Abstract

There is substantial evidence that preschooler’s performance in early math is highly correlated to math performance throughout school as well as academic skills in general. One way to help children attain early math skills is by using targeted educational software and the paper discusses potential gains of using such software to support early math development. Furthermore it is argued that the content of early math software should be centered around notions such as number sense and spontaneous focus on numerosity. Beyond that, the paper argues for seven design criteria to consider if the goal is to provide strong support for early math via educational software: (1) use a pedagogical approach clearly based on research on early learning of mathematics, (2) provide a set of relevant representations in an appropriate order, (3) provide informative and meaningful feedback, (4) pay attention to motivational aspects for the age group, (5) provide individually adapted support as well as challenge, (6) include a reporting function for educators, and (7) enable the use of an inclusive pedagogy. These seven design criteria are described and illustrated by concrete examples drawn from a newly developed play-&-learn game in early math: Magical Garden.
Introduction

Mathematics is a school subject that receives a lot of attention around the globe. One reason is that performance in math seems to correlate closely to performance in other subjects and overall academic success. A meta-review by Duncan et al. (2008) showed that the two single most important factors in predicting later overall academic achievement – regardless of whether or not a child has social or emotional problems – are a mastery of early math concepts and of early literacy concepts by the time the child begins school.

There is substantial evidence supporting the importance of early math intervention from as early as kindergarten (Griffin & Case, 1997; Griffin, Case, & Siegler, 1994; Jordan, Kaplan, Ramineni, & Locuniak, 2009; Locuniak & Jordan, 2008; Mazzocco & Thompson, 2005; Räsänen, Salminen, Wilson, Aunio, & Dehaene, 2009; Wilson, Dehaene, Dubois, & Fayol, 2009). Jordan, Kaplan, Locuniak, and Ramineni (2007) showed that early math performance could account for up to two thirds of the variance in first grade math achievement. Early number skills predict mathematics outcomes over and above general cognitive skills, such as verbal and spatial skills or working memory (Locuniak & Jordan, 2008; Mazzocco & Thompson, 2005). In the National Research Council (2009) report Mathematics learning in early childhood: Paths toward excellence and equity, several research examples show that high quality early mathematic education has long term impacts on achievement even beyond first grade.

One way to deliver early math intervention is with dedicated educational software, which is the subject of this article. The paper addresses the potential benefits in using such a tool, that is, what can be achieved by educational software that is difficult or impossible with non-digital materials and interventions and discusses criteria to ensure that high quality in educational software for early math.

As of July 2012 there were more than 20,000 education related iPad apps at App Store (Brian, 2012). Yet, according to Ginsburg, Jamalian, and Creighan (2013) the majority of these apps “[…] seem to emerge with no evident plan, rhyme or reason.” (p. 84). Blair (2013) carried out a survey of the 50 most popular “preschool math” apps from App Store revealed that only 7% used feedback of a sort that can guide towards understanding rather than just encouraging trial-and-error behavior with no cues given as to why a choice is correct or not and how to arrive at a correct response.
The article begins by discussing the added value of educational software. The arguments provided apply to educational software in general, not specifically software for early math. Next two fundamental notions with respect to the content of early math software are discussed, and lastly and thereafter design principles to ensure pedagogical quality of such software are presented and argued for.

**Educational Software – What Can Be Gained?**

This section discusses potential strengths in educational software. The focus is on what can be accomplished by educational software that is difficult or even impossible to achieve by non-digital means. Importantly, if the software is not designed to capitalize on the advantages offered by digital formats, then it is no different than its non-digital counterparts.¹

1. A major benefit of using high quality educational software is that each student receives immediate feedback based on actions taken. Well-designed feedback and interactivity can generate so-called feedback loops where feedback on one action helps to modify next action, which in turn generates novel feedback from the software and so on, until a goal is reached. Research on motivation indicates that feedback loops are one of the most powerful functions for maintaining interest and learning to regulate one’s own learning (Zimmerman & Cleary, 2009; Chin, Dohmen, Cheng, Oppezzo, Chase, & Schwartz, 2010). While feedback from an actual teacher to a student is often richer, more nuanced, and more contextualized than feedback given by an application, it is virtually impossible for a single teacher to provide detailed and meaningful feedback simultaneously to each class member as they are performing a task.

