Preschoolers Favour Teachable Agent's Action over Distraction

Anton Axelsson
anton.axelsson.287@student.lu.se

Studies on teachable agents (TA) have repeatedly demonstrated their benefits in primary school pupils' learning, but no study has yet been devised to investigate whether the same effects can be observed in preschoolers. Preschool age is an important time for development of executive functions (EF) and theory of mind (ToM), and it can be argued that preschoolers might not be able to pay enough attention to a TA due to underdevelopment of these cognitive abilities. In this study, visual distractions in the form of animated objects were incorporated into a mathematics game for preschoolers which utilises a TA. 65 preschoolers participated in the study which investigated whether they were able to ignore these distractions in favour of focusing on the TA's actions. The results showed a statistically significant difference in preschoolers visual attention to the animations played during the TA's action to those played after the TA's action. This result is a crucial step forward in further development of TA-based games for preschoolers.

Keywords: teachable agent, attention, executive functions, theory of mind, preschooler, distractibility, eyetracking

1 Introduction

The Swedish National Agency for Education states in the preschool curriculum that the preschool work team should "challenge the curiosity of children and their growing understanding of … mathematics, as well as science and technology" (Skolverket, 2011, p. 11). The curriculum also states that the "preschool should strive to ensure that [all children] … develop their ability to identify technology in everyday life, and explore how simple technology works, … develop their ability to distinguish, express, examine and use mathematical concepts and their interrelationships" (p. 10). Furthermore, the preschool should offer "[p]edagogical activities … related to the needs of all children in the preschool" (p. 5).

In order to relate to the pedagogical needs of pupils, individualised tutoring is crucial which enables support for struggling pupils. It is not uncommon for primary school pupils to struggle with mathematics. This can be traced back to not being trained enough in simple mathematical reasoning at an early age for *number sense* to emerge (Gersten & Chard, 1999). Using educational software in preschool, customisable for each individual, could be a way to more easily fulfil the quite demanding goals of the preschool curriculum mentioned above. It can also facilitate the use of a very successful teaching paradigm called *learning by teaching*, which has shown great success in low-achieving primary school pupils' learning through the use of digital *teachable agents* (Chase, Chin, Oppezzo & Schwartz, 2009). The question is whether the same effects can be observed in preschoolers. Preschool age is an important time for cognitive development and preschoolers might not possess the cognitive prerequisites necessary to reap the same learning benefits as primary school children.

The study presented in this thesis explores the possibilities of using a teachable agent in a computer based game of mathematics for preschoolers. The main goal was to investigate whether preschoolers are too easily distracted, due to underdevelopment of cognitive functions, to be able to pay attention to the agent.

Teachable Agents and Learning by Teaching

A teachable agent (TA) can be described as an autonomous, digital tutee incorporated in educational computer software. Studies have shown that a TA is a fruitful tool for educating primary school pupils (e.g. Gulz, Haake & Silvervarg, 2011; D. Schwartz & Blair, 2007). The idea is that a pupil takes the role as a teacher in order to tutor the TA. This role switching encourages the pupil to take responsibility for someone else's learning (c.f., *Protégé Effect*; Chase et al., 2009) within the learning-by-teaching framework (see e.g. Biswas, Leelawong, Schwartz, Vye & The Teachable Agents Group at Vanderbilt, 2005; Brophy, Biswas, Katzlberger, Bransford & Schwartz, 1999).

It has been shown that teaching others is a very effective way of learning for oneself (Bargh & Schul, 1980). One explanation for this is that in order to teach someone else you will need to be well-read and prepared. Some great advantages of using a TA for this purpose are that *all* pupils can become teachers, regardless of their abilities and beliefs in their own ability, and that no actual pupil suffers from a poor teacher. Also, the learning-by-teaching paradigm creates what is called an *ego-protective buffer*. When, for example, tests are conducted they can be taken by the TA. This enables the pupil to attribute responsibility to the TA, which makes test failures easier to handle because the pupil does not have to carry the full burden of a poor result since the test result can be partly attributed to the TA (Chase et al., 2009). This can lead to that a pupil will not become as easily discouraged by a difficult subject.

Another proposed major benefit of the learning-by-teaching framework is that it stimulates *reflective* thinking about problem-solving and learning, so called *metacognition*. This is made possible through the tutor's monitoring of the tutee's actions and problem-solving over time. A study by Gelman and Meck (1983) showed that children were better at monitoring and reflecting upon adults counting, near the limit of the children's abilities, than the children were when performing the counting themselves. The children were thus able to free cognitive load when observing the adults which allows these freed resources to be utilised on metacognitive reasoning. It is of course vital that the child pays close attention to the adult in order to be able to reflect on the adults progress in counting. The same is true in the use of TAs. A study by Lindström, Gulz, Haake and Sjödén (2011) showed that primary school children were concentrating on, as well as attending to, their TA regardless of whether they were in charge of game play or just observed the TA playing. Just as with the child observing the adult counting, this is important in order for the pupil to be able to reflect on the agents learning which facilitates the emergence of metacognition.

The largest gains in using a TA have been observed in low-achieving pupils. They seem to have a higher learning rate with a TA whilst their high-achieving peers do just as good with as without a TA (Chase et al., 2009).

In sum, there is a body of research on the topic of TAs that all provide evidence for the educational benefits (Chase et al., 2009; Gulz et al., 2011; Pareto, Arvemo, Dahl, Haake & Gulz, 2011; Pareto, Haake, Lindström, Sjödén & Gulz, 2012; D. Schwartz & Blair, 2007; D. L. Schwartz et al., 2009; Sjödén, Tärning, Pareto & Gulz, 2011). However, all of these focus on primary school pupils aged between 7 and 14. Thus, there is hitherto no clear evidence that the benefits of a TA can be generalised to preschoolers.

In a pilot study, Axelsson, Anderberg and Haake (2013) tested a mathematical game on 10 preschoolers. The game, — called *Bird Hero* — has a TA incorporated in the form of a panda. The study showed that these preschoolers were able to play the game with ease without the TA being obtrusive to game interaction and it also showed that the children seemed to pay attention to the TA and its actions.

With the knowledge that TAs serve as a very beneficial tool for learning, the purpose of the present study was to build on the work by Axelsson et al. (2013) by conducting a larger and more systemised study on preschoolers ability to attend to TAs. Previous mentioned studies on TAs have mostly used games built around mathematics. This because mathematics is easy to adapt into software games due to its strict formal structure. Bird Hero will be used in the present study and its preschool mathematical concept revolves around helping children acquire number sense.

Number Sense

Number sense refers to an understanding of the meaning of numbers and the ability to make comparisons, as well as showing fluency with numbers (Gersten & Chard, 1999), and an understanding that they relate to quantities (Griffin, 2004). Basic number sense usually emerges in a child through normal interaction with parents and siblings. If it does not emerge, or if the child does not develop it sufficiently during preschool years, it is not unusual for the child to have difficulties in understanding more complex mathematics once in primary school (Berch, 2005; Gersten & Chard, 1999; Jordan, Kaplan, Nabors Oláh & Locuniak, 2006). Number sense can be taught (Griffin, 2004), and for children who have not been exposed to numerical reasoning at home, formal training of number sense is essential (Bruer, 1997).

