Computer versus human-based support: Effect on computer game performances in (in)effectively learning pre-schoolers

Baukje Veenstra, Paul L.C. van Geert &
Bieuwe F. van der Meulen

This research focuses on the effects of human versus computer instruction on improving the learning behaviour of pre-school children. One-hundred-and-eighty-four unresponsive, impulsive or reflective Dutch pre-schoolers were randomly assigned to one of the four instruction conditions (computer-assisted instruction, adult-assisted instruction, both or no instruction). The children played a computer game focused on improving learning behaviour during two or three sessions. The results show that the pre-schooler's behaviour during the game corresponds to regular learning behaviour. Impulsive children showed most errors and mouse clicks and unresponsive children showed the least mouse clicks and a warming-up phase. As expected, in the computer-assisted instruction plus adult-assisted instruction condition all learners showed positive learning outcomes. Computer-assisted instruction reveals positive effects on learning outcomes of reflective and unresponsive learners and adult-assisted instruction reveals positive effects on impulsive children. Considering the overall development across the games, impulsive children did not improve their learning behaviour. However, reflective and unresponsive children showed a learning effect. Reflective children showed a clear decrease of trials in the beginning and unresponsive children showed a relatively large increase in mouse clicks after a warming up-phase. However, their number of clicks remained lower than the reflective children.

We can conclude that, since learning type is relevant, this game might function as an objective and reliable tool to assess the type of learning behaviour of pre-school children. It is concluded that computer-assisted instruction in combination with adult-assisted instruction is the best manner to regulate learning skills.

Keywords: *learning styles; reflection, impulsivity; early years; computer-assisted learning.*

1. Introduction

EDUCATIONAL computer-games are increasingly used as a learning tool in pre-school education. First, many pre-school children already possess sufficient fine motor skills to move and click on the mouse adequately (Crook, 1992; Shimizu & McDonough, 2006; Stronmen et al., 1996). Second, computer use in pre-school has various advantages. Computers provide immediate feedback, make objective registrations of performances of the child (information for the teacher) and allow for working independently, which is saving time for the pre-school-teacher (DuPaul & Eckert, 1998; Hall, Hughes & Filbert, 2000; Lillie, Hannun & Stuck, 1989). Computer games also provide the opportunity of playful learning. Guided playful learning advances social development and offers a foundation for academic success (Hirsh-Pasek et al., 2009). Another advantage of educational computer games is that they evoke curiosity and interest in young children. This often results in better learning than with traditional methods (Vernadakis et al., 2005). While playing a computer game, young children often achieve 'flow' (Inal & Cagiltay, 2007). Flow can be described as a strong engagement in a task, associated with enjoyment and satisfaction to complete the task. The occurrence of flow depends on the balance between an individual's skills and the difficulty of a task (Csikszentmihalyi, 1990).

Computer games may function as an adequate learning tool, especially for ineffectively learning children, for instance impulsive children, who often have difficulties with achieving flow or staying on-task during a traditional educational task (DuPaul et al., 1998; Mautone, DuPaul & Jitendra, 2005; Ota & DuPaul, 2002). Children with such learning disabilities often lack good self-regulation strategies and have to be taught learning-to-learn skills in the early years in order to reduce the risk for a developmental delay (Diamond et al., 2007). Computer-tasks are able to improve on-task behaviour of impulsive children (Mautone et al., 2005; Ota et al., 2002). Given the fact that computers are becoming more widely available in pre-school education, it is likely that computer games focused on improving learning behaviour are more easily implemented than other interventions that require professional time from the pre-school-teachers (DuPaul et al., 1998; Mautone et al., 2005).

1.1 Ineffective and effective learning: impulsiveness, unresponsiveness and reflectiveness

Based upon the reflection-impulsivity dimension (Kagan, 1965), learners can be divided into two groups: ineffective (impulsive and unresponsive) versus effective (reflective) learners. Impulsive children finish their task quickly, but with many errors, fast response times and a high response uncertainty (Kagan, 1965; Wyatt & Fulton, 1987). In contrast with impulsive children, unresponsive children do not actively seek instruction or help. They make almost no errors, and withhold their response too long.

We see impulsive and unresponsive children as learners with deficiencies in their self-regulation system, not having (enough) strategic knowledge. They do not pay enough attention to instructions, do not sufficiently monitor their own progress, do not sufficiently organise their task, or do not seek instruction when they have difficulties (Bornas, Servera & Llabrés, 1997; Newman, 1990; Stright & Supplee, 2002).

These two kinds of ineffective learners form the extremes of a strategic continuum. In the middle part we find a third kind of learners, i.e. reflective children, defined as effective learners, who show self-control and adequate problem-solving strategies. They withhold their responses until they have a high probability of giving a correct answer (Bornas et al., 1997; Kagan, 1965). These children gather their information systematically or carefully, and show achieving flow.

