Children's engagement with mathematics in kindergarten mediated by the use of digital tools.

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The purpose of this paper is to study children's engagement with mathematics in the kindergarten mediated by digital tools within the context of interactive whiteboard (IWB). *Our study reports from a research project aiming at analysing in what ways digital tools may nurture children's appropriation processes relative to mathematics. In adopting a sociocultural perspective on learning and development, observations together with video recordings have been analysed. Our study shows that the children make sense of the digital tools and are able to apply the tools purposefully due to interaction with an adult within the zone of proximal development. The children make their reasoning explicit through multimodal interaction, such as drag-and-drop actions, verbal responses and non-verbal pointing gestures. Their engagement and interaction with the IWB made the children become involved in a process of appropriating mathematical tools such as pair of contrasts, comparison of weights, and the transitive ordering relation.*

Introduction

In the last few years, Norwegian authorities have emphasised the importance of implementing mathematics and the use of ICT in the kindergarten (Ministry of Education and Research, 2006a, 2006b). The former document contains recommendations and ideas for how to implement ICT in the kindergarten and the latter mathematics as a subject area. However, a combined emphasis on mathematics and use of ICT is not explicitly elaborated.

This study reports on our conducted research within a project called ICT Supported Learning of Mathematics in Kindergarten[i]. According to Sarama and Clements (2004), there is a need for research aiming at identifying the role of digital tools and their contributions with respect to mathematics learning. Our study aims at gaining insights from implementing and using digital tools as regards children's mathematical learning within the kindergarten setting. Our hypothesis is that kindergarten children's engagement with digital tools may support their learning of mathematics. The literature has so far not offered this topic careful attention. In their meta-analysis, Plowman and Stephen (2003) argue that mathematics and use of digital tools in pre-school settings has not frequently been an object of study.

We believe the children in our study are involved in a learning process when engaging with the digital tools mediated by the interactive whiteboard (IWB). Hennessy (2011) explored interaction possibilities of IWB used in teaching and she lists their affordances, among others the direct manipulation of objects and multimodal nature of interaction. These affordances offer "strong support for cumulative, collaborative and recursive learning" (p. 483). However, we believe it is a challenge to explore to what extent the users of the IWB, in our case children aged 4-5 years, engage in the learning of *mathematics*, i.e. whether the children become participants in processes of appropriating mathematical tools.

From these considerations, we have formulated the following research question for our study: In what ways did the use of digital tools in kindergarten give learning opportunities in mathematics? More specifically, we study in what ways the children make experience related to the use of a digital pair of scales and comparison of weights in interaction with the IWB.

Theoretical framework

In our study we adopt a sociocultural perspective on learning. We view learning as a situated and social process in which individuals, i.e. in our case kindergarten teachers and children, appropriate (mathematical) concepts, tools, and actions by collaboration and communication (Rogoff, 1990; Wertsch, 1998). Our reason for adopting this theoretical perspective is that a sociocultural stance offers a lens through which learning activities involving the use of digital tools may be analysed.

Learning as appropriation

Appropriation as a sociocultural metaphor of learning is viewed as an individual process of 'taking something that belongs to others and making it one's own' (Wertsch, 1998, p. 53). In order for this process to be nurtured, the individual has to participate in social interaction with others where communication and contributions regarding ideas and arguments are essential elements. Appropriation is describing the process through which individuals gain from participating in sociocultural activities (Rogoff, 1995). To become a cultural knower, i.e. in our case to become a novice participant within mathematics, one has to (1) involve oneself in joint activity with others; (2) establish together with others shared foci of attention; (3) develop agreement with others regarding shared meanings for words and concepts, (4) reason with respect to the words and concepts used by others and transform these in future, purposeful actions; and (5) attend to the relationship between their individual sense of mathematical concepts and tools and the mathematical meanings of these (Moschkovich, 2004; Rogoff, 1990).