Bird Hero

The game Bird Hero — developed by Anderberg, Axelsson, Bengtsson, Håkansson and Lindberg (2013) — revolves around a flock of chicks that are blown out of their nests and whom need help to get back up. The player helps the chicks return home via a lift by pushing lift buttons. The chicks, one at a time, presents a number of feathers representing the floor they live on. The player's task is to match this number with one of eight lift buttons presented at the bottom of the computer screen (see e.g. Figure 3a). After a while, the TA is introduced and asks the player if he can watch the player in order to learn how to operate the lift. Further on, the TA asks whether he can take over and try to help the birds by suggesting which lift button the player should press. The player is then allowed to correct the TA when the player believes the TA makes a mistake.

If the player or the TA chooses the correct lift button, the bird will arrive at its nest and will give off a cheerful chirp. If the player or the TA chooses an incorrect lift button, the bird will end up on the wrong floor and explain to the player that she lives either further up or lower down. The idea behind using a lift is that it represents a vertical number line. It gives a good representation of parts of the whole — branches as floors — and that higher numbers are placed higher up spatially. It is important, in a child's numerical development, to use familiar concepts (Griffin, 2004; Hannula, Mattinen & Lehtinen, 2005), and a lift, which in itself contains mathematical properties — numbered buttons representing floors — is a common feature in our society.

Educational mathematical software — such as Bird Hero — should well fit the purpose for formal training of number sense in preschool. The ability to customise educational software is essential to meet the needs for individualised tutoring. This in conjunction with the use of a TA could potentially be an enhancement in a child's acquisition of number sense, partly due to potential benefits such as the ego-protective buffer, but also because the TA and the game environment can provide *consequence feedback*. An example of this from above is when the bird arrives at the floor which the player has sent her. Instead of just telling the player whether a choice is correct or incorrect, the feedback is incorporated into the game's narrative and gives more concrete feedback as to whether his or her choice was correct, over-, or underestimated. This is far more insightful than just being told whether an answer is correct or incorrect (Zhao & Shen, 2012). Furthermore, a TA can be developed as to also provide mathematical reasoning geared towards the preschooler's level of number sense.

Prerequisites

There are two possible caveats with regard to intentional focus on TAs when it comes to the cognitive abilities of preschool children. These are related to *executive functions* and *theory of mind*.

To stay focused on what is essential, it is very important to be able to perform top-down guidance of one's own attention. This is handled by our executive functions, such as inhibitory skills (Sarter, Givens & Bruno, 2001). If an object appears to be moving in you peripheral vision, it is very hard to resist the temptation of looking at that object. The ability to do so is an example of the executive function of inhibition.

TAs are meant to learn and they are programmed to act as social characters. Thus, any teacher of such an agent must be able to reflect upon the agent's learning. This would suggest that a developed theory of mind might be necessary in order to make use of a TA's full potentials. A developed theory of mind means that you understand that other people have a mind, which can hold views, beliefs, and desires separate from your own.

Executive functions and theory of mind share an important development period during the ages between 3 and 5 (Garon, Bryson & Smith, 2008; Perner & Lang, 1999). There is, however, no fixed moment in time at which these abilities come into play, the development of them is instead gradual. As discussed above, primary school pupils pay a lot of attention to their TA (Lindström et al., 2011) similarly to the children paying attention to adults counting in the study of Gelman and Meck (1983). Because of the development period of executive functions and theory of mind during preschool age, it can be argued that preschoolers are not developed enough in their cognitive abilities to benefit from a TA the way primary school pupils do. Developing a fully functioning TA-based game is very costly and time consuming. Thus, it is vital to conduct a study to investigate whether preschoolers have the basic cognitive abilities necessary to even begin benefiting from a TA.

Executive Functions. Executive functions enable humans to become conductors of their own lives. Among these, inhibitory skills are found which facilitates control of attention. Several cognitive scientists consider inhibition to be a primary function in executive control (Burgess, Alderman, Evans, Emslie & Wilson, 1998; Garavan, 2002; Norman & Shallice, 2000). If an object appears to be moving in you peripheral vision, it is very hard to resist the temptation of looking at that object. The ability to do so is an example of the executive function of inhibition. Inhibition is thus the explicit control of your mental and motor reflexes, and it is also deemed important to selective attention (Kok, 1999; Tipper & Cranston, 1985). Selective attention is your ability to stay so focused on one aspect of your environment that you ignore other, a study showed that focusing intently on a task can essentially render you deaf (Dalton & Fraenkel, 2012). Sustained attention, on the other hand, is your ability to remain alert and refrain from letting your mind slip. This can be particularly hard when performing a mundane, monotonous task. In such situations, your mind can easily wander and it then becomes very easy not pay attention to what you are doing.

Another important part of attention is the ability to shift focus, this is usually called *set shifting* and is viewed, alongside inhibition, as one of the most important aspects of executive functions (Monsell, 2003).

Theory of Mind and False Belief. If you have a developed theory of mind, this means that you understand that other people have a mind which can hold views, beliefs, and desires separate from your own. The most standardised way of measuring theory of mind is looking at a persons understanding that others can possess a *false belief*, that is, that others can hold beliefs which diverge from your own.

Clements and Perner (1994) showed that some children, although they did not fully pass the false belief tasks, did seem to have an implicit understanding of false belief. This finding was later corroborated by Garnham and Perner (2001). This means that there are different levels in the development of theory of mind. Generally, at the age of six all children have a fully developed theory of mind which they can explicitly verbalise and it has been suggested that a fully explicit theory of mind is developed through language understanding. However, false belief has been observed in children as young as seventeen months (Southgate, Chevallier & Csibra, 2010). There are also indications of connections between executive functions and theory of mind. For example, Moore, Jarrold, Russell, Lumb and Sapp (1995) found that some theory of mind tasks are dependent on executive control.

Distractibility

From studies on attention deficit hyperactivity disorder it has been demonstrated that people with attention problems have trouble performing many executive function tasks (Barkley, 1998 and Pennington, 1997 in Garon et al., 2008). Due to the ongoing development of executive functions in preschoolers, a very convincing argument can thus be made against using TA-based games in preschool education, namely that preschoolers might be too easily distracted — especially in a lively environment such as a preschool — to be able to spend the time and effort needed to engage with and attend to a TA. Attention, however, is an elusive concept and near impossible to measure. Studies have found a close relation between attention and eye movements (see e.g. Deubel & Schneider, 1996). However, looking does not imply attending. Anyone who has spent time with a dull character at a social event can attest to that just because you are looking at something does not mean you are paying attention to it. One way around this problem is instead to measure preschoolers' distractibility in a short time span where focus is needed elsewhere in a TA-based game.

Purpose

The aim of the present study was to shed light on the use of TAs in a mathematical game for preschool children. The study primarily focused on investigating preschoolers ability to inhibit distractions in a situation where they needed to attend to the actions of a TA. Furthermore, the study was designed to look at preschoolers inclination to inhibit distractions in relation to their development of executive functions and theory of mind. The long term goal is to aid further development of games utilising TAs, such as Bird Hero, with its potential educational benefits in store for preschoolers.

Research Questions

(1) Can preschoolers be focused enough on a TA's actions to inhibit distractions?

(2) What differs between preschoolers who are able to inhibit distractions from those who are less able to do so, in terms of executive control and theory of mind?