1.2 Reducing ineffective learning behaviour through adult- and computer-assisted instruction

Unresponsive or impulsive learning may be channeled into a more reflective learning strategy if adequate instruction is provided. In the context of computer activities, two types of instruction can be defined: adult-assisted instruction and computer-assisted instruction . Research (e.g. Jelsma & Pieters, 1989; Jelsma & Van Merriënboer, 1989) indicates that by creating adequate instructional conditions, impulsive children may be led towards a more reflective strategy, which may then improve their learning outcomes. In order to be effective in improving learning behaviour, instruction must be focused on the self-regulatory behaviour in the learning of the skill at issue (DuPaul & Stoner, 2003; Pfiffner & Barkley, 1998).

However, to improve learning behaviour the instructional context should not only be focused on the specific skill that has to be learned, for example, counting or writing letters, but also on the children's self-regulation (e.g. Manlove, Lazonder & De Jong, 2007; Montague, 2007). The negative effect of impulsiveness and unresponsiveness on learning a skill may then be compensated by the use of an adaptive instruction condition that is focused on the learning process itself. To enhance learning in ineffectively learning children, immediate feedback on learning behaviour and specific learning goals in a stimulating learning environment are required (DuPaul et al., 1998). To improve learning in unresponsive children, positive behaviour should be emphasised and negative feedback should be avoided (Slavin, 2006).

This preceding overview results in the question whether computer-assisted instruction can be equally effective in improving learning behaviour as adult-assisted instruction, in particular in impulsive and unresponsive children. computer-assisted instruction, like adult-assisted instruction, can also be individualised to meet the particular needs of the learner. It might, therefore, be expected that computer-assisted instruction is able to improve learning outcomes (Bornas et al., 1997; DuPaul et al., 1998; Mautone et al., 2005; Ota et al., 2002). However, we could not find any empirical studies on the relative effectiveness of individual adult-assisted instruction compared to computer-assisted instruction. Hence, no general conclusions can be drawn about effects of computer-assisted instruction in comparison to individual adult-assisted instruction. Although, other empirical research about effects of computer-assisted instruction not related to adult-assisted instruction, indicates that during computer-assisted instruction-tasks on-task behaviour of impulsive learners improves relative to independent seatwork tasks (DuPaul et al., 1998; Mautone et al., 2005). Computer programs can be effective tools to increase attention and impulse control (DuPaul et al., 1998; Navarro et al., 2003; Slate et al., 1998). However, it must be taken into account that the subjects who participated in these studies were older than pre-school children. No empirical research was found on the effectiveness of computer-assisted instruction on improving unresponsive learning behaviour of pre-school children.

These findings pertain to individualised, adaptive instruction (computer-assisted instruction or adult-assisted instruction) for ineffective and effective learners. However, the question still remains which form of instruction – adult- or computer-assisted – is the most effective in improving learning behaviour. Various studies emphasise the importance of mediation by an adult and the impact of scaffolding in supporting children's learning (Elias & Berk, 2002; Karpov, 2005). Scaffolding can be defined as support that makes a particular learning process possible and can be withdrawn when the learner is capable to do the task independently (Wood, Bruner & Ross, 1976). If scaffolding is also integrated in computer software, computers might also be a powerful tool to modify ineffective learning behaviour, if appropriate software is used. The software must be easy to use for the target group and should provide immediate feedback and reinforcement in order to give the learner the opportunity to self-assess and self-monitor the progress while playing the game (Bornas et al., 1997).

The disadvantage of adult-assisted instruction (e.g. from a pre-school teacher) is that individual assistance is not always available. Computer-assisted instruction does not have this disadvantage and may thus provide a powerful tool, maybe as effective as adult-assisted instruction, to regulate learning behaviour of impulsive or unresponsive learning children, if adequate instruction is specifically adapted to the child's learning behaviour, self-regulation and cognitive level. These considerations lead us to the research question whether computer-assisted instruction that is focused on the aforementioned criteria, is effective to improve learning behaviour of impulsive or unresponsive pre-school children. If computer-assisted instruction is effective, is it equally or eventually more effective than adult-assisted instruction for ineffective learning children?

Although we expect positive effects of computer-assisted instruction, we hypothesise that the combination of adult-assisted instruction and computer-assisted instruction will be the best way of improving learning behaviour and outcomes of both ineffective and effective learners. The sociability and flexibility of adult-assisted instruction and the consistency of computer-assisted instruction complement each other. This combination will best suit the needs of ineffective learners. For reflective learners, we expect that combining computer-assisted instruction with adult-assisted instruction, will not have any superior effects to computer-assisted instruction or adult-assisted instruction taken apart, because they already show effective learning behaviour. This results in the question as to whether a combination of adult-assisted instruction and computer-assisted instruction is more effective than each of them separately. Is the effectiveness of these forms of instruction also dependent on the type of learner (impulsive, unresponsive or reflective)?

1.3 The present study

The aim of our study is to investigate which instruction conditions (computer-assisted instruction or adult-assisted instruction, computer-assisted instruction plus adult-assisted instruction, or no instruction) is the most effective for improving learning behaviour in reflective, unresponsive and impulsive children during playing an educational computer-game. Learning outcomes will be defined as the number of games needed to reach the highest game level and the number of trials needed to finish a game.