2. A second related benefit is that high quality educational software can continuously assess the performance of each individual student and accordingly present challenges that follow the progress of the particular student. That is, the individualized feedback involves not only comments and support with respect to the performed action but also involves a decision of what challenges should come next for the individual – so that the challenges presented will follow the progress of the particular learner. This way, the learner

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¹ It should also be emphasized that we do not argue for abandoning or replacing non-digital interventions with digital ones. In our view they should complement each other. Notably, there are advantages in the non-digital over the digital as well, not developed here.
will always be within the zone of proximal development (Vygotsky, 1978), where challenges are at the right level to maintain interest and avoid frustration.

3. Individual adaptation as described in point 2 above, can be combined with inclusive pedagogy (Florian & Black-Hawkins, 2011). Each student is presented with activities at levels of difficulty that meet their individual needs, but all students use the same application and no student risk marginalization by being treated differently. Importantly, the entire application is in principle available for all. This is a major advantage compared to when a teacher seeks to make individual students work at different levels by selecting different tasks or different amounts of tasks to respond to individual needs. Such an approach risks putting a ceiling due to low expectations for the students who struggle, which can make them underachieve or not reach their full potential because they are not challenged enough. A supportive educational application does not assign particular tasks to a group of students, but continuously evaluates the needs and level so as to always expose the student to the adequate amount of challenge. This kind of environment does not single out any particular individual or risk leaving any student behind. Moreover, individual differences among students are only visible to the ones who need to know, such as educators (see point 6 for more details).

4. The use of educational software can provide a “safer” learning area for students who are reluctant to participate in front of an entire class because of low self-efficacy or fear of failing. In the software environment, they can be more inclined to try and explore without risking anything. Gee (2003) calls this a sandbox; a place where learners can feel comfortable to explore and where mistakes do not have any profound consequences – thus leading to deeper learning.

5. Educational software that includes narratives and other kinds of meaningful contexts makes it possible to entice and engage students who are not intrinsically motivated by the educational content in and of itself. This is also possible to accomplish with non-digital materials, but is easier to obtain by well-designed, rich, and varied software that can exploit different ways of evoking interest and motivation in different children. A rich digital world with intrinsic rewards allows the child to understand the “rules” in a certain context and to produce flow, an important factor to keep up motivation and interest and lead to deeper learning (Csikszentmihályi, 1975).
6. Yet another potential benefit is a reporting feature to help educators to follow the progress of each individual student as well as the class as a whole. A reporting feature can record data about successes and roadblocks along the learning curve to outline top strengths as well as weaknesses. It can help inform the teacher which aspects of a topic need revision and which are mastered and serve as a basis for targeted pedagogical activities with groups of children who struggle with similar areas. That way, the limited time a teacher has to convey a topic can be maximized.

7. Last, a crucial potential benefit is that once a high quality application is developed and proven efficient, it can quite easily be distributed and used by a large number of children. Distribution of software has an inherent advantage over distribution of printed materials and can provide children with opportunities to learn regardless of economic or educational constraints. To borrow a phrase from Ginsburg et al. (2013), good software “[…] can be a lifeline for students with weak teachers – who are unfortunately more numerous than we would like.” (p. 115).

**Number Sense and Spontaneous Focus on Numerosity**

As mentioned, there are countless educational applications targeting early math. However, many focus on superficial aspects of math such as simple enumeration or rote teaching of number words. This is in part due to the fact that some curricula as well as teacher’s interpretations of them focus to a large extent on numbers and the idea that kindergarten children need to know the number words when they arrive at school (Griffin & Case, 1997). This generates the risk that the very grounding of mathematics is left out making numbers appear as disembodied, non-meaningful, entities (Griffin, 2004; Griffin & Case, 1997; Griffin et al., 1994). Therefore, it is essential for high-quality software for early math to build on a well-supported view of the motivational and cognitive processes involved in children’s successful learning of basic mathematics.

**Number Sense**

A well-developed *number sense* (Griffin, 2004; Griffin & Case, 1997) involves an understanding of the following: (1) numbers indicate quantity, and as such, have magnitude; (2) the relevance of the word “bigger” or “more” in the context of sets and numbers; (3) numbers occupy fixed positions in the counting sequence; (4) numbers that come later in the sequence correspond to a larger quantity; (5) each incremental
number corresponds to an increase of one; (6) the meaning of different representations and cultural metaphors and how all those meanings are connected to a symbolical number.