(3) With the results from research question 1 and 2, is it possible to find a recommended age at which TA-based games should be introduced in order to be beneficial for preschoolers?

Expected Outcomes

The general hypothesis behind this study is that a preschooler with more developed executive functions and theory of mind should be less inclined to attend to a distraction during a TA action than a peer with less development of such cognitive abilities. The expectation is to find a gradient of development of these abilities among the participants, and thus a correlative gradient of attention to distractions. The expectation is also to find a stronger relation between distractibility and development of executive functions than with development of the-

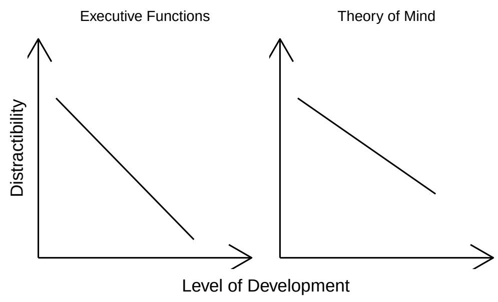


Figure 1: Regression lines of hypothesised data where executive functions and theory of mind act as predictors of distractibility.

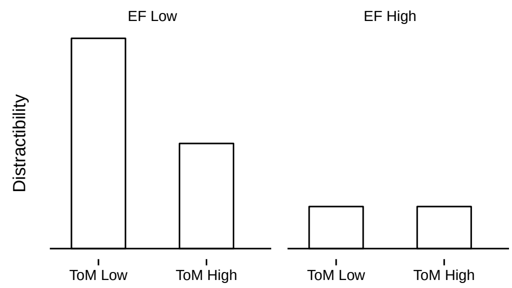


Figure 2: Hypothesised relation between distractibility and high/low development in executive functions and theory of mind.

ory of mind (see hypothesised regression in Figure 1), simply because executive functions are the driving forces of explicit, top-down guided attention.

Thus, on a side note, because of the intertwined relationship between executive functions and theory of mind, one potentially interesting and more exploratory aspect of this study could be to look at whether a well-developed theory of mind could have a motivational effect strong enough to compensate for less developed executive control with regard to distractibility in relation to social characters (see hypothesised graph in Figure 2).

2 Method

Participants

65 children (34 girls) aged between 3;1 and 6;3 years from a preschool in Southern Sweden were given permission through written consent forms by their guardians to participate in the experiment. The particular preschool was selected because it is situated in an area which is representative of Sweden with regard to level of education and income among its population.

Ethics

This study was conducted as a part of the project "Play for Knowledge: Can Preschoolers Learn Through Teaching, and can Speech Production Enhance Their Understanding for Other Peoples Perspective?", and has been approved by the Regional Ethical Review Board of Lund (ref. 2013/111).

Equipment

A remote eye tracker (SMI RED 500) was used along with two desktop PCs, an external computer microphone, external sound card (Edirol UA-25), and headphones (AKG K271). All pre-test stimuli were developed in Python using the open source PsychoPy2 application (v.1.76.00; Peirce, 2007).

Measurements and Procedures

All participants were subjected to pre-tests which measured their current level of development in executive functions and theory of mind. The results of these tests were used to build a profile around each participant in order to facilitate extraction of vital components in voluntary focus of attention and inhibition of distracting stimuli.

The executive functions measured were inhibition and sustained attention. To test inhibition, Apple Defender was used, which tests motor inhibition, and Shape School, which tests task inhibition. To test sustained attention Colour-SART was used.

Correct attribution of false belief was tested in two tasks as a measure of theory of mind through the Sally-Anne and Droodle tasks.

General Procedure. All tasks were carried out over three separate sessions for each participant in a secluded part of the participant's department of the preschool. The room utilised was either a play or computer room to which the door could be closed. In the first session the Apple Defender task, Sally-Anne task, and Colour-SART task were performed. After the pre-tests, the participants played Bird Hero without any distracting visual stimuli in order to familiarise themselves with the game. In the second session the Shape School and Droodle tasks were performed together with a second experiment leader who was collecting data from the same participants for a separate study at the preschool. In the third and final session, the participants played Bird Hero with the distracting visual stimuli.

Apple Defender. To measure inhibition, an antisaccade task (Hallett, 1978) was used which was embedded in a narrative to appeal to younger participants. The task was presented on a computer screen and the eyetracker was used to measure eye movements. Two apples were shown on either side of a centred diagonal cross on the screen. The participant was instructed to imagine that the apples belonged to him or her. A cartoon monster was shown to the participant and it was explained that this monster would appear and eat one of the apples, and that between each of the monster's appearances the participant should look at the cross in the centre of the screen. Once the monster appears, the other apple is defended by the participant looking at it. This task was a test of the participants' inhibitory skills of reflexive motor movement when presented with visual stimuli, and is a way to measure the development of executive control with regard to inhibition.

Coding. The Apple Defender task consisted of 24 trials. Children under the age of 8 have trouble suppressing reflexive saccades towards moving stimuli (Munoz & Everling, 2004) and thus it is not meaningful to measure this task through correct and incorrect trials, simply because most of the children are likely to fail on most of the trails. Furthermore, children are a lot more impatient than adult participants and it was hard to get all children to complete the full 24 trials. Therefore, in order to be able to take a fair measure of this task the present study measured how much time the participant spent *not* looking at the monster as a fraction of how much time the monster was displayed during the task.

Colour-SART. Sustained attention was tested through an adaptation of the Sustained Attention to Response Task (Manly, Robertson, Galloway & Hawkins, 1999; Robertson, Manly, Andrade, Baddeley & Yiend, 1997). Instead of using digits from 1 to 9, five colours were used; red, green, yellow, blue, and orange. The stimulus was presented on a computer screen and an external keyboard was used to capture the participant's response. Each colour was shown separately, in the form of a rectangle, 15 times. The order of the colours was semi-random and equal for each participant. Each colour was displayed for 500 ms with a 100 ms pause of a blank screen between each colour. The participant was asked to press the spacebar of the keyboard each time a new colour was shown on the screen (60 go-trials) except for when the colour was blue (15 no-go-trials). First the participant was shown all colours one at a time and was asked to name them. After that, the participant was given a test run of 15 trials after which the task started.

Coding. From the total 75 trials, one point was awarded for each correct trial. A trial was considered correct if the participant did not press the spacebar when the colour blue was presented, or if the participant did press the spacebar when any other colour was presented. Go- and no-go-trials were then separately standardised through calculating a z-score, and the mean of the two z-scores was used as measure of the Colour-SART task.

Shape School. In order to measure task inhibition Espy's (1997) Shape School was used. Stimuli were presented in the form of a story with eight illustrations using a binder. The Shape School task is divided into four scenes: (1) baseline, (2) inhibit, (3) switch, and (4) inhibit and switch.

In each scene, coloured shapes with cartoon faces representing pupils of a preschool was presented to the participant. The task was always to name the pupils as fast as possible.

In the first scene the participant was told that these pupils were lining up to go in to their preschool, and that each pupil's name was the same as its colour. The participant was then asked to name all the pupils. This was the baseline measurement of the participant's performance.

In the second scene, the pupils were shown lining up for lunch. Some of the pupils were sad to go for lunch because they were not ready to go back in, whilst others were ready and thus happy. The participant was asked to name only the ready pupils.