However, the emergence of digital tools within educational practices such as kindergartens and schools, transforms the way we learn and come to know new things (Säljö, 2010). In a digital world the interesting thing is our abilities to make productive and insightful use of digital tools in locally suitable ways. Learning in technological environments is a process of performative actions, which applies to children's engagement with digital tools in the kindergarten. Learning is about mastering the tools and performing in appropriate ways when interacting with the ICT applications, or as Säljö (2010, p. 62) puts it: 'our mastery of such tools is a critical element of what we know'. These claims suggest that becoming familiar with digital tools at an early stage, in the kindergarten, is important for the children in an educational perspective. In order to become competent participant in an increasingly sophisticated and specialised society, the upcoming generation is in need of skills and competence regarding digital tools, their affordances and constraints.

According to Plowman and Stephen (2003), the use of ICT in educational practices is a valuable supplement, or 'benign addition', to existing resources. Nevertheless, they claim, employing these tools does not transform kindergarten practice. Moreover, they assert that there is a scarcity regarding research on kindergartners' use of ICT tools. Other researchers, in reviewing studies on young children's learning with digital tools, have found that digital tools are effective in improving mathematical and problem-solving skills for children ages 3 to 6 (Lieberman, Bates, & So, 2009). Clements and Sarama (2007) studied the effects of a preschool mathematics curriculum focused at creating technology-enhanced mathematics materials. They argue that early mathematical interventions contribute to children's developing mathematical knowing.

Sarama and Clements (2004) found that when children were engaging with computer software opportunities for mathematics learning were provided. In using the digital tools children's appropriation of mathematical concepts and skills was nurtured. The software helped the children to mathematise their everyday activities and supported the children in their participation in mathematical activities interacting with computers. The digital tools the children worked with supported them in representing mathematical ideas as well as modelled mathematical activity with objects, i.e. numbers and shapes, and mathematical actions such as counting, adding, and subtracting. Nevertheless, Sarama and Clements point to a critical issue concerning children's play and use of digital tools. In order for the children to make meaning of the digital tools, it is crucial the way they interpret and grasp the objects, actions, and screen design represented and offered through the software. Careful observations and conversations with the children are thus necessary in order to explore their meaning-making.

The mediating role of digital tools

Within a sociocultural perspective one tenet is the mediating role of cultural tools such as computer software and interactive boards (Säljö, 2010; Vygotsky, 1986). Children's interaction and collaborative participation is fundamentally dependent on the use of these tools. The ICT applications become digital tools by way of their mediating function. These tools mediate mathematical concepts and ideas. According to Leont'ev (1979, p. 56), "The tool mediates activity and thus connects humans not only with the world of objects but also with other people". The mediating role of digital tools is quite evident in that children interact with each other through communication and with the software by way of the dynamic mathematical objects incorporated in the software.

Plowman and Stephen (2003) argue that with accessible technologies with tangible interfaces, such as interactive boards, a distinction between playing with digital tools and embodied play in kindergarten may be neglected. In a kindergarten environment where these new technologies are available, the notion of children's play ought to be enlarged in order to encompass playing with digital tools as a mediated, physical and embodied activity. The software applications are used as digital tools which children ought to mathematise in order to develop their mathematical thinking. The applications mediate reality in a particular way that the children need to make mathematical sense of. Displayed pair of scales, cars, trucks, buses, toy bears and dolls, footballs, and violins ought to be made sense of as objects that may be compared relative to their individual weights.

The children also have to consider various semiotic contexts in order to make sense of the ICT applications, the semiotic context of real toys and pair of scales as well as the semiotic context of the application. The children's sense-making in the former context has to be mapped onto the semiotic context of the application, e.g. the weights of violins, teddy bears, dolls, cars, and trucks, their internal weight relationships and how the producers of the application have implemented various weights of these toys, not necessarily in the same manner as the children reason. Additionally, these issues have to be related to the pair of scales and its functionality as well as the boxes or areas (labelled heavy/light, heavier/lighter, and heaviest/lightest respectively) in which the toys ought to be placed after the comparisons of toys' weights. From a sociocultural perspective, the reliance on symbolic tools such as interactive screens with manipulative objects exemplifies the crucial role that semiotic tools play in mediating a physical world with physical objects for the children (Säljö, Riesbeck, & Wyndhamn, 2009). Moreover, we will argue that the children are involved in inter-semiotic work, i.e. coordination of iconic categories and mathematical ideas and operations.