The focus for early math activities or interventions should accordingly be on the set of conceptual relationships between quantities and numerical symbols that form a basis for understanding mathematics (Griffin, 2004). In their outline of *Number Worlds*, an educational (non-digital) program to develop number sense, Griffin and Case (1997) stress the importance of presenting numbers and their magnitude using a variety of cultural representations of numbers, such as groups of objects, dot patterns, positions on horizontal or vertical lines, points on a dial, and connecting them to concepts such as taller/shorter, higher/lower, larger/smaller, etc.

Although some of these concepts may seem obvious and intuitive, they are not and must be learned (Griffin & Case, 1997; Griffin et al., 1994). Longitudinal studies show that the majority of preschool children, who have not learned this, never catch up (Jordan et al., 2009; Hannula, Räsänen, & Lehtinen, 2007; Hannula, Lepola, & Lehtinen, 2010; Griffin & Case, 1997; Griffin et al., 1994).

**Spontaneous Focus on Numerosity**

Number sense thus concerns the conceptual basis on which mathematics abilities can be built. Another fundamental notion is what Hannula and collaborators (Hannula & Lehtinen, 2005; Hannula et al., 2007; Hannula et al., 2010) denote *spontaneous focus on numerosity*. The notion refers to attention to numerosity. Their studies have shown a considerable variability in children aged 3-6 as to their spontaneous focus on numbers and magnitude. Children with a spontaneous focus on numerosity will, in everyday situations, notice and identify information related to sets and numbers and to make use of this information – for instance while playing, observing that there is one grape short to give one to each teddy bear or trying to put the same number of Lego figures into each toy vehicle. Children without spontaneous focus on numerosity will not do this. Likewise, if a child is asked to repeat what someone else just did and the action just performed involves a specific number of objects, a child with low spontaneous focus on numerosity is likely to repeat the action but with a different number of objects (Hannula & Lehtinen, 2005). With such divergence in the spontaneous focus on numbers and magnitude, it does not take long for there to be differences in experience and – as a consequence – in the amount of feedback from kindergarten teachers,
parents, and peers with respect to these vital concepts. This in turn leads to some children entering elementary school with an initial disadvantage as to the conceptual foundations of math, leading to a downward spiral throughout school and beyond.

It is important to notice that the variation discussed here concerns attention and that this variation and its consequences are relatively unknown. Many believe that sets and numbers are such basic aspects of the world that the awareness and basic understanding of them unfolds all on its own in every child, as long as they have no explicit cognitive impairments – this, however, does not seem to be the case (Hannula & Lehtinen, 2005).

Early Math and Implications for Elementary School and Beyond

Hannula and collaborators (Hannula, Mattinen, & Lehtinen, 2005) have also attempted to support development in children who lag behind through the use of targeted forms of social interaction. Kindergarten teachers have been instructed to work dedicatedly with sets and numbers in the everyday activities in preschool (such as play and conversation with the children), but studies showed that this was a difficult task even for well-trained kindergarten teachers who are aware of the problem and the challenges. The very children who need the support most – because of their lack of spontaneous interest – give fewer and weaker signals compared to their peers. This makes them difficult to identify and the corresponding lack of feedback results in a negative snowball effect, leaving these children increasingly more behind (Hannula et al., 2005). Longitudinal studies show that a majority of these children will later have difficulty to perform well in mathematics at school (Jordan, Kaplan, Nabors Oláh, & Locuniak, 2006; Hannula et al. 2007; Hannula et al., 2010; Griffin & Case, 1997). In essence – as they never established a conceptual foundation for number sense – they are not susceptible for mathematics learning when they enter school.

To sum up, the important lesson for the development of early math software is that the content must be centered around notions like number sense (Griffin, 2002; Griffin, 2004; Griffin & Case, 1997) and spontaneous focus on numerosity (Hannula & Lehtinen, 2005; Hannula et al., 2007; Hannula et al., 2010). These two notions are what the Magical Garden, an application we have developed, is based on. More details are provided in the following section.