In the third scene, the participant was introduced to a new class lining up for art. Some were wearing hats. The participant was told that these pupils were named after their shape. The participant was then asked to name all the pupils in the line; either named after their shape, or, if hatless, after their colour.

In the fourth scene, the pupils were lined up to wash their hands after the arts class. Some of the pupils were sad to wash because they were not finished doing art, whilst others were ready and thus happy. The participant was asked to name only the ready pupils; also here either by shape or colour.

Coding. Unfortunately, the experiment leader of this particular test misunderstood how it was supposed to be carried out, which lead to that only the scores for the inhibition task of this test could be used. 1 point was awarded for each correctly inhibited pupil's name with a maximum total of 6 points.

Sally-Anne Task. The Sally-Anne task (Baron-Cohen, Leslie & Frith, 1985) was used in order to test the participants' ability in attributing false beliefs. The story is presented on the computer screen as a video and the participant was given the headphones in order to hear the story as told by a recorded voice. A room with a basket and a box was shown in the video along with two doll protagonists, Sally and Anne. Sally played with a ball which she then placed in the basket covering it with a blanket. She then left the room. Anne picked up the ball and moved it to the box and put on the lid. Once Sally returned the recorded voice said "I wonder where Sally will look for her ball?". After a short pause the participant was asked to point where he or she believed Sally would look for the ball. Once the participant had pointed, he or she was asked three memory questions: (1) "Where did Sally place the ball?", (2) "Did Sally see when Anne moved the ball?", and (3) "Where is the ball now?". Lastly an evaluative question was asked: "Why would Sally look for the ball in this place?". A second trial was run with exactly the same setup except that this time Sally stayed in the room whilst Anne moved the ball. The memory questions were asked in order to make sure that the participants had fully understood the story, and the evaluative question shows to what extent the participant can verbally explain Sally's behaviour and thus is a measure of verbalised theory of mind. This study collected data of the false belief task jointly with a concurrently running study which focused on theory of mind. Due to experiment setup of the joint study, a second version of the the false belief task was also used where a boy named Max had been given a chocolate bar which he placed in a cupboard (Perner & Lang, 1999). In this version his mother moves the chocolate and the same procedure as in the Sally-Anne true and false belief conditions were used. Half of the children were assigned to the Sally-Anne version and the other half were assigned to the Max-Mother version. Verbal responses to the questions asked were recorded through the computer microphone and non-verbal responses were marked in a protocol.

Coding. Which container the participant points to when asked, and the answer the participant gives as to why Sally or Max looked for the object where they did, were used to assess the participants' understanding of false belief. A participant was awarded 1 point for pointing correctly and 1 point for a correct verbal account (e.g. "Sally did not see Anne move the ball" for the false belief condition). With the two conditions, a participant could therefore score a possible total of 4 points.

Droodle Task. A second task for measuring understanding of others' false beliefs used in this study was the Droodle Task (Chandler & Helm, 1984). In this task, participants are shown stylised drawings. It could for example be a doodle of a cat. Then a piece of cardboard with a small cut-out square is placed on top of the drawing, revealing only a small portion of the picture, such as the cat's tail. The participant is then asked what a friend of his or hers would make of the picture if only shown this small part. The idea here is that if a participant is unable to attribute false beliefs to others then he or she will say that the friend will think it is a cat or a cat's tail. On the other hand, if the participant has a developed theory of mind and thus is able to attribute false beliefs to others, he or she will say that the friend would think that it is an image of a hockey stick, for example. The stimuli were presented in a binder.

Coding. If the participant's report on what the friend would say was congruent with the complete drawing, the participant was awarded 0 points. If the participant said that he or she did not know what the friend would think they were awarded

1 point. If the explanation of what the friend would think was incongruent with the complete drawing, the participant was awarded 2 points. Three images were shown to each participant thereby giving them a possible total of 6 points.

Main Task. The main task of the present study consisted of playing the TA-based mathematics game Bird Hero which is developed in JavaScript and HTML5. The game initially consisted of three game modes: (1) pupil plays; (2) TA watches pupil play; (3) pupil guides TA. The original game has been adapted for this study and a fourth game mode has been added: (4) pupil watches TA play. The four game modes are depicted in Figure 3.

Thus, in Game Mode 1 the participant played alone, helping the chicks to the correct branch through manoeuvring the lift panel. In Game Mode 2 the TA was introduced, and all he did was observing the participant play. In Game Mode 3 the TA suggested which lift button should be pressed by presenting his choice in a thought bubble. The participant then chose whether the TA was correct or incorrect through a binary choice by pressing a green tick or a red cross respectively. These binary buttons were presented centred at the bottom of the computer screen (see Figure 3c) and the TA's thought bubble did not disappear until the participant pressed one of these binary buttons. In Game Mode 4 the TA played without any help from the participant. Each mode consisted of helping two birds home to their nests, except for Game Mode 3 in which four birds were helped. Participants wore headphones during game play in order to be able to listen to the TA and the birds.

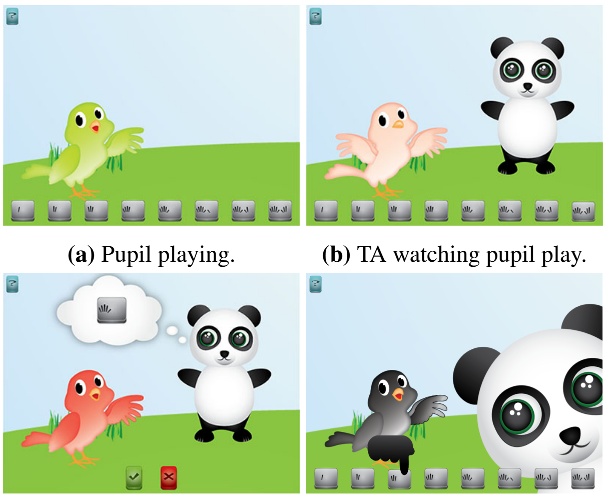
Throughout the game, four different distracting visual stimuli were used in the form of animations that were irrelevant to game play (Figure 4): (1) an aeroplane passing by in the background; (2) a branch falling from the tree; (3) a football rolling across the grass in front of the TA and the bird; and (4) a flickering square symbolising a program glitch. These visual stimuli were intended to distract the participants. The animations are not meant to be a part of a final version of Bird Hero but were used as a simulated noisy environment, condensed into an eye-trackable area, and are a means of measuring distractibility. The aim was to investigate which participants were able to inhibit these stimuli throughout game play and focus their visual attention on the task at hand.

The distractive animations were played in Game Mode 3 and 4 at crucial parts of game play when the player — to profit from the game — would have to concentrate on the TA. In Game Mode 3, in which the TA helps four birds while the pupil guides the TA, the football (Figure 4a) rolled passed on the lower part of the screen as the TA presented his suggestion in the thought bubble on the second bird, and the branch (Figure 4b) fell passed to the far right on the screen as the TA presented his suggestion in the thought bubble on the fourth bird. The football animation played for 3 seconds whilst the branch animation played for 2 seconds.

