between post-tests and delayed-tests, when the children did not play the game, are non-significant with none or low effect sizes. Design principles and results are discussed with special emphasis on children who "struggle to learn math".

Extended summary
Introduction
A basic level of mathematical literacy is to master arithmetic concepts and skills, among other things to understand the number concept and to add and subtract natural numbers. According to Baroody (2009) the learning of arithmetic starts, at the age 2-4 years, with developing a good understanding of the so called intuitive numbers one, two, and three. Another key step in the development of arithmetic is to be able to compose and decompose numbers. This ability makes it possible for the child to discover patterns and regularities in addition and subtraction, which is the ground for becoming proficient and flexible at mental arithmetic. Children who experience difficulties with arithmetic seem to lack this ability to use simpler arithmetic facts to derive other results (Gray & Tall, 1994). Instead they become reliant on counting as the only method of arriving at sums and differences. To counteract this tendency we have developed an iPad game called Fingu.

Fingu is a game and a game platform aimed at children 4 to 8 years old, that has been developed in a project (CoDAC) founded by the Swedish Research Council. The basic idea is that the player is exposed to two moving sets of objects, and is supposed to respond by touching the screen by the same total number of fingers. The total number of objects is in the range 1 to 10. There are seven levels in the game with increasing sums and more challenging patterns of objects. So the task is presented in a visual mode while the response is given by the fingers, which includes tactile and motor activities. To solve this task thus often requires a transformation from the exposed partition of the sum to another partition given by the hands. A key part of the game is also that the player is forced to give a coordinated response, i.e. you cannot touch the screen with one finger at a time, but is forced to touch it with all the fingers giving the response at the same time. Thus the player is stimulated to focus on the parts and the total sum instead of enumerating the sum. In this way the task, which on a surface level can appear as a simple skill-focused activity, becomes more of a problem solving activity. This is amplified by the player's freedom of choosing which fingers and which partition to use in his/her response. Learning to manage the fingers to express sums is in this way an essential part of what Fingu provides.

Aims

One of the aims of the CoDAC project is to investigate how children come to understand part-whole-relations within the numbers 1 to 10, and which strategies they develop to accomplish this. The main tool we use for studying this question is Fingu. In this study we will focus on whether the competence developed while playing Fingu has any generic value, i.e. if the children that are allowed to play Fingu also will become better at ordinary school mathematics.

Methodology

We have studied 87 children (33 five-year-old, 28 six-year-old, and 26 seven-year-old) that for about eight weeks were allowed to play Fingu as one part of their practice in pre-school or school. Before this experimental period we measured their arithmetic ability by using different measures. These data were collected by interviewing the children individually, and video-recording parts of the interviews. Directly after the eight weeks experimental period we repeated the measuring of their arithmetic ability. And this was repeated once more another eight weeks later as a delayed follow-up. In this later eight week period the children were not allowed to play Fingu. We used four measures of arithmetic ability: Tema3, a problem solving test (PS), a test of part-whole knowledge (PWK), and a pattern recognition test (PR). Tema3 is an American test developed by Ginsburg and Baroody (2003) that we have translated for this study. It is normed for American children, but we use it here solely as a test of an all-round arithmetic ability. The PS-test consisted of 8 verbally presented problems where the children were invited to present their solutions. All problems were of an addition or subtraction problem type, and had sums ≤ 10. The PWK-test consisted of 29 tasks that indirectly tested the child's knowledge of different number combinations, using fingers or reasoning about hidden objects. Lastly the PR-test is a specially constructed test consisting of 20 tasks presented using the Fingu platform, and investigating the children's knowledge of a representative selection of the number patterns used in the Fingu game.

Another set of data that we have gathered consists of log-files that record data such as which task, the child's answer, answering-time, and the location of the fingers used to answer the task. These log-files can also be used to replay a session in Fingu, where the locations appear as red dots making the finger use visible. Complementing these data we have also video-recorded three sessions with each participant, documenting how they manage their fingers while playing the game.