Design Criteria for High Quality Software for Early Math
Above it has been argued for how good educational software can provide advantages and central notions for educational software for early math. The present section is concerned with a set of design principles that need to be followed to ensure quality. The design principles are illustrated with an educational application called *Magical Garden*, which will be briefly introduced before discussing the criteria.

**Magical Garden – Early Math for Preschool**

The Magical Garden software (http://magicalgarden.herokuapp.com) is jointly developed by Lund and Linköping Universities in Sweden with the collaboration of School of Education, Stanford University. The underlying educational approach assumes the definition of number sense provided by Griffin and Case (Griffin, 2004; Griffin & Case, 1997) and is implemented using increasing levels of difficulty from simple counting to basic addition and subtraction in combination with different representations, ranging from fingers over objects/dots, sticks, and dices to numbers. Each combination is practiced several times through several different mini games.

*Figure 1.* The three “friends” (teachable agents): the panda *Panders*, the mouse *Mille*, and the hedgehog *Igis*.

At the start, the child is presented with a set of friends to choose from – at present, a mouse, a panda, and a hedgehog (Figure 1). These friends have a garden that has withered over time and needs water to flourish again. With the help of the child, the garden can gradually come back to life. A variety of trees, flowers, and bushes – ordinary ones as well as strange and magical ones – will start to grow. While the narrative presented to the child is about helping his or her friend, the underlying requirement of each task is to learn and practice number sense. Each mini game is repeated three times in three different and subsequent modes. First (*Mode 1*), the child learns and practices on her own by playing the game. Next (*Mode 2*), she teaches her friend how to play. Third (*Mode 3*), the child monitors her friend who attempts to play on its
own with opportunities to correct the friend if needed. As a set of tasks are successfully completed, the child collects water drops for the garden. The three modes originate from the *learning-by-teaching* paradigm (Biswas, Katzlberger, Brandford, Schwartz, & The Teachable Agent Group at Vanderbilt, 2001). This aspect of Magical Garden and the idea and concept of teachable agents are discussed in detail in other papers (Biswas, Roscoe, Jeong, & Sulcer, 2009; Chase, Chin, Oppezzo, & Schwartz, 2009; Blair, Schwartz, Biswas, & Leelawong, 2007; Chin et al., 2010; anonymized).

At its core, Magical Garden is composed of a set of *pedagogical scenarios* (at present 60) defined by the following parameters: method (counting, incremental counting or proto-addition and proto-subtraction, addition, subtraction, etc.), range (1-4 or 1-9), and representation (none, fingers, objects/dots, strikes, dices, numbers, mixed, transitions). The pedagogical scenarios are ordered according to difficulty. The same scenario can appear in several mini games, which are all related to the overarching narrative.

Currently, there are four mini games implemented, but others are in progress of being developed. In *Sniffling Bee*, the bumble bee Humfrid has a cold, so he cannot find the right flower. The child thus needs to guide him to the right place so he can get the nectar (Figure 2a). In *Bird Hero*, baby birds have fallen out of their nests in the tree and need help to get back to their parent via an elevator (Figure 2b). In *Juicy Jungle*, the chameleon Kamilla the Pirate is always hungry, but her aiming skills are not that good and so she needs help to be able to catch insects on the palm tree on the other side of a creek (Figure 2c). Finally, in *Treasure Hunt*, the woodlouse Grålle, a passionate treasure hunter, needs help to reach the right cave in the cliff by attaching the correct number of balloons to his basket (Figure 2d). The uniting theme is that each character needs help to achieve a goal where the focus is not on numbers, but requires the child to learn and practice simple counting, incremental counting, correcting by adding or subtracting, etc.

Next, Magical Garden will serve to exemplify the proposed design criteria.
Design Criteria

Design criterion 1: Base the pedagogical approach on evidence based research on early mathematic learning and potential obstacles to learning. The first criterion relates to Ginsburg et al.’s (2013) first and fifth principles, namely that a high quality application for early math must engage children in cognitively and mathematically appropriate activities (Principle 1) and encourage children to take on accurate and efficient strategies (Principle 5).

In the case of Magical Garden, the basic pedagogical approach is built upon the notion of number sense as elaborated by Griffin et al. (1994) and Hannula and colleagues (Hannula & Lehtinen, 2005; Hannula et al., 2005) findings regarding spontaneous focus on numerosity.