The animations are played back when the TA makes an action which the player must attend to, however, in Game Mode 3 the player is in control of the game and can look at the thought bubble any time after the distracting animation has finished. Thus these distractions were implemented to give a more general view of how distractions affect the participants and are a means of comparing two similar time windows where the distracting animations are either present (bird 2 and 4) or absent (bird 1 and 3).

In Game Mode 4, in which the TA helps two birds whilst the pupil watches the TA play, the glitch (Figure 4c) flickered in the top left corner of the screen just as the TA made his choice on the first bird, and after he had made his choice the aeroplane (Figure 4d) flew past diagonally, entering the top left corner of the screen. On the second bird, the same two animations were played but in reversed order (i.e. aeroplane during the TA's choice and glitch after the TA's choice). These animations both played for 2 seconds.

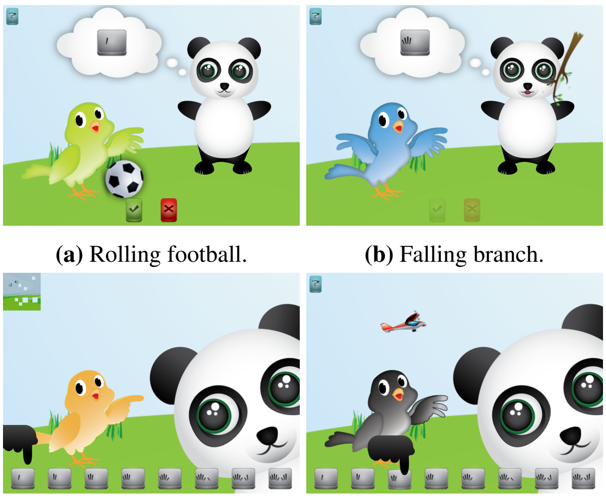
The way the TA makes his choice is by moving his hand horizontally, from left to right, along the eight lift buttons at the bottom of the computer screen (see Figure 3d), once he reaches the end of the screen, he moves his hand back from right to left and makes his selection. His hand then continues all the way to the left, and the hand is moved horizontally once more from left to right and back again and leaves the screen on the far left. The TA's hand movement across the screen takes 2 seconds. The reason why the TA moves his hand along the lift buttons twice is so that when the two animations are played — during and after the TA's choice — the TA's hand is situated at the same spot in order to make the two conditions as similar as possible with the only difference that a lift button is up or down, depending on whether it has been pressed by the TA



(a) Pupil playing. **(b)** TA watching pupil play.

(c) Pupil guiding TA. **(d)** Pupil watching TA play.

Figure 3: The four different game modes of Bird Hero.



(a) Rolling football. **(b)** Falling branch.

(c) Flickering glitch. **(d)** Flying aeroplane.

Figure 4: The four visually distracting animations.

or not. The animations were played 1 second before the TA reached the button he was meant to press (during TA choice) or had recently pressed (after TA choice). This is a time limited situation where the TA is in charge of the game and the participant has to make an active choice of either attending to the TA's actions or to the distracting animations.

Coding. Eye tracking, at a rate of 250 Hz, was used throughout game play on all participants. Because the game holds many moving elements fixations are extremely hard to measure, instead, gaze proportions of, or accumulated gaze time on, areas of interest (AOIs) were used. The AOIs were defined as Bird, Lift Buttons or Binary Buttons, Distraction, and TA or TA Hand. These measures were calculated by dividing the eye-tracking data during animation playback (2 or 3 s) into 100 ms blocks and measuring how many milliseconds were spent gazing at these AOIs during each block. This gives a measure of gaze proportion (%) which could easily be presented in a graph over time (10 samples per s), or these proportions could be summarised across all blocks for a particular AOI and thus translated into gaze time (ms) on that AOI. The gaze time spent on the glitch and aeroplane in Game Mode 4 *during* the TA's choice was used as measure of distractibility. The reason is that this is a very important part of the game where the TA is meant to show what he has learnt. Player's allowing themselves to be distracted at this crucial moment will not be paying enough attention to the more vital parts of the game and will therefore not be able to benefit as much from the use of a TA.

3 Results

Of the 65 participants, 36 were part of the analysis (20 girls; $M_{age} = 5;2$ years, $SD = 9$ months). The large drop-off was due to three reasons: (1) some of the participants were not at all familiar with numbers and could not complete the main task; (2) some participants were reluctant to complete all pre-tests; and (3) the eye tracking data were too poor for some participants in the main or pre-tests. Furthermore, due to a programming error not all participants were presented with the branch animation distraction. Therefore, the eye tracking data concerning the branch animation was not subjected to any analysis. Statistical analysis was performed in RStudio (v.0.97.316) using the statistical programming language R (v.2.15.1).

Pre-Tests

In general, the participants seemed able to carry out the pre-test tasks, although many of them needed some encouragement to complete them. The means and standard deviations summarised in Table 1 show that participants performed quite well on the pre-test tasks in general, except for the Droodle Task as indicated by its low mean value.

Screening of the pre-test measures with the participants' ages (Table 2) revealed a positive, statistically significant Pearson coefficient of correlations between age and the Apple Defender task, and also between age and the Colour-SART task. The Sally-Anne task showed a tendency towards a statistically significant and positive correlation coefficient with age ($p = 0.06$) as well as with Colour-SART ($p = 0.06$). None of the pre-tests of executive functions showed statistically significant correlation coefficients with one another, and neither did those of theory of mind.

Table 1: Mean and standard deviation of the measures of executive functions (EF) and theory of mind (ToM). The unit of all measures are number of correct trials except for *Apple Defender* which is a fraction (see Method section).

		M	*SE*	Max
EF	Apple Defender	0.60	0.03	1
	Colour-SART			
	Go	48.94	1.38	60
	No-Go	8.89	0.50	15
	Shape School	4.47	0.36	6
ToM	Sally-Anne	2.19	0.22	4
	Droodle	1.36	0.37	6

Main Task

The graphs of Figure 5 show two similar time windows of the game — just when the TA presents its choice in a thought bubble of Game Mode 3 — where the difference is that the football animation was played as a distraction in the second time window (Facet B of Figure 5). The two time windows are illustrated in the game screen shots (Figure 3c and 4a). In both time windows, gaze proportions are averaged over the 36 participants. As can be noted by the graphs, the distracting animation takes quite a lot of the participants' attention. Looking at the difference graph (Facet C of Figure 5), it is evident that the distraction steals equal amounts of attention from the more relevant areas of interest. On average, the participants spent 994 ms ($SE = 125$ ms) of the total 3 seconds animation playback time looking at the distraction.

This can then be contrasted with the graph of Figure 6 which represents gaze proportions on AOIs during (Facet A of Figure 5) and after (Facet B of Figure 5) the TA makes his choice in Game Mode 4. Gaze proportions are averaged over the 36 participants and consists of the TA helping two birds. A majority of the participants did not attend to the distracting animations at all during the TA's choice (20 out of the 36) and only 2 participants attended to both of them.