Interacting with the digital tools through the zone of proximal development

Links between learning as appropriation and the mediating role of tools are in a sociocultural perspective found in the Vygotskian notion of the *zone of proximal development* (ZPD). In order for children to learn something, Vygotsky (1978) argues that interaction with more capable peers needs to take place within this zone. ZPD is the difference between what a child is able to do alone and without assistance and what she is able to do in collaboration with adults or more competent others. With this notion, Vygotsky addresses the potentiality in the child's appropriations and actions. This zone therefore could be seen as the adult's guiding of the child within a culture and the collective knowing of that culture (Säljö, 2001). The notion of ZPD is useful when analysing children's interaction with digital tools and the collaboration with the kindergarten teacher(s) within that interaction, because this notion may be used to describe the communicative qualities of their interaction. In a social setting and collaboration with the adult, the children are exposed to reasoning and actions that they gradually appropriate by becoming able to make those arguments and carry out those actions themselves. According to Chaiklin (2003), it is the quality of the interaction that takes place within the zone of proximal development among children and adults that makes the notion fruitful for analysing children's engagement with ICT tools. The interaction has to be ontogenetically adaptive in order to be purposeful, both with respect to the current situation of the child and with respect to future developments; an interactive creation of an intellectual space (Zack & Graves, 2001). Sarama and Clements (2004) found that children of a particular age often seemed to be more competent than the software designers assumed them to be at that age. The age indicators associated with different programs does not meet the competences appropriated by children at that particular age in their zone of proximal development (Vygotsky, 1978).

Methodology and methods

Our methodology in conducting this research is based on what Wagner (1997) calls a co-learning agreement among us as researchers and the kindergarten teachers as practitioners. Researchers and kindergarten teachers collaborate in order to develop new forms of mathematical practice in kindergarten, a practice in which children interact with and use digital tools to appropriate mathematical concepts and actions. The reason for establishing a co-learning agreement is that, according to Wagner (1997, p. 16), within this agreement:

> …researchers and practitioners are both participants in processes of education and systems of schooling. Both are engaged in action and reflection. By working together, each might learn something about the world of the other. Of equal importance, however, each may learn something more about his or her own world and its connections to institutions and schooling.

We argue that a co-learning agreement is useful when aiming at exploring the subtleties of the children's opportunities for appropriating mathematical concepts and actions by way of using the digital tools on the IWB. Working with digital tools on the IWB to stimulate learning of mathematics, was a new experience for the children, kindergarten teachers and researchers. Thus, a co-learning agreement was fruitful for common explorations of the new area of practice and research, in which both parties contributed with ideas and arguments.

More particularly, we used observations, video data of the sessions, field notes and conversations with the kindergarten teachers as data collection methods to address our research question. In our opinion these various methods complemented each other in our on-going efforts to do in-depth analysis of naturally occurring talk in interaction. The context of our project is collaboration with three kindergartens called Bee Pre-school centre, Swan Pre-school centre, and Frog Pre-school centre. We collaborated with two kindergarten teachers at each of these kindergartens.

In this paper we analyse data collected in an IWB-session on Frog Pre-school centre planned and led by one of the researchers. The researchers had observed this group of children and their kindergarten teachers several times working with different digital tools on IWB ahead of this session.

Analysis and Results

The digital tool used on the IWB was a Norwegian software package for mathematics, Multi 1b[ii]. The software package Multi 1b is supposed to be appropriate for Grade 1 students in Norway, which means an age of 6-7 years. At this age many children are able to read in Norway. However, the children that engaged in the activity we observed were 4-5 years old. Thus, we did not expect any of the children to be able to read. Consequently, all the written instructions in the digital tool were explained by the adult who lead the session. In this paper we consider the work with the three afforded difficult levels 1, 2 and 3 in an application within the digital tool Multi 1b treating measuring, particularly measuring of weights.