Regarding number sense, the pedagogical scenarios implemented in the mini games aim to stepwise introduce and (extensively) practice crucial concepts such as higher/shorter, upwards/downwards, more/less, larger/smaller, equal/different, and their relations to sets of different sizes. The overall idea is to engage the children in quite a substantial amount of training, but still varying the games. From the perspective of a teacher or an adult, the tasks and activities are highly repetitive, but from a preschooler’s perspective, there is a wide variety of games to encounter and enjoy. Behind the scenes, the application automatically adapts to
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the child’s ability and progress by individually varying the amount of exposure to different pedagogical scenarios. If a child needs more practice, the same pedagogical scenario (but not same mini game) will appear more times than those the child has already mastered.

With respect to Hannula et al.’s (2007) concepts of spontaneous focus on numerosity, the overarching narrative in the application has no relation to sets and numbers. Rather, the idea is to present the children with an abandoned magical garden and entice them to help the different game characters (the “friends”) to make it flourish. By not explicitly focusing on set and numbers, but infusing them in this narrative of a magical garden, the application’s objective is to appeal to children who are not spontaneously attracted to set and numbers.

Design criterion 2: Exploit a set of relevant representations in an appropriate order. This point can be seen as an aspect of our first design criterion presented above, but nevertheless deserves to be highlighted. A high-quality application for early math should involve an adequate mix of relevant representations introduced in a certain order and associated to concepts such as higher/shorter, upwards/downwards, more/less, larger/smaller, more/fewer, equal/different, etc. and provide scaffolds to connect different representations in meaningful ways. As Ginsburg et al. (2013) point out, there is a general lack of this in current software, where some provide representations that are conceptually confusing, some utilize multiple representations for the same concept but lack the scaffolding to promote synthesis, and others stress rote learning of number facts and hardly involve sets of relevant representations at all. Magical Garden uses a variety of representations such as fingers, dots, sticks, dices, spoken numbers, and written numbers. The children are exposed to these representations in the application in this order, depending on their individual progress. To support the transitions between representational states, the children are also exposed to appropriate combinations. In particular, if a child shows difficulties with a novel representation, a representation already learned appears alongside it to allow the child to connect the two forms before continuing with the new representation. Furthermore, if the new representation proves difficult, this transition can be prolonged.

Design criterion 3: Provide informative and meaningful feedback and create feedback loops. In view of the pedagogical power in feedback loops, as discussed above, a high quality application for early
math must initiate and support such loops. This cannot be accomplished by simple right/wrong-feedback, since such feedback does not scaffold reflective thinking and understanding but encourages trial-and-error behavior. The feedback must instead be such that it provides hints about why and how an answer is right or wrong, and stimulates thinking about how to correct an answer. One way to do this is by using *implication feedback* (Blair, 2013) where each choice made by the child solicits a response of *how* or *why* an answer is correct or incorrect by showing the implications of the choice. It then allows the child to adjust the response to arrive at the correct one.

Notably, Blair’s (2013) review of the 50 top-hits on preschool math apps on App Store revealed that 87% only indicate *right* or *wrong*, and thus scaffold trial-and-error behavior, 7% tell the right answer, and only 6% provide meaningful feedback. Magical Garden is designed to provide meaningful implication feedback. For instance, in the *Bird Hero* mini game, the baby birds can be reunited with their parents by choosing the right level on the tree. If the child chooses a level that is too high, the bird chirps “this is not my parent, I live further down”. In the *Treasure Hunt* game, the correct choice of a representation allows the woodlouse *Grålle* to reach the chest and get the treasure. If the choice is incorrect, he will not get any treasure and will say something like “this is too high”, “this is too low”, “maybe not so many balloons” or “maybe some more balloons” – to encourage the child to add or take away balloons next time. In other words, there is meaningful feedback and scaffolding provided for the child along the process of finding the solution to the task, not just a simple: right/wrong.

**Design criterion 4: Consider what is motivating for the age group.** A high-quality application for early math should be motivating for the target age group and make them want to use it and continue to use it over time. Meaningful feedback and feedback loops as mentioned above works as one motivating factor, for everyone, including young children (Tunsall & Gipps, 1996; Hattie & Timperley, 2007).