Distractibility Analysis

In Game Mode 4, the average time during which the participants gazed at the distraction during and after the TA's choice was 198 ms ($SE = 43$ ms) and 581 ms ($SE = 82$ ms), respectively. A paired t-test of dependent measures revealed a statistically significant difference in attention to the distractions during these time windows ($t = -4.08, df = 35, p < 0.001$). The frequency distribution of accumulated time spent gazing on distractions during the TA's choice is presented in Figure 7, it shows the frequency of participants within a given gaze time interval. This measure was used as a dependent variable in two multiple regression analyses using the enter method with the executive functions and theory of mind pre-test measures as independent variables. The models are presented in Table 3 ($F_{3,32} = 1.9, p = 0.149, R^2 = 0.151$) and 4 ($F_{2,33} = 1.385, p = 0.265, R^2 = 0.077$). Only Colour-SART showed a statistically significant relationship with distractibility.

Table 2: Pearson's coefficient of correlations between age and pre-test results of 36 observations.

	Age	Apple Defender	Colour-SART	Shape School	Sally-Anne
Apple Defender	0.45**				
Colour-SART	0.33*	0.27			
Shape School	0.07	0.13	0.27		
Sally-Anne	0.32	0.18	0.32	0.23	
Droodle	0.24	0.23	–0.10	0.03	–0.15

$^{*}p < 0.05$ (two-tailed).
$^{**}p < 0.01$ (two-tailed).

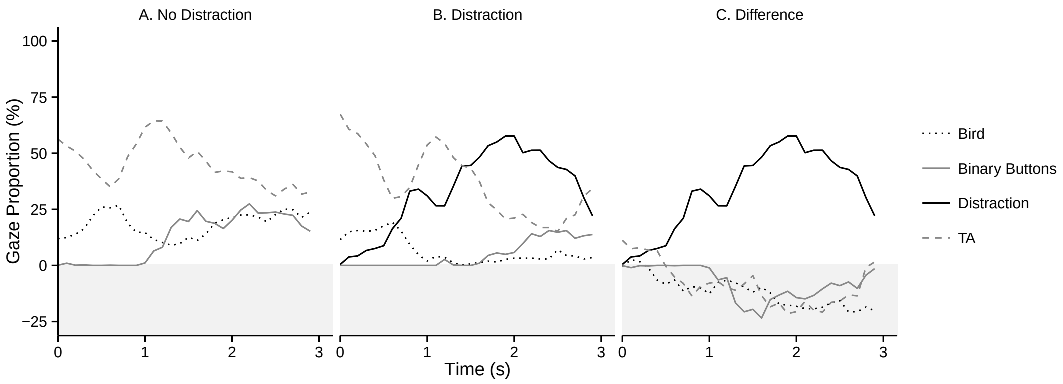


Figure 5: Gaze proportion in two similar time windows of four areas of interest over time with (Facet A) and without (Facet B) the football distraction in Game Mode 3. Graph (Facet C) shows the resulting difference from gaze proportions of graph (Facet A) subtracted from those of graph (Facet B). Duration is the length of the football animation distraction, and 0 on the x-axis denotes distraction onset.

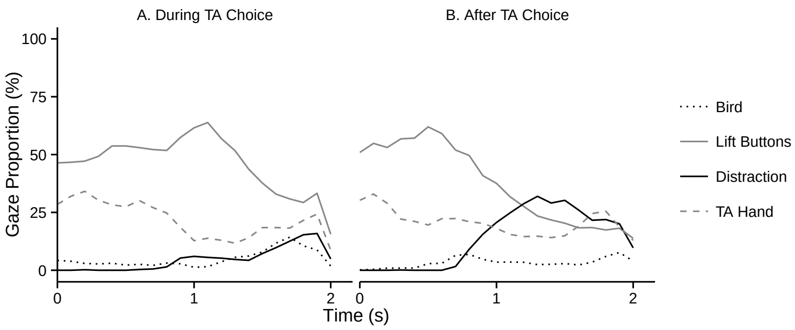


Figure 6: Gaze proportion of four areas of interest over time during (Facet A) and after (Facet B) TA choice in Game Mode 4. The time duration is the length of the glitch/aeroplane animation distractions, and 0 on the x-axis denotes distraction onset.

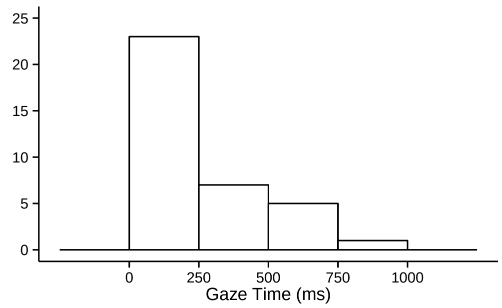


Figure 7: The frequency distribution of the distractibility measure.

Table 3: The results of a multiple regression analysis using the enter method of 36 observations with distractibility as dependent variable and the pre-test measures of executive functions as independent variables.

	β	t	p
Apple Defender	–0.093	–0.550	0.586
Colour-SART	0.731*	2.283	0.029
Shape School	–0.211	–1.241	0.224

$^*p < 0.05$ (two-tailed).

Table 4: The results of a multiple regression analysis using the enter method of 36 observations with distractibility as dependent variable and the pre-test measures of theory of mind as independent variables.

	β	t	p
Sally-Anne	0.251	1.482	0.148
Droodle	–0.088	–0.518	0.608

Table 5: The results of a step-wise multiple regression analysis of 16 observations with all pre-test measures of executive functions as well as theory of mind as independent variables, and distractibility as dependent variable.

	β	t	p
Apple Defender	–0.344*	–2.271	0.042
Colour-SART	0.793	2.164	0.052
Sally-Anne	0.244	1.496	0.161

$^*p < 0.05$ (two-tailed).

Delimited Analysis

The frequency distribution of the distractibility measure reveals something of a floor-effect (Figure 7); the participants were simply too good at focusing on the TA at a crucial point of the game. This means that distractibility did not present itself in a gradient across participants as hypothesised. Due to the low predictive value of the Shape School and Apple Defender measures (Table 3), it can be suggested that the cognitive ability of inhibition, as measured in this study, does not play as vital role in attending to the TA's actions as first thought. Neither does the measures of theory of mind seem to play any role. Only the Colour-SART measure showed any statistically significant relationship with distractibility, which could suggest that attentional abilities are more important than inhibitory or social.

However, there are also possible issues with some of the pre-test measures with regard to how they were collected. Age is usually a good predictor of development of executive functions and theory of mind, however, as shown above only two of the pre-test measures had a statistically significant correlation coefficient with age (Table 2). It was explained in the method section that the experiment leader misunderstood how to collect data for the Shape School task. This could have affected this measure's predictive abilities. Furthermore, the tasks for theory of mind were carried out with very few trials on each participant and might not give a fair representation of the participants' current level in development of theory of mind.

By using only the participants that spent more than 0 ms gazing at the distractions during the TA's choice and analyse their distractibility against their performance on the pre-tests, it was hypothesised that it should give an indication of whether it is at all possible to predict distractibility from the collected pre-test data.

The 16 participants that had been distracted by the animations during the TA's choice was used in a step-wise multiple regression analysis with distractibility as dependent variable and all the pre-test measures as independent variables ($F_{3,12} = 4.967, p = 0.018, R^2 = 0.554$). Table 5 illustrates the best model in predicting distractive gaze behaviour from all pre-test measures. Only the three pre-tests that showed strong correlation coefficients with age remained in the model: Apple Defender, Colour-SART, and Sally-Anne task. Apple Defender now showed a statistically significant relationship with distractibility and Colour-SART showed only a marginally statistically significant relationship with distractibility. It should of course be noted that this result is based on a too small sample to give enough statistical power to draw any far-reaching conclusions, but at least it is an inkling towards these measures' possible predictive ability of distractibility in preschoolers, given a larger sample.