Firstly, we will investigate whether impulsive and unresponsive show a significant lower Standard Scores on multiple developmental domains as compared to reflective learners. We hypothesise that impulsive learners are connected with the lowest Standard Scores and that reflective children are connected with a relatively high Standard Scores. We expect that unresponsive children show Standard Scores between the other learners. However, their performances are closer to reflective children than to impulsive children, since unresponsive learners often know what to do, but show more passive behaviour.

Secondly, it might be expected that all children who receive computer-assisted instruction plus adult-assisted instruction (cai + aai), perform better than children who either receive computer-assisted instruction (cai) or adult-assisted instruction (aai). Children in the computer-assisted instruction or adult-assisted instruction condition perform better than children who do not receive any instruction at all. Additionally, we hypothesise that reflectively learning children will show the best learning outcomes in comparison to unresponsive and impulsive children, irrespective of the instruction condition. Impulsive children are likely to show the worst learning outcomes compared to unresponsive children, since impulsive children show more errors and, therefore, need more trials.

Thirdly, we expect differences in learning outcomes between the three learning types in the four different instruction conditions, see Table 1.

We hypothesise that for all children computer-assisted instruction plus adult-assisted instruction will reveal optimal learning outcomes. Furthermore, we expect that unresponsive children who only receive computer-assisted instruction may work more effectively than in the adult-assisted instruction condition, because they do not have to seek help from an adult and receive immediate instruction from the computer, which may lead to better learning outcomes. For impulsive children it is expected that adult-assisted instruction is more efficient than computer-assisted instruction, because of the flexibility, the emotional and social aspects that are needed to slow down the fast responses.

Table 1: Hypotheses concerning learning outcomes between four instruction conditions.

Learning type	Hypotheses
Unresponsive	CAI + AAI > CAI > AAI > No instruction
Reflective	CAI + AAI ≈ CAI ≈ AAI > No instruction
Impulsive	CAI + AAI > AAI > CAI > No instruction

Fourthly, our hypothesis is that all three types of learners show different learning patterns, irrespective of the instruction condition. We expect that the nature of their mouse performances correspond with their regular learning behaviour during more traditional tasks. Reflective learners show relatively good performances on errors, trials and the number of (multiple) clicks. In the extremes we expected the impulsive to make a large number of errors and (multiple) clicks and unresponsive children to make a small number of errors (equally to reflective children) and (multiple) clicks. We expect that impulsive children click more frequently and more impulsively on one or more objects than unresponsive and reflective children.

Furthermore, as a more exploratory study of learning processes, we would like to demonstrate whether unresponsive children need a longer warming up phase (do not show immediately enough mouse clicks to finish a game correctly) than reflective or impulsive children. Secondly, we would like to investigate whether impulsive children show a decrease in a relatively high number of mouse clicks and trials during the sessions. Thirdly, we would like to demonstrate that reflective children show a relatively constant learning pattern, with less variability in the performances than impulsive children.

2. Method

2.1 Participants

A total of 184 (87 male, 97 female, chronological age in years Mean (M)=3.49, Standard deviation (SD)=.34) Dutch pre-school children living in the northern area, participated in this study, after approval of their caregivers. The youngest and oldest children were 2.6 years and 4.16 years, respectively. None of the participants had received information on the aim of the game.

2.2 Design

Prior to the main part of the study, pre-school-teachers, parents and a trained rater received a questionnaire to determine the type of learning behaviour of the individual children (see Appendix 1). The questionnaire consisted of descriptions of behaviour of typical unresponsive, reflective and impulsive children. The raters had to categorise each individual child into the best fitting category according to their regular learning behaviour. After categorisation, each child was randomly assigned to one of the four instruction conditions: (no) adult-assisted instruction and/or (no) computer-assisted instruction (see Table 2).

Table 2: Experimental design: distribution of the number of children over type and instruction.

Learning type	No instruction	AAI	CAI	CAI + AAI	Total
Unresponsive	5	5	9	6	25
Reflective	26	27	44	36	133
Impulsive	8	8	5	5	26
Total	39	40	58	47	184

2.3 Procedure

In the main part of the study, each child played two or three computer-game-sessions (dependent on their performances) during two or three weeks in a quiet room at the playgroup. In case of no adult-assisted instruction, a supervisor was present only for technical help like starting and ending the game. In the adult-assisted instruction condition, the trained supervisor assisted the child if necessary, but only with adaptive hints or stimulating instructions, for example, 'you first have to move, then you must click on the object'). After completing a maximum of seven computer games during one session, the child returned to the classroom.

2.4 Instruments

Type of regular learning behaviour. The type of learning behaviour (unresponsive, reflective or impulsive) was identified on the basis of the scores of the three (or two, in case of a missing or disagreed rater) *a priori* ratings from the parents, pre-school teacher and a trained rater (see Appendix 1). Ninety-six per cent of the 184 participating children were rated consistently between at least two raters (p<.01). The percentage agreement between teacher and the trained rater was 70 per cent (p<.01), between teacher and parents was relatively low 49 per cent (p=.42) and between trained rater and parents was also relatively low 60 per cent (p=.09). This implies that especially parents might have a different view of their child's learning type. In total 184 children participated in the analysis.