Surprises throughout the game is yet another way (Kelle, Klemke & Specht, 2011). In Magical Garden one finds for example the following: some of the flowers and plants that grow in the garden are unusual and magical; the treasures in the *Treasure Hunt* are not always typical treasures; in one of the mini games two little eyes glow in a bush and clicking on them makes a funny creature appear.
Moreover, the use of a narrative suitable for the age group – such as the story about our magical garden – can be an extremely powerful motivator (Rowe, Shores, Mott, & Lester, 2011; Rai, Heffernan, Gobert, & Beck, 2009).

The motivation criterion is especially important for children who are not spontaneously interested in sets, quantities, magnitudes, numbers, and related activities. For this group, framing the activities in a more compelling narrative can be a powerful scaffold to support attention by means of motivation. Ginsburg et al. (2013) propose that narratives and stories need to be integrated with mathematical concepts. This article proposes that an application for early math should also use narratives that are not specifically focused on mathematical content in order not to miss out on motivating children with low spontaneous focus on numerosity.

As previously mentioned the simple and for the target group compelling narrative used in Magical Garden is seemingly detached from math concepts. Yet, each mini game requires use of math skills in order to succeed in a setting where the math skill is naturally meaningful.

Moreover, the use of animal “friends”, each with a unique personality, in need of help is yet another way to capture the interest of different children. Lisetti (2009) shows that children best relate to characters close in age and personality.

**Design criterion 5: Provide individually adapted support as well as challenge.** A high-quality educational application for early math should provide adequate challenges to each individual child by continuously adapting the feedback, tasks, and level of difficulty to that individual child’s progress throughout the application. Incorporating adaptive narratives and levels of adjustment is not only pedagogically beneficial (Lieberman, 2009), but also contributes to flow and intrinsic motivation (Peirce, Conlan, & Wade, 2008). Simpler or more straightforward forms of leveling can be found in many educational applications of today, where a given level contains a set of tasks and when sufficiently many tasks are solved, the next level is unlocked. More advanced adaptivity, however, requires dynamic assessment to be able to tailor the tasks on the basis of each learner’s actions and performance as she plays. The underlying rationale is that there is a large individual variation in any group of children. Some children
need more time with a certain skill than others. With this kind of program, all students’ needs are met and they are allowed to advance at their individual pace.

Such adaptivity is implemented in Magical Garden with an elaborated state machine that follows the progress of the child in order to “recycle” tasks that require more practice and speed through those that are mastered. The logic behind it is that the child who scores well in a pedagogical scenario then moves on to the next pedagogical scenario. Those that do not perform well are presented with the same scenario until the performance improves – but the mini game will vary. If the performance remains low, then the system goes back a level to where the student is more capable before gradually moving up again. From the child’s perspective, there will be variation in the form of different mini games, even if, the pedagogical content is actually the same, making it possible to get repetition without too much monotony. This way, each child is exposed to relevant material for the amount of time it takes for them to learn it. Some children will get a substantial amount of training with a certain kind of task, whereas others quickly leave the same task behind.

**Design criterion 6: Include a reporting function.** Our sixth design criterion is to include a reporting tool for educators to keep track of progress for each individual student as well as for a class or group of children. This kind of data can easily be logged by the system as the children play and then be processed to give educators an indication of children’s progress as well as their strengths and weaknesses. In this way, educators can identify the areas that require more attention, get a sense of what individuals need to do to catch up or where to focus teaching efforts. It can also be used diagnostically to indicate that an individual child may need support from a specialist teacher.

It is crucial that this kind of feature (sometimes called a teacher client) is carefully developed to seamlessly and efficiently present the information of relevance to the educators without suffocating them with and abundance of raw data often presented in teacher clients.

With regard to Magical Garden, this feature is for the moment implemented in a prototype version but will be functionally implemented and evaluated during 2015.

**Design consideration 7: Enable the use of an inclusive pedagogy.** It is often crucial for children to experience that they are able to work with similar things and are not treated differently from others,
especially if they have difficulties (Klingner & Vaughn, 1999). When a student is treated differently from others, there is a risk that she feels marginalized (Florian & Spratt, 2013).

As previously mentioned, it can be proposed a hallmark of high quality when educational software enables inclusive pedagogy, where students, on the one hand get individually adapted support and challenge, but on the other hand, are not singled out as “different” – neither for struggling, nor for being more advanced than other.