Findings

The children have as a mean value played three times a week, but there is a big variation in the total number of times the children have played. Preliminary analysis of the test results show that there are significant differences with $p < 0{,}01$ in mean values with modest to large effect sizes between pre- and post-tests for the different age groups: Tema3 (Cohen's d = 0,38; 0,32; 0,60), PS (d = 0,56; 0,48; 0,54), PWK (d = 0,43; 0,34; 0,75), and PR (d = 0,84; 0,88; 1,02). Studying the differences in mean values between the post-test and the delayed-post-test for the different age groups resulted in the following effect sizes: Tema3 (d = 0,20; 0,29; 0,23), PS (d = -0,01; -0,09; 0,02), PWK (d = 0,36; 0,19; 0,02), and PR (d = -0,03; -0,39; -0,11), i.e. only low or negative effects. The only significant differences in mean values appeared for Tema3 ($p \approx 0{,}01$) and for PWK for 5-year-olds ($p < 0{,}5$). An analysis of the effect sizes for groups of low, medium, and high pre-test-results show that there are the same amount of effects in all these groups, i.e. also low-performing children gain from playing Fingu.

In order to study in more detail the conditions of playing that promote arithmetic knowledge we have to analyze individual cases. This is however an analysis that we have only started, but we hope to be able to give more information on this issue at the conference.

Theoretical and Educational Significance

Fingu was constructed with the aim of helping all children who play to become fluent with the basic combinations of addition in order to develop adaptive and flexible arithmetic knowledge (see Baroody (2003) for a definition of these concepts). The design principles are in accordance with perceptual learning as discussed by Gibson and Pick (2000) and Kellman e.a. (2008). These include varied and many short tasks, where the child has the opportunity to develop rapid selection of task-relevant information, and the pick-up of higher-order relations and invariances in different modalities such as visually and by using the sensory-motor system. You get feedback in Fingu on whether the answer was correct or not, but you are not told or shown what the correct answer was. This is part of preserving the game as a problem-solving activity, and not turning it into a tutorial one. Much too often tasks for children who "struggle to learn math" are deprived of conceptual dimensions aiming only for rote learning.

Although Fingu can be played "as is", another strength lies in the fact that it is developed as a research platform offering numerous possibilities for adaptation, both by researchers and teachers. Teachers can easily change settings such as the speed with which the patterns move around on the screen, the number of mistakes the player can make before having to play over any level, the exposure time of the patterns, as well as the time for answering. The number of levels and assignments per level can be defined by creating an xml-file that can be loaded into the game. This makes it possible to create special profiles for different groups of children based on teachers' requirements. Log-files provide the possibility to replay and study how children use the game. This adjustability makes it possible to vary the game to better suit special individuals.

References

Baroody, A.J., Bajwa, N. P. & Eiland, M. (2009). Why can't Johnny remember the basic facts? *Developmental disabilities research reviews, 15*, 69 – 79.

Baroody AJ. 2003. The development of adaptive expertise and flexibility: the integration of conceptual and procedural knowledge. In: *Baroody AJ, Dowker A, editors. The development of arithmetic concepts and skills: Constructing adaptive expertise.* Mahwah, NJ: Erlbaum. p 1–34.

Gibson, E.J. & Pick, A. D. (2000). *An ecological approach to perceptual learning and development.* New York, NY: Oxford University Press.

Ginsburg, H.P. & Baroody, A.J. (2003). *Test of early mathematics ability – Third edition.* Austin: Pro-ed.

Gray, E. M., & Tall, D. O. (1994). Duality, ambiguity, and flexibility: A "proceptual" view of simple arithmetic. *Journal for Research in Mathematics Education, 25,* 116-140.

Kellman, P. J., Massey, C. M., Roth, Z., Burke, T., Zucker, J., Saw, A., Aguero, K., & Wise, J. (2008). Perceptual learning and the technology of expertise: Studies in fraction learning and algebra. *Learning Technologies and Cognition: Special issue of Pragmatics & Cognition, 16(2)*, 356–405.