Standard Scores. Cognitive and motor development on four domains (fine motor skills, visual reception, language comprehension and production) of each child were measured with the Composite Standard Scores of the Dutch version of the Mullen Scales of Early Learning (AGS Edition; Mullen, 1995).

Learning behaviour during computer tasks. Individual mouse data (e.g. number of clicks per game, (in)correct object clicks) of each game were collected automatically during playing on www.samenslim.nl, resulting in a continuous measurement of the children's level of knowledge and skills. The goal of the computer game (on www.samenslim.nl) is to stimulate effective learning behaviour (see Appendix 2).

In this study, mouse skills were practiced with a trained supervisor before the child played the *Samenslim* games. The child had to practice until he was able to control the mouse.

2.5 Analysis

Firstly, the Standard Scores were assessed using the Composite Standard Scores of the Mullen Scales of Early Learning. Secondly, five main specific variables were selected from the automatically registered mouse-data.

1. *Trial:* total number of clicking moments that a child needed to finish a game, with a maximum of four trials
2. *Slope of performance:* the number of games needed to achieve the highest level (5). For instance, a child who reaches level three within 14 games, has a slope of 3/14. The maximum of the slopes is Smax=1.
3. *The number of clicks:* the total number of correct and incorrect mouse clicks per game.
4. *Errors:* the sum of all clicks on a wrong object, as defined by the task construction.
5. *Frequency of multiple clicks during one clicking moment:* nine clicking moments during a game were defined: four instruction moments and five moments before or after instruction. In case of more than two clicks during a clicking moment, this was scored by a '1', with a maximum of '9' per game. After that the frequency of multiple mouse clicks per clicking moment was summed up per game.

Finally, each variable was divided by the total number of games the child has played.

By means of a linear regression, all five mouse variables were corrected for normalised Standard Scores (Composite Standard Scores), except the process-data (presented in Figure 3).

The statistical procedures consisted of descriptive analyses (performed in Microsoft Excel) and permutation tests (Monte Carlo analysis (Good, 1999; Todman & Dugard, 2001) performed in Poptools (Hood, 2008)). The Monte Carlo analysis is particularly efficient to analyse data that are not normally or regularly distributed. Each significance test was based on 1000 simulations. With this random permutation test it is possible to combine opposite effects in one test. Effect sizes are expressed as proportions of standard deviations. The data concerning learning patterns were smoothed with a Savitzky-Golay-smoothing technique (Simonoff, 1996).

3. Results

3.1 Comparison of Standard Scores of three learning types

When comparing the Standard Scores of the three learning types, reflective children showed on average the highest Standard Scores (see Table 3). However, the differences between reflective and unresponsive children were relatively small. In general, impulsive children showed the lowest scores.

3.2 Comparison of mouse performances between instruction conditions and learning types

To compare the learning outcomes in the different instruction conditions and in the three learners, slopes of performances and the number of trials needed to finish a game are shown in Table 4. A negative score on the average number of trials means that the child performed better than expected for his Standard Scores (the fewer the trials, the better the skill). A negative score on slopes of performances means that the child performed worse than expected for his Standard Scores (the smaller the slope, the worse is the skill).

Irrespective of their type of learning behaviour, children who received both computer-assisted instruction and adult-assisted instruction needed on average fewer number of trials in combination with better-slope of performance as compared to the children in the adult-assisted instruction, the computer-assisted instruction, and in the no instruction condition (see the first three columns of Table 4). The effect size of differences between instruction conditions were as follows: the effect size of the difference between computer-assisted instruction plus adult-assisted instruction and adult-assisted instruction was .18, between computer-assisted instruction and no instruction was

Table 3: Means and standard deviations of chronological age and Standard Scores per learning type.

Learning type	Gender		Chronological age		Normalised Standard Scores (M=100; SD=15)	
	N male	*N* female	Mean	SD	Mean	SD
Unresponsive (*N*=25)	9	16	3.41	.35	113.30	18.6
Reflective (*N*=133)	60	73	3.52	.34	114.29	19.8
Impulsive (*N*=26)	17	9	3.43	.30	105.73	18.9

.47, between adult-assisted instruction and computer-assisted instruction was .00, between computer-assisted instruction and no instruction was .29, between computer-assisted instruction plus adult-assisted instruction and computer-assisted instruction was .18 and between adult-assisted instruction and no instruction was .29. The permutation test demonstrated that the effect size between these instruction conditions were all significantly higher than would be expected on the basis of chance (p<.01). Children who did not receive instruction showed the highest number of trials in combination with the lowest slope of performance compared to the children in the other instruction conditions (p<.01).

Irrespective of the instruction condition, the learning outcomes of the three types of children differed significantly (see the last three columns of Table 4). Impulsive and unresponsive children performed the worst (both slope of performance and number of trials combined), and did not differ substantially, with an effect size of .00 (p<.01). Reflective children performed significantly better than the unresponsive and impulsive children, with both ES of .20 (p<.01).