Magical Garden caters to inclusive pedagogy in this sense. All children use the same application as opposed to only those who struggle or those who excel. The overall narrative and reward system of water drops in the water jug and the watering of one’s growing garden is the same for all children. Since a random generator directs what starts to grow at the spot that the child chooses to water, the gardens will look different and thus not allow straightforward comparisons on “how far one has got”. The only person who is made aware of the differences in advancement between children is the educator.

This is not to say that competition cannot be used in education to inspire and motivate children, yet the domain of early mathematics is not were to use it. The individual differences in early mathematics skills at the onset of formal schooling are very large -- but many of the preschoolers who are weak in early math do not have any developmental disorder but are low-performers whose difficulties primarily stem from external factors, such as low socio-economic status (Griffin et al., 1994; Jordan et al., 2006; Denton & West, 2002) and little exposure and training at home and at kindergarten. In addition there are large individual variations in the sense that some children are early developers and other late. Comparing performance in early math may therefore have undesired consequences of making some children unjustly feel less capable than their peers and negatively impact their future learning.

It is well established that the belief in one’s own ability in a domain (self-efficacy) has effects on actual performance (Stodolsky, Salk, & Glaessner, 1991). Even though the developmental path of self-efficacy in young children it not well explored it is known that by the age of 7-8 many children have low self-efficacy and may even fear mathematics (McLeod, 1992). A child who early on is misled to believe that she is weak in mathematics, may be hampered in her development because of self-confirming expectations – both self-imposed and from others (Rattan, Good, & Dweck, 2012).
Apart from the criteria listed above, it is important to also consider several factors that are relevant for all educational software aimed at this age group, such as attention to user experience and providing the right amount of feedback and instruction (not too much and not too little) to create flow, which is vital for engagement (Csíkszentmihályi, 1975).

**Discussion and Future Work**

To summarize a set of design criteria that can be used both by designers and teachers to assess the value of educational software have been proposed: (1) base the pedagogical approach on evidence based research on early mathematic learning; (2) exploit a set of relevant representations in an appropriate order; (3) provide informative and meaningful feedback; (4) consider what is motivating for the age group, such as a good narrative, interesting characters, and surprises along the way; (5) provide individually adapted support as well as challenge; (6) include a reporting function for educators; (7) enable the use of an inclusive pedagogy.

Magical Garden was designed with the seven criteria in mind. It is possible, however, that the continued work with Magical Garden, in turn, leads to additional or refined criteria. The reason is the double function of the application: both as a real world pedagogical support for children and teachers and as a research instrument to study learning in young children. Ginsburg et al. (2013) have a similar approach to their educational program *MathemAntics*, stating that it does not only “provide the context for dynamic learning, but the software also supplies the means for studying it” (Ginsburg et al., 2013, p. 114).

There are several features of educational software such as Magical Garden, MathemAntics, and others that make it potentially powerful for studying learning. Instead of only studying the difference between a pre- and post-test with a black box between the two tests, you can follow each action or choice that a learner makes and thus study the learning processes. Furthermore, it provides a possibility to manipulate variables such as feedback format, the timing of feedback, the order of tasks, the inclusion of narratives, the inclusion of different support tools, and so on – and see if learning outcomes differ. In other words, comparative intervention studies can relatively easily be carried out on the basis of large scale data.

It should also be stressed that the logging of actions produce data sets very close to where learning actually takes place without disturbing the natural learning processes in the way observational methods or
think-aloud-methods can do. Yet another main benefit is that the use of educational software as research instruments in preschool does not present the children with anything strange or unfamiliar since the data collection is embedded in everyday pedagogical activities. Preschools are to an increasing extent being equipped with iPads or tablets. Children are often familiar with the technology and touch interaction from home and generally engage and feel at ease. Together this affords high ecological validity in these kinds of studies.

In previous studies Magical Garden has been used as a research instrument to study aspects of cognitive development relating to attention and distractibility (anonymized) and to mentalizing (anonymized). In the near future our intention is to use Magical Garden as a research instrument to learn more and get closer to the developmental process of number sense as a fundamental and crucial concept in early math learning. In turn, this may feed back into expanded and refined design criteria for educational software for early math.
References