In the following we will present two transcribed excerpts from video data and our analyses of those in order to address aspects of our research question. The digital tool displayed a pair of scales and the users were supposed to use the scales to compare the weight of displayed toys. Three levels of activities are presented in the tool. In excerpt 1 we present children's work with level 1 where the tool asks the user to weigh two different, displayed toys and based on their weighing and reasoning drag the toys to two boxes labelled "HEAVIEST" and "LIGHTEST" respectively. At level 2, which was not engaged with in the session presented below, the users of the tool were supposed to use the pair of scales to compare the weight of one specific toy to four other toys. Each of these four toys was supposed to be dragged to either a box labelled "HEAVIER THAN" or LIGHTER THAN" the toy they compared with. At level 3, engaged with in excerpt 2, the mathematical challenges for the users of the tool are to relate the weights of three different, displayed toys with each other.

In the observed session three children were placed close to the IWB. The adult started off the session by briefly demonstrating the functionality of the digital tool, pointed at the various elements of the screen and labelled them. Throughout the session, he read the written text presented within the application, called forward one child at a time to the touchable screen and asked questions while the children interacted with the IWB. The session lasted for approximately 15 minutes before a new group of children accomplished the same activity. Both sessions followed the same pattern of interaction, addressing similar mathematical contents, and for convenience of the reader we refer to only one of them in the two excerpts below because similar observations were made.

Figure 1: The screen relative to excerpt 1 at level 1 in Multi 1b, measuring with scales. Source: http://web3.gyldendal.no/multi/1-4nettoppgaver/multi1b/kapittel7/oppgaveC/nivaa1

Excerpt 1 Familiarisation with the application and its use on the IWB

In the following excerpt four persons are interacting, it is one boy, Peter, two girls, Christina and Helen, and Ove (researcher).

1. Ove: Now we are supposed to be weighing with the help of the computer, and we are supposed to figure out which one of these two things is lightest and which is heaviest.
2. Christina: A ball
3. Ove: A ball and a doll. Here it says: Put the toys in the correct box ((Ove points to the text at the top of the screen and reads)). Here it says lightest and here it says heaviest. But this thing here, do you know what that is? ((Points at the pair of scales))
4. Helen: The thing they are supposed to be laying at.
5. Ove: The thing they are supposed to be laying at. It is a pair of scales, it goes upwards and downwards as we put the toys into the pans. I will show you. Let's take the doll and drag it onto the left pan. Then it goes downwards. Let's then take the football and drag it onto the other, right, pan. What do you think will happen? ((No response)) It went just a little downwards. Which one of the two toys do you believe is the heaviest one?
6. Christina: The doll
7. Helen: The doll
8. Ove: The doll. Why do you mean that?
9. Helen: Because it went furthest down.
10. Ove: Yes, because it went furthest down.

This excerpt starts off by Ove demonstrating and explaining the functionality of level 1 in the application and the associated drag-and-drop affordance to use when interacting with the IWB. Ove emphasises the comparison words *lightest* and *heaviest* in relation to comparisons of the weights of toys (That is the reason why the comparison words are underlined in the excerpt), in order to focus the children's attention to what the comparisons are about. At the screen, see Figure 1, the following elements are displayed: A pair of scales to the right, two side by side boxes to the upper left corner labeled "TYNGST" (heaviest) and "LETTEST" (lightest) respectively in which the toys are supposed to be placed after the weighing, and two toys – a football and a doll. Ove asks the three children's opinions regarding the displayed pair of scales. It seems as if Helen makes sense of it even though she has never tried the application out before. The visualisation of the pair of scales seems to communicate with her in such a way that she rationalises on its functionality. Ove is confirmative with respect to her reasoning, and exemplifies the functionality of the pair of scales. Ove drags the two toys onto the two pans, first the doll onto the left pan and afterwards the football onto the right pan. Just before he drops the ball onto the pan, Ove asks the children what they believe will happen. There is no recognisable response from the children to that question: But after having dropped it (there is only a small movement visible in the pair of scales when the football is placed onto the right pan), Ove asks a question addressing the conclusion that can be drawn from what they saw happen. Which one of the toys is heaviest? Both the girls conclude that it is the doll that is heaviest. Ove confirms their reasoning by repeating their answer, but continues by asking them to argue for their conclusion. Helen then utters her argument. We interpret this utterance to explicate the following conclusion: The doll is heaviest because the pan in which the doll is laying got further down than the pan with the ball. The pan with the doll is visually lower on the screen than the pan with the ball. In this situation with two different toys, a mathematical underlying element is the concept of pair of contrasts. One of the toys is lightest and the other one is therefore, logically, heaviest.