3.3 Comparison of three learning types between four instruction conditions

To test the third hypothesis that there were differences between instruction conditions and learning types, a general trend of performances is shown in Figure 1. The number of trials across the three learning types and four conditions is qualitatively highly comparable to Figure 1. For additional information about this figure with the number of trials see: www.paulvangeert.nl/articles_appendices.htm.

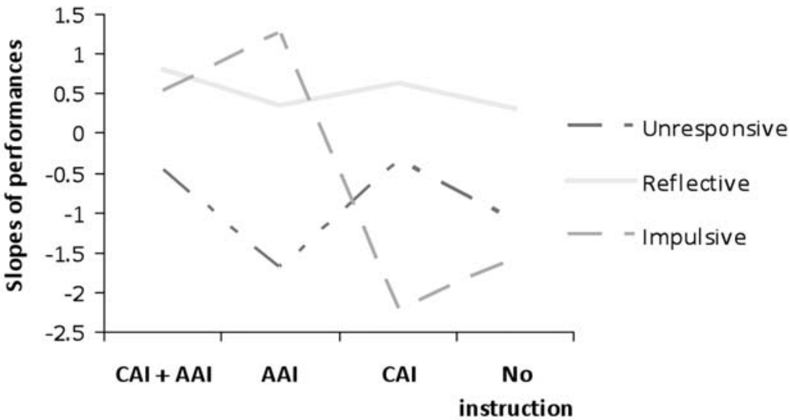
Children scored better in the computer-assisted instruction plus adult-assisted instruction condition than in the other three conditions. However, impulsive children showed better slope of performance in the adult-assisted instruction condition, although the differences with both computer-assisted instruction and adult-assisted instruction were small. In the adult-assisted instruction, the computer-assisted instruction and in the no instruction condition, a relatively large variability between the three learning types was observed. It is striking that if there was no adult involved in the instruction, the impulsive children showed a large drop in their performances.

Table 4: Averages of learning outcomes between instruction conditions and between learning types.

Instruction condition	M number of trials	M slope of performances
CAI + AAI (N=47)	–0.28	0.61
AAI (N=40)	–0.09	0.29
CAI (N=58)	–0.09	0.24
No instruction (N=39)	0.22	–0.26

Learning type	M number of trials	M slope of performances
U (N=25)	0.25	–0.79
R (N=133)	–0.19	0.56
I (N=26)	0.22	–0.42

Figure 1: Averages of the slopes of performances from the three learning types in the four instruction conditions.



On the contrary, unresponsive children showed the best performances in the conditions with computer-assisted instruction. Furthermore, reflective children performed slightly better when there was computer-assisted instruction involved. Differences between the performances (slope of performance and number of trials combined) of impulsive, unresponsive and reflective children in the four instruction conditions were clearly significant (see Table 5). In these tables only the differences between instruction and learning types are presented which correspond to the expected direction of differences, mentioned in Table 1 in paragraph 1.3.

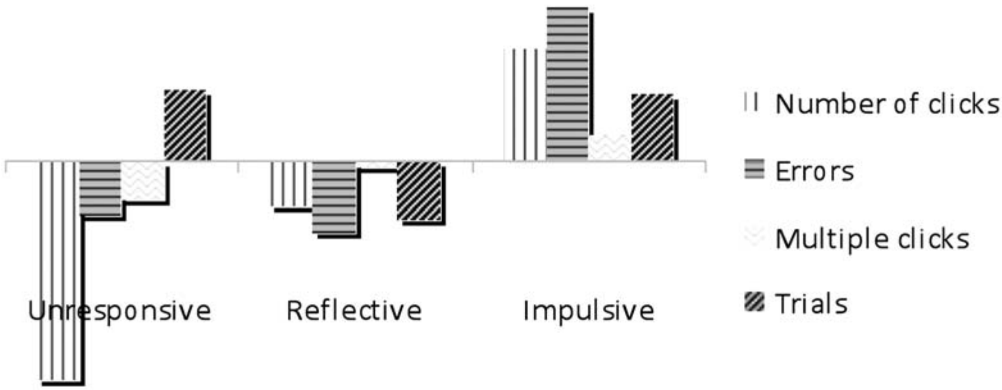
Table 5: Results of permutation test, categorised into learning type and into instruction condition.

Hypothesis	Learning type	ES
CAI + AAI > AAI	U	0.58[1]
CAI +AAI > No	U	0.28[1]
CAI > AAI	U	0.61[1]
CAI > No	U	0.31[2]
CAI + AAI > AAI	R	0.18[1]
CAI + AAI > CAI	R	0.10[1]
CAI + AAI > No	R	0.27[1]
CAI > No	R	0.17[1]
AAI > No	R	0.09[3]
CAI > AAI	R	0.08[1]
CAI + AAI > CAI	I	1.11[1]
CAI + AAI > No	I	1.00[1]
AAI > CAI	I	1.25[1]
AAI > No	I	1.15[1]

Hypothesis	Instruction-condition	ES
R > U	CAI + AAI	0.50[1]
R > I	CAI + AAI	0.11[1]
R > U	AAI	0.90[1]
R > U	CAI	0.37[1]
U > I	CAI	0.04[1]
R > I	CAI	1.11[1]
R > U	No	0.52[1]
U > I	No	0.32[1]
R > I	No	0.99[1]

[1] *p*=<.01; [2] *p*=.01; [3] *p*=.04; ES = Effect size

Figure 2: Averages relative to the grand mean of different aspects of mouse performances of the three learning types.