4 Discussion

The present study found a statistically significant difference in preschoolers attention to distracting visual stimuli during versus after a teachable agent's (TA) actions. These findings reveal that preschool children were less inclined to be distracted during a TA action than they were after completion of the action. By being able to inhibit distractions, the preschoolers increases their chances of attending to more important features of the game. As is shown in the graph of Figure 6, the preschoolers focus more of their attention on the TA's hand and the lift buttons, one of which the TA is about to press, and less on the bird and distraction which are less important to benefit from the game.

Similar to the findings of Lindström et al. (2011), the results of the present study show that, just as primary school children, preschoolers also pay close attention to the TA even when only observing and not actively playing the game. Furthermore, this corroborates the findings of Axelsson et al. (2013) that preschoolers pay attention to their TA.

The general hypothesis proposed in this thesis was not confirmed: no true gradient of attention to distractions which correlated to this study's measurements of executive functions and theory of mind were found amongst the preschoolers. This makes it difficult to portray preschoolers distractibility with relation to executive control and theory of mind. Regarding the 20 participants that were not distracted at all during the TA's choice, there must be one or more cognitive abilities that these participants have in common which were not measured in this study. The upside to this outcome is that preschoolers are very much able to perform top-down guidance of their attention in the crucial moment of game play when the TA displays his newly learnt skills, regardless of how well they performed on the pre-tests.

Implications

As previously discussed, attention to the TA's actions is very important in order to allow for metacognitive reasoning, just like the children observing adults counting in the study of Gelman and Meck (1983). The currently presented results gives reason to believe that preschoolers at least have the basic abilities in place in order to enable metacognitive reasoning.

TA-based games can provide a much more tailored and individualised learning experience. This could be a means for preschools to more easily fulfil the curriculum's goal of individualised tutoring which can be demanding given that preschools usually have a high ratio of pupils to teachers. This has, for example, posed benefits for preventing number sense deficiency in primary school, in line with the findings that low-achieving pupils usually benefits the most from TA-based games (Chase et al., 2009).

Furthermore, this study showed that preschool children are not as distracted by visual animations as one might believe. The results of this study suggests that children are able to filter out distractions when their interest and focus is elsewhere. The big differences in attention to the Football animation (Game Mode 3; Figure 5) in relation to the aeroplane and glitch (Game Mode 4; Figure 6) may indicate that there exists a motivational effect grounded in time limited event of the TA action of choosing which helps the preschoolers to focus.

It was noted during data collection and also in the eye-tracking data that children pay close attention to the characters faces. A sugesstion to developers of TA-based games could be to add facial expressions to TA characters in order to convey emotional cues that can be read by the player, and by that let them conclude whether the TA seems confident or diffident in suggested solutions to problems. Especially with preschoolers, this could be a way to further aid metacognition.

Limitations

When considering the significance of the Colour-SART measure with relation to distractibility, it can at a first glance seem counter-intuitive that the relation is positive (Table 3; i.e. the better you perform on Colour-SART the more likely you are to be distracted). Colour-SART was chosen as a measure of sustained attention and the idea was initially that it would relate to the sustained attention to the TA. However, it is rather a measure of sustained attention to changes in the environment. What the positive relation to distractibility entails is that children who are better able to remain focused and notice when the colour blue appears in Colour-SART are also the ones more sensitive to the distractive animations. Instead of measuring sustained attention, this study should have employed a measure of *selective* attention (see the Introduction Section).

Though the delimited analysis of Colour-SART and Apple Defender did show significant results in relation to distractibility, with regard to participants that *were* distracted, this study had too few participants to enable any conclusions of the relation between preschoolers' distractibility and level of development of executive functions and theory of mind. Because of the floor-effect of the distractibility measure, a much larger sample of participants would be needed to have enough statistical power to draw any useful conclusions.

Future Research

In this study, two new ways of measuring young children's executive functions have been developed from tasks designed for measuring these abilities in adults. Both Apple Defender and Colour-SART gave a hint of their predictive ability through the delimited analysis. It would be interesting to further investigate their use in evaluation of executive functions in children of preschool age.

Because research question 2 remains unanswered there is no way of saying whether a well developed theory of mind could compensate for lack in development of executive functions. There is, however, one very interesting aspect of theory of mind that could be further explored. First of all, there is no way yet of concluding whether preschoolers would actually benefit from a TA-based game. To answer this, a more longitudinal study of learning effects would have to be conducted. In this research it would be interesting to relate the development of theory of mind to metacognitive reasoning with regards to teachable agents. Could there, for example, be an interaction between playing TA-based games and development of theory of mind which lets children develop a theory of mind quicker than children learning through more conventional learning methods?

In conclusion, preschoolers seem to be sufficiently developed in their cognitive abilities to enable them to focus enough on teachable agents to inhibit distractions. Although the present study cannot establish a cut-off age of when TA-based games should be introduced, we can at least with confidence continue to investigate the use of teachable agents with children aged 3 to 6.

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References

Anderberg, E., Axelsson, A., Bengtsson, S., Håkansson, M. & Lindberg, L. (2013). Exploring the use of a teachable agent in a mathematical computer game for preschoolers. In C. Balkenius, A. Gulz, M. Haake & B. Johansson (Eds.), *Intelligent, socially oriented technology* (Vol. 154, pp. 161–171). Lund: Lund University Cognitive Studies.

Axelsson, A., Anderberg, E. & Haake, M. (2013). Can preschoolers profit from a teachable agent based play-and-learn-game in mathematics? In H. C. Lane, K. Yacef, J. Mostow & P. Pavlik (Eds.), *AIED 2013, LNAI* (Vol. 7926, pp. 289–298). Berlin, Heidelberg: Springer.

Bargh, J. A. & Schul, Y. (1980). On the cognitive benefits of teaching. *Journal of Educational Psychology*, *72*(6), 583–604.

Baron-Cohen, S., Leslie, A. M. & Frith, U. (1985, October). Does the autistic child have a "theory of mind"? *Cognition*, *21*(1), 37–46.

Berch, D. B. (2005, August). Making sense of number sense: Implications for children with mathematical disabilities. *Journal of Learning Disabilities*, *38*(4), 333–339.

Biswas, G., Leelawong, K., Schwartz, D., Vye, N. & The Teachable Agents Group at Vanderbilt. (2005). Learning by teaching: A new agent paradigm for educational software. *Applied Artificial Intelligence*, *19*(3-4), 363–392.

Brophy, S., Biswas, G., Katzlberger, T., Bransford, J. & Schwartz, D. (1999). Teachable agents: Combining insights from learning theory and computer science. In S. P. Lajoie & M. Vivet (Eds.), *Artificial intelligence in education* (pp. 21–28). IOS Press.

Bruer, J. (1997). Education and the brain: A bridge too far. *Educational researcher*, *26*(8), 4–16.

Burgess, P. W., Alderman, N., Evans, J., Emslie, H. & Wilson, B. A. (1998, November). The ecological validity of tests of executive function. *Journal of the International Neuropsychological Society : JINS*, *4*(6), 547–58.