From this excerpt it seems as if the children have made sense of the application, both the functionality of the pair of scales and what they are supposed to do when interacting on the application through using the drag-and-drop affordance in the IWB. It seems as if the children quite spontaneously master the digital tool (Wertsch, 1998). After a few repetitions of similar tasks at level 1, Ove decided that the children needed greater mathematical challenges. The children's engagement with the tasks at level 1 did not result in significant difficulties for them, and the tasks were solved with few actions on the IWB by the children. Thus, we find indications that the children were not met in their zone of proximal development to any significant degree (Vygotsky, 1978). The decision was then taken to continue with the application at the most difficult level, level 3, to enrich the intellectual space created in the interaction between the children and Ove (Zack & Graves, 2001).

Excerpt 2 Engaging with the application on the IWB

This excerpt sort of continues where the previous excerpt ended. The same four persons are interacting, but now with the application at level 3. At the screen, see Figure 2, there are currently three boxes to the upper left corner, labelled from left to right "TUNG" (heavy), "TYNGRE" (heavier), and "TYNGST" (heaviest).

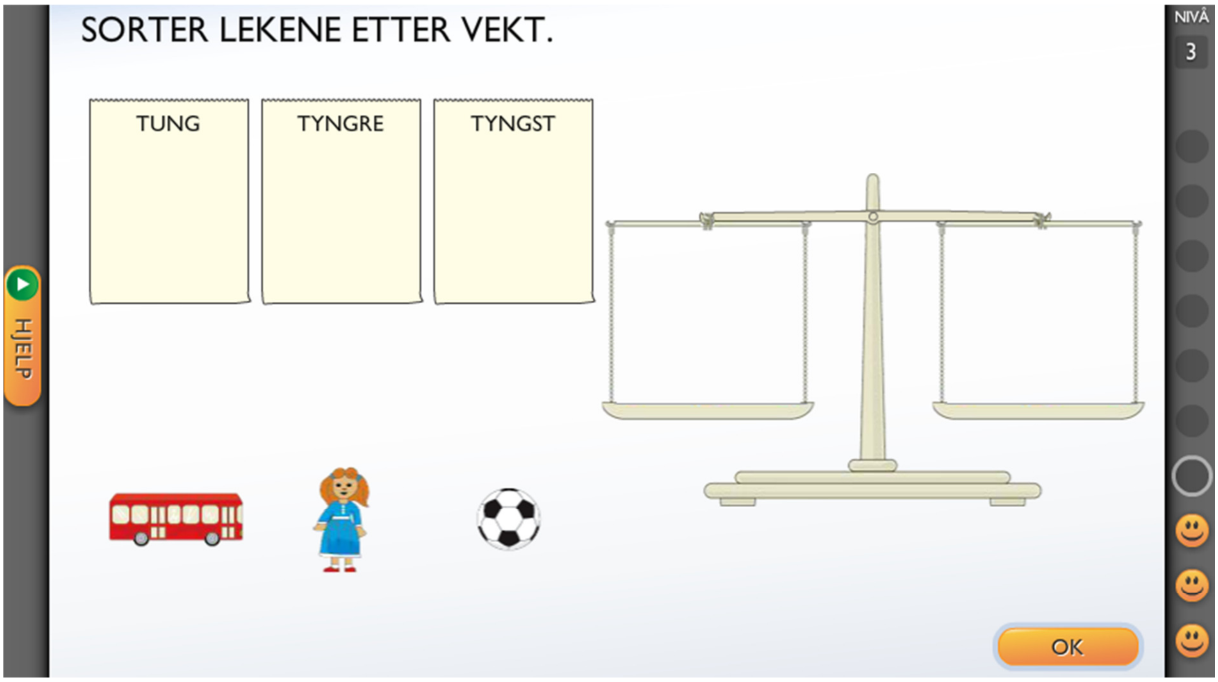

Figure 2: The screen relative to excerpt 2, at level 3 in Multi 1b, measuring with scales
Source: http://web3.gyldendal.no/multi/1-4nettoppgaver/multi1b/kapittel7/oppgaveC/nivaa3

78.	Ove:	((Ove informs about the screen seen in figure 2, reads the text and indicate where the toys are supposed to be dropped according to their weights)) Do you want to compare them?
79.	Christina:	((She drags the doll to the left pan and the bus to the right pan))
80.	Ove:	Wow. Which one of those is the heaviest one?
81.	Christina:	((She immediately points at the left pan, which is correct))
82.	Ove:	Yes, that's correct. It is the doll. But we still don't know what the relationship is between the ball and the bus. Shall we weigh the ball and the doll?
83.	Christina:	((She removes the bus and replace it with the ball))
84.	Ove:	Which one of them is the lightest one?
85.	Christina:	((She immediately points at the ball, which is correct))
86.	Ove:	Yes, it's the ball. Then the ball has to go over here ((Points at the left box))

This excerpt is characterised by Christina's action oriented approach to solve the measuring problem. She does not say anything, but she performs actions as responses to Ove's questions. In our opinion, these non-verbal actions makes Christina's thinking explicit. She communicates her reasoning by dragging and dropping the toys where they are supposed to, and she correctly answers two of the questions by a pointing gesture. In this dialogue we also reckognise that Ove holds back some of the apparent difficulties in the task. He deliberatley uses the word "lightest" when Christina compares the weights of the ball and the doll, rather than asking