3.4 Mouse behaviour of the three learning types

When comparing the learning patterns of the three types of learners, reflective children scored on two of the four mouse aspects in the middle of the range between unresponsiveness and impulsiveness (see Figure 2). They showed (multiple) clicks between unresponsive and impulsive children. The results indicate that impulsive children performed worser than reflective children in all mouse aspects (errors, multiple clicks, mouse clicks and trials combined) (p<.01). Impulsive children made the most errors, showed the most (multiple) clicks and needed the most trials. This means that they did not wait for the next clicking moment that appeared after the instruction and they showed an unnecessarily high number of mouse clicks. Unresponsive children clearly showed the lowest number of (multiple) clicks compared to reflective children (p=.01) and compared to impulsive children (p<.01). However, it is striking that there was no significant difference between the number of errors that reflective and unresponsive children made. This indicates that if the unresponsive child clicks on an object, this is just as effective as the problem solving behaviour of reflective children. Since there were no differences in errors between these unresponsive and reflective children, only impulsive children can be distinguished from the other learners according to their errors (impulsive versus reflective and impulsive versus unresponsive respectively p<.01, p=.02).

Furthermore, unresponsive and reflective children can be distinguished by their number of trials. Unresponsive children showed almost the same number of trials as impulsive children, which might indicate that the mouse behaviour distinguishes ineffective learners from effective learners. Subsequently, a relatively low or high number of (multiple) clicks seems to be an indicator for the specific type of ineffective learning behaviour (unresponsive or impulsive).

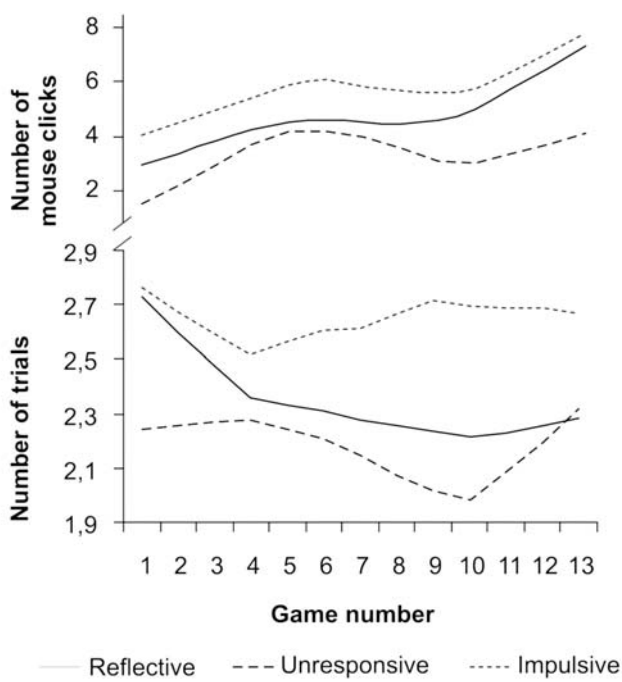
3.5 Improvement of learning behaviour

In order to test the last hypothesis (each of three types of learners show different learning patterns), the number of mouse clicks and the number of trials were smoothed (see Figure 3). The results show that impulsive children needed on average more trials to finish the games than reflective children (p=.02). The impulsive children also showed more mouse clicks than reflective children (p=.04). Secondly, during all games, unresponsive children performed better (they showed fewer clicks) than reflective children (p=.02). Although, they did not need significantly fewer trials (p=.08). However, these differences might correspond to the child's cognitive level, since these process data were not corrected for Standard Scores.

If we focus on the learning process within groups of learners during the games, we observed that unresponsive children showed a slow decrease in trials and an increase in mouse clicks until the ninth game. On the contrary, reflective and impulsive children showed a clear drop of trials with a relatively lower increase in mouse clicks in the first four games. This might indicate that unresponsive children need a longer warming-up phase than the other learners. The clear drop of trials in the beginning indicates a learning effect for reflective children, since they still showed a slight decrease in trials after that phase. However, for impulsive children, we observed that after the warming-up phase of four games, the number of trials increased again, which does indicate that there was no strong learning effect for impulsive learners. In the ninth game they still needed as many trials as during the first game.

For all types of learners, there was no clear overall decrease in the number of clicks during the games. However, a small decrease was observed in the number of clicks of unresponsive children between game 4 and 10. This might imply that there is a small learning effect, since a low number of clicks of unresponsive children corresponds to a lower number of trials in game 5 until game 10 (see Figure 3). Furthermore, unresponsive children also showed an increased number of mouse clicks during the first five games. This suggests that unresponsive children knew well what to do, but it took time to arrive at a level of optimal performance.

Figure 3: The smoothed average number of mouse clicks and trials (not corrected for Standard Scores) during the games of the three learning types.