Chandler, M. J. & Helm, D. (1984). Developmental changes in the contribution of shared experience to social. *International Journal of Behavioral Development*, *145*(7), 145–156.

Chase, C. C., Chin, D. B., Oppezzo, M. A. & Schwartz, D. L. (2009, June). Teachable agents and the protégé effect: Increasing the effort towards learning. *Journal of Science Education and Technology*, *18*(4), 334–352.

Clements, W. & Perner, J. (1994). Implicit understanding of belief. *Cognitive development*, *9*(4), 377–395.

Dalton, P. & Fraenkel, N. (2012). Gorillas we have missed: Sustained inattentional deafness fordynamic events. *Cognition*, *124*, 367–372.

Deubel, H. & Schneider, W. X. (1996). Saccade target selection and object recognition: Evidence for a common attentional mechanism. *Vision Research*, *36*(12), 1827–1837.

Espy, K. (1997). The shape school: Assessing executive function in preschool children. *Developmental Neuropsychology*, *13*(4), 37–41.

Garavan, H. (2002, December). Dissociable executive functions in the dynamic control of behavior: Inhibition, error detection, and correction. *NeuroImage*, *17*(4), 1820–1829.

Garnham, W. A. & Perner, J. (2001, September). Actions really do speak louder than words – but only implicitly: Young children's understanding of false belief in action. *British Journal of Developmental Psychology*, *19*(3), 413–432.

Garon, N., Bryson, S. E. & Smith, I. M. (2008, January). Executive function in preschoolers: A review using an integrative framework. *Psychological bulletin*, *134*(1), 31–60.

Gelman, R. & Meck, E. (1983). Preschoolers counting: Principles before skill. *Cognition*, *13*, 343–359.

Gersten, R. & Chard, D. (1999, April). Number sense: Rethinking arithmetic instruction for students with mathematical disabilities. *The Journal of Special Education*, *33*(1), 18–28.

Griffin, S. (2004, January). Building number sense with number worlds: a mathematics program for young children. *Early Childhood Research Quarterly*, *19*(1), 173–180.

Gulz, A., Haake, M. & Silvervarg, A. (2011). Extending a teachable agent with a social conversation module – effects on student experiences and learning. *Artificial Intelligence in Education*, 106–114.

Hallett, P. E. (1978). Primary and secondary saccades to goals defined by instructions. *Vision Research*, *18*, 1279–1296.

Hannula, M. M., Mattinen, A. & Lehtinen, E. (2005). Does social interaction influence 3-year-old children's tendency to focus on numerosity? a quasi-experimental study in day care. In E. De Corte, G. Kanselaar & M. Valcke (Eds.), *Studia paedagogica, 41* (pp. 63–80). Leuven University Press.

Jordan, N. C., Kaplan, D., Nabors Oláh, L. & Locuniak, M. N. (2006). Number sense growth in kindergarten: A longitudinal investigation of children at risk for mathematics difficulties. *Child development*, *77*(1), 153–75.

Kok, A. (1999, April). Varieties of inhibition: Manifestations in cognition, event-related potentials and aging. *Acta Psychologica*, *101*(2-3), 129–58.

Lindström, P., Gulz, A., Haake, M. & Sjödén, B. (2011, February). Matching and mismatching between the pedagogical design principles of a math game and the actual practices of play. *Journal of Computer Assisted Learning*, *27*(1), 90–102.

Manly, T., Robertson, I., Galloway, M. & Hawkins, K. (1999). The absent mind: Further investigations of sustained attention to response. *Neuropsychologia*, 550–559.

Monsell, S. (2003, March). Task switching. *Trends in Cognitive Sciences*, *7*(3), 134–140.

Moore, C., Jarrold, C., Russell, J., Lumb, A. & Sapp, F. (1995). Conflicting desire and the child's theory of mind. *Cognitive Development*, *10*, 467–482.

Munoz, D. P. & Everling, S. (2004). Look away: The anti-saccade task and the voluntary control of eye movement. *Nature*, *5*, 218–228.

Norman, D. A. & Shallice, T. (2000). Attention to action: Willed and automatic control of behavior. In M. S. Gazzaniga (Ed.), *Neuroscience: A reader* (pp. 376–390). Malden, MA: Blackwell Publishers Inc.

Pareto, L., Arvemo, T., Dahl, Y., Haake, M. & Gulz, A.

(2011). A teachable-agent arithmetic game's effects on mathematics understanding, attitude and self-efficacy. In G. Biswas, S. Bull, J. Kay & A. Mitrovic (Eds.), *AIED'11 proceedings of the 15th international conference on artificial intelligence in education* (pp. 247–255). Berlin, Heidelberg: Springer-Verlag.

Pareto, L., Haake, M., Lindström, P., Sjödén, B. & Gulz, A. (2012, April). A teachable-agent-based game affording collaboration and competition: Evaluating math comprehension and motivation. *Educational Technology Research and Development*, *60*(5), 723–751.

Peirce, J. W. (2007). Psychopy - psychophysics software in python. *Journal of Neuroscience Methods*, *162*(1-2), 8–13.

Perner, J. & Lang, B. (1999, September). Development of theory of mind and executive control. *Trends in cognitive sciences*, *3*(9), 337–344.

Robertson, I. H., Manly, T., Andrade, J., Baddeley, B. T. & Yiend, J. (1997). 'Oops': Performance correlates of everyday attentional failures in traumatic brain injured and normal subjects. *Neuropsychologia*, *35*(6), 747–758.

Sarter, M., Givens, B. & Bruno, J. P. (2001). The cognitive neuroscience of sustained attention: where top-down meets bottom-up. *Brain Research Reviews*, *35*(2), 146 - 160.

Schwartz, D. & Blair, K. (2007). Animations of thought: Interactivity in the teachable agent paradigm. In R. Lowe & W. Schnotz (Eds.), *Learning with animation: Research and implications for design* (pp. 114–140). Cambridge, UK: Cambrige University Press.

Schwartz, D. L., Chase, C., Chin, D., Oppezzo, M., Kwong, H., Okita, S., … Wagster, J. (2009). Interactive metacognition: Monitoring and regulating a teachable agent. In D. Hacker, J. Dunlosky & A. Graesser (Eds.), *Handbook of metacognition in education* (pp. 340–358). Routledge Press.

Sjödén, B., Tärning, B., Pareto, L. & Gulz, A. (2011). Transferring teaching to testing – an unexplored aspect of teachable agents. *Artificial Intelligence in Education*, 337–344.

Skolverket. (2011). *Curriculum for the preschool lpfö 98 revised 2010* (policy document No. 2704). Stockholm, Sweden.

Southgate, V., Chevallier, C. & Csibra, G. (2010). Seventeen-month-olds appeal to false beliefs to interpret others' referential communication. *Developmental Science*, *13*(6), 907–912.

Tipper, S. & Cranston, M. (1985). Selective attention and priming: Inhibitory and facilitatory effects of ignored primes. *The Quarterly Journal of Experimental Psychology*, *37*(4), 591–611.

Zhao, G. & Shen, Z. (2012). Learning-by-Teaching: Designing Teachable Agents with Intrinsic Motivation. *Educational Technology & Society*, *15*, 62–74.