for what toy to be heavier. Their attention is then focused at the pair of constrast 'heavy – light" or 'heaviest – lightest'. In this situation with three different toys the children, in particular Christina but also Helen and Andreas who carefully watched the interaction among Christina and Ove, have the opportunity to experience the transitive ordering relation of quantities: If $a > b$ and $b > c$, then $a > c$. In this particular case, Christina concluded that the doll is lighter than the bus. In the second weighing, suggested by Ove, she compartes the weight of the doll and the ball. She then found that the ball is the lighter of those two toys. Algebraically, if the bus is quantity a, the doll is quantity b, and the ball is quantity c, she did the following: In the first weighing she found that $a > b$. In the second weighing she kept the lighter toy, b, and compared with c. She concluded that $b > c$. By the support of Ove, she then could decide the transitivity, that since $a > b$ and $b > c$, then $a > c$. If that had not been the case, that the second weighing led to the conclusion that $b < c$, then a third weighind would be necessary in order to decide the ordering of the quantities.

In this excerpt we also observe how the more capable peer and the child are collaborating in order to solve the problems. Christina is apparently in need of assistance in her problem solving, and Ove raises questions to explicitly involve Christina in their joint activity but also, and more importantly, in the process of apporpriating the involved mathematical tools such as pair of contrasts and the transitive ordering relation. Their chared focus of attention is the comparisons of the toys' weights to order them accordingly. Both the ICT application(s) and the goal-directed activity of weighing in this case were new to the children. We therefore argue that the children, in an initial phase, have become involved in a process of appropriating the implicit mathematical tools (Moschkovich, 2004, Rogoff, 1990). Additionnally, we argue that the ICT applications supported the facilitation of mathematical learning as regards measuring (Clements & Sarama, 2007)

Discussion

Through the two excerpts analysed in this study we have seen how the children make meaning of the ICT applications, but also mathematical meaning. We argue that the children, through their utterances and actions, reveal that they make meaning of the digital tools offered and represented at the screen. It is decisive to oblige and surpass this critical issue, as argued by Sarama and Clements (2004), in order for the children to appropriate mathematical meaning mediated by the digital tools (Plowman & Steven, 2003; Säljö, 2010). The children seem to interpret the displayed elements at the screen in accordance with the mathematics community. They seem to immediately interpret and grasp the meaning of the displayed pair of scales and its functionality. If the pan moves upwards the toy in that pan is lighter than the toy in the pan that moves downwards at the screen.