4. Discussion

We first investigated whether learning behaviour of unresponsive, reflective and impulsive children can be distinguished on the basis of mouse data. Secondly, we analysed whether computer-assisted instruction might be equally effective as individual adult-assisted instruction to improve the learning behaviour of ineffective learners.

The results demonstrate that reflective children, irrespective of the instruction conditions, showed on average the best learning outcomes and Standard Scores. However, unresponsive and impulsive children performed significantly worse on learning outcomes (i.e. the slope of performances and the number of trials) compared to reflective children. Furthermore, compared to unresponsive children, impulsive children did not perform significantly worse on learning outcomes, despite the low Standard Scores of impulsive children compared to unresponsive children. Since the data were corrected for Standard Scores, we can conclude that learning behaviour of effective and ineffective learners can be distinguished on the basis of their mouse data.

The results show that for all children, irrespective of their learning type, a clear distinction can be made between the learning outcomes (i.e. the slope of performances and the number of trials) in the computer-assisted instruction plus adult-assisted instruction condition and the computer-assisted instruction or adult-assisted instruction condition. On average, computer-assisted instruction plus adult-assisted instruction was the most effective instruction condition. However, no clear differences were found in the slopes of performances and the number of trials between the computer-assisted instruction and the adult-assisted instruction condition. Furthermore, the computer-assisted instruction or adult-assisted instruction condition had a clear added value as compared to the no instruction condition. The results indicate that, in general, a combination of social and flexible adult instruction and consistent and immediate computer instruction is the most optimal type of instruction for preschool children. In this instruction condition an optimal balance between already achieved skills and challenge can be created, which is an important aspect for good learning outcomes (DuPaul et al., 2003; Pfiffner et al., 1998).

These findings confirm that educational computer games can indeed function as an adequate learning tool, specifically for impulsive children (Shaw & Lewis, 2005). Despite the positive effects of an interactive learning task focused on self-regulatory skills (e.g. DuPaul et al., 2003) on reducing ineffective behaviour, however, the learning behaviour of impulsive and unresponsive children is still worse than that of reflective children.

Considering the third hypothesis, we observed significant differences in relation to the learning types and instruction conditions. In general, the results demonstrate that both ineffectively and effectively learning children do profit from both computer-assisted instruction plus adult-assisted instruction. These outcomes support the hypothesis that adult-assisted instruction in combination with computer-assisted instruction is the best method to improve learning behaviour in effectively as well as effectively learning children. In the instruction conditions without adult-assisted feedback, impulsive children showed the worst learning outcomes. This indicates that for impulsive learners, adapted adult-assisted instruction is the optimal instruction condition. These findings are in line with the hypothesis that the social and emotional mediation of an adult is important to scaffold and regulate the children's learning (Elias et al., 2002; Karpov, 2005).

Unresponsive children, however, showed relatively good learning outcomes in the conditions with computer-assisted instruction only. It is striking that, even in the no instruction condition, unresponsive children showed better learning outcomes than in the adult-assisted instruction condition. This might indicate that adult-assisted instruction only might interrupt or inhibit these children from taking any action, while computer-assisted instruction (in combination with adult-assisted instruction) is more stimulating for unresponsive children to initiate and plan their actions. If not combined with computer-assisted instruction, adult-assisted instruction does not appear to stimulate the unresponsive children's actions.

Reflective children showed relatively constant performances during all instruction conditions, even in the no instruction condition. This indicates that for effective learners, the instruction is not as important as for ineffective learners. These findings are in line with the hypothesis that impulsive and unresponsive children have more problems with effective learning than reflective learners. As a consequence, the instruction-type can have relatively more influence on the learning outcomes of such children (Bornas et al., 1997; Kagan, 1965).

Another striking result is that the difference in the learning outcomes of unresponsive learners between computer-assisted instruction and adult-assisted instruction conditions was considerably smaller than the corresponding difference in learning outcomes of impulsive children. This result indicates that for unresponsive children the type of instruction condition has a smaller influence than for the impulsive children. These findings imply that unresponsive children only have difficulties with initiation, but not with factual knowledge, referred to as 'knowing what or that' by Gibson (2008) and McCormick (1997). On the contrary, the results demonstrate that impulsive children who have by definition no difficulties with initiation, have problems with their strategic knowledge. They do not know when to respond and how to respond and they show significantly more errors (Gibson, 2008; McCormick, 1997).

Considering the fourth hypothesis, regarding the learning patterns of the three learning types, impulsive children made significantly more errors, showed more (unnecessary) mouse clicks (during one clicking moment) and needed more trials to finish a game than reflective children. They also showed more errors and clicks (during one clicking moment) than unresponsive children. However, they showed almost the same number of trials as unresponsive learners. These outcomes support the earlier findings that learning behaviour, in particular mouse behaviour of impulsive children, can be clearly distinguished from that of reflective learners (Kagan, 1965). Although, unresponsive children showed the lowest number of mouse clicks (during one clicking moment) and errors, the differences between reflective and unresponsive children were smaller than the differences between reflective and impulsive children. Furthermore, the results indicate that ineffective – impulsive and unresponsive – and effective – reflective – learning behaviour differ as to the number of trials a child needs to finish a game. However, to determine the specific type of ineffective learning behaviour, a combination of multiple mouse behaviour aspects must be taken into account (e.g. number of clicks (during one clicking moment), errors) the number of clicks (during one clicking moment) and errors should be taken into account.

Considering the overall development of the three types of learners during the game sessions, we observed no clear improvement in the learning behaviour of impulsive children. We expected that the impulsive learners would learn to control their impulses by showing a decrease in the number of unnecessary mouse clicks and the number of trials needed (Navarro et al., 2003; Slate et al., 1998). However, the results demonstrate an increase in mouse clicks. Except for the first four games, we also could not observe a decrease in trials during the sessions, in contrast to reflective children. We can thus conclude, taking the increase in mouse clicks and no decrease in trials into account, that there was no learning effect for impulsive children and a small learning effect for reflective children. A possible explanation for the absence of a learning effect for impulsive children might be that there was only variation in the setting and objects within the games, but not in the specific assignments. Since impulsive children need relatively more stimulation than reflective children to stay on-task and to remain highly motivated, under stimulation or low variation in the game and in the rewards might have caused a decrease in motivation across the games (Shaw & Lewis, 2005), preventing any learning effects to occur. Our expectation unresponsive children would show an increase of the number of mouse clicks was confirmed in the form of a steeper increase in mouse clicks (during the first six games) compared to impulsive and reflective learners. The results demonstrate that unresponsive learners need a relatively long warming up phase and show a small learning effect after that phase (with a decreasing number of trials needed). This implies that unresponsive children relate their efforts to success and as a result they learn to complete a task more independently (Mercer & Pullen, 2005).

It is also striking that all three types of learners show an increase in mouse clicks after 10 games. A possible explanation for this drop in quality of performance is that the children were losing motivation compared to the first games.

Further research is needed in order to generalise the results to other educationally adequate computer games. In order to fully test the learning effect, we need games with more complexity levels than the game described in this article, for instance allowing children to step in on a level that is not under their current level of skill. In the current game, the better performing children might have experienced an unbalance between already achieved skills and the in-game challenge which might have affected their motivation. We also wonder whether children with relatively low scores on, for instance, language comprehension and fine motor skills, will profit as much as children with more advanced language skills, in particular listening skills. A long-term study following individual cases is needed to investigate the long-term effects of educational computer games focused on improving learning behaviour and the generalisation to other educational tasks.

In summary, we can conclude, first, that in combination with adequate adult assisted instruction, adaptive computer games that focus on ineffective learning behaviour can serve as an effective and motivating tool for improving learning behaviour of both impulsive and unresponsive children in pre-school education. Furthermore, this study suggests that an adult teaching an impulsive child *how* and *when* to react is the best type of instruction to achieve optimal performances. For unresponsive children, computer-assisted instruction only focusing on initiation and on teaching children to relate efforts to success by using positive rewards will result in good learning outcomes. For reflective children, computer-assisted instruction only seems to have sufficient influence on their learning behaviour. Additionally, these data open up the possibility to objectively distinguish different learning types, and to validate subjective criteria consisting of teacher- or parent-based judgments. We can conclude, finally, that an educational computer game can serve as an adequate and less time-consuming diagnostic instrument than traditional diagnostic instruments for assessing types of learning behaviour.

Address for correspondence:
Baukje Veenstra, MSc
E-mail: B.Veenstra@rug.nl

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Appendix 1: Pre-schoolers' Learning Behaviour Questionnaire

Name of child:..
Date of birth: ....
Sex: ....
Name rater:..
Date: ....

Fill out the category (unresponsive, reflective or impulsive) that fits best with the pre-school child's learning behaviour, according to the regular learning behaviour during a task, such as making puzzles, building blocks or drawing. Read the definitions of the three concepts carefully in order to circle the best fitting category. Please circle only one category.

The pre-school child regularly works concentrated on a task. However, the child does start only with help or with a stimulus. The child waits until someone encourages or stimulates him or her to take action.
Unresponsive

The pre-school child regularly works concentrated on a task and regularly completes a task. The pre-school child takes initiative to start a (new) task and does what has been requested.
Reflective/Normal

The pre-school child is easily distracted, stops relatively fast during a task and after that starts a new task. The child regularly gives up relatively fast and is very active.
Impulsive

Appendix 2: Samenslim game

In the *Samenslim* game of hide and seek (www.samenslim.nl), two children play the leads: 'Sim' and 'Sanne'. The toddler playing the game is supposed to help Sim to find Sanne by clicking on objects behind which Sanne could be hiding. If the child clicks on a wrong object, only shifts the mouse or does nothing at all with the mouse, he or she is given helpful pointers (adapted to the performances of the toddler) focused on the mouse behaviour, for example, 'you first have to look, than to click' or 'no, this was not the right object, look further'.

The *Samenslim* game consists of five increasingly complex levels, each of which has nine games in three different settings (park, farm and living room). A standardised decision model determines whether a child can progress to a higher level or has to go back to a lower level. Every child starts at the lowest level (one) and depending on how well he or she plays, reaches the highest level (five) sooner or later.