When children use digital tools, opportunities are made in which children have the possibility to make their mathematical thinking explicit. The children are offered possibilities to establish shared meanings for mathematical concepts due to flexible displaying of these concepts by way of the computer. The digital tools also make powerful links between the *per se* abstract mathematical concepts and visual concretising by various representations. In using digital tools, children may establish shared focus of attention as well due to their dynamic and multimodal nature. Interaction with digital tools may encourage the children to pose problems and conjecture regarding mathematical actions and objects. Due to interaction with the digital tools and the more capable peer, the children become participants in a process of appropriating (Moschkovich, 2004, Rogoff, 1995) the mathematical tool of measuring, in particular comparison of weights, pair of contrasts, and the transitive ordering relation.

In this application, both at level 1 and level 3, mathematical problems with similar cognitive demands were engaged with repetitiously. At level 1 different toys appeared in each turn and the order of the labels heaviest and lightest on the screen changed (sometimes heaviest was written on the left hand side and sometimes on the right hand side). While engaging with the tasks at level 3 the labels of the boxes changed into light, lighter, and lightest (from left to right). Nevertheless, it seems as if the children do not have severe difficulties with that. From a mathematical point of view, the ordering of the toys relative to their weight is opposite of each other at these occasions. In the first situation the heaviest toy ought to be placed to the lefthand box, but in the second situation the heaviest toy ought to be placed in the box to the right (in both situations the middle-sized toys ought to be placed in the box in the middle – whether the toys are characterised as lighter or heavier). These issues are deliberately hidden by Ove in the excerpts above, in order to competently guide and assist the children within their zone of proximal development (Vygotsky, 1978). The level of difficulty in the application is competently adapted to the children's level of competence. An intellectual space (Zack & Graves, 2001) is thus interactively created in order for the children to competently pariticipate with ideas, actions and arguments.

Additionally, these excerpts reveal that the children are challenged by the displayed toys, the correspondance of the toys with reality, the weight of different toys in reality compared with what the application shows. Thus, the children are involved in inter-semiotic work (Säljö et al., 2009). The displayed buses and trucks, are they supposed to be interpreted as toy buses and toy trucks or real buses and trucks? What about the violin – is it supposed to display a real playable violin or some toy violin with a much smaller size? What images and thoughts are eroused among the children when displaying these objects? From the dialogues we argue that the children, through inter-semiotic reasoning, are able to relate to the world of objects within the application and their representatives in the physical world, respectively.

From the excerpts we observe how Ove challenges the children mathematically through asking questions directly and indirectly linked to the mathematical issues implicitly imbedded in the applications. In competently assisting the children's engagement with the ICT applications, Ove nurtures possible links between the challenges and previous experience. Thus, the mathematical potentials are focused, through which the children get opportunities to participate in processes of appropriating the imbedded mathematical tools. From our analyses of the children's interaction with the ICT applications, it is evident that in excerpt 1 there is a mismatch between the competencies of the children involved and assumed competence of children of that age by the software designers. This finding is in accordance with the result of Sarama and Clements (2004). It seems as if the children are able to master applications designed for children that are from two to three years older. An intellectual space (Zack & Graves, 2001) where the children are appropriately challenged is established in excerpt 2. Kindergarten teachers therefore need to make an effort to choose software programs and applications that meet and challenge the children within their zone of proximal development (Vygotsky, 1978). It is needed in order for children to continue their individual process of appropriating the mathematical tools and actions incorporated in the digital tools.

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[ii] Source: http://web3.gyldendal.no/multi/1-4nettoppgaver/multi1b/kapittel7/oppgaveC/