# Chapter 12
# Early Maths Via App Use: Some Insights in the EfEKt Project

**Laura Birklein and Anna Susanne Steinweg**

**Abstract** Nowadays, computer, tablets, and mobile phones are part of everyday life. This leads to an integration of ICT into schools and into curricula. Especially mobile devices are offering new possibilities for kindergarten education. The digital learning environment MaiKe has been developed to foster mathematical competencies in kindergarten. The research study EfEKt evaluates the effects of MaiKe use in different settings. First results of the pilot study are illustrated by insights into two case studies outlining the effects of the digital features offered by the app MaiKe on habits and competencies performed.

**Keywords** Attitudes towards ICT · Casxee studies · Development of competencies · Different settings · Digital learning environment · Early maths approaches · Early maths topics · EfEKt (Effects of an early maths app use on the development of mathematical competencies) · Evaluation · ICT · Intervention · MaiKe (Mathematics in Kindergarten)

## Introduction

Family homes, including those with young children, are usually equipped with different media devices (e.g. Feierabend, Plankenhorn, & Rathgeb, 2013). It is not surprising that an increasing number of specific offers of applications for the younger ones are available online on the software market or at app stores. Most of the apps are alleged to have been developed with a focus on playing and learning, often in connection with each other.

In the context of education and learning in kindergarten, the use of digital media, like tablet apps, is still being controversially discussed in Germany. In addition, the huge number of apps offered on common websites is vast and confusing. Google Play Store, for instance, shows more than 250 results for the search terms 'mathe

L. Birklein · A. S. Steinweg (✉)
University of Bamberg, Mathematics & Computer Science Education, Bamberg, Germany
e-mail: laura.birklein@uni-bamberg.de; anna.steinweg@uni-bamberg.de



C. Benz et al. (eds.), *Mathematics Education in the Early Years*,
https://doi.org/10.1007/978-3-319-78220-1_12

vorschule' (maths preschool[1]). However, a critical view at these applications has to be taken, because quantity must not be confused with quality here (e.g. Krauthausen, 2012). Many of the designs are far from satisfactory from a mathematical and educational perspective (Steinweg, 2016). In order to give a digital playground a special educational value, it is important to consider the respective empirical research findings. Krauthausen (2012) points out that there are very few findings in regard to evaluating mathematical learning apps and programmes.

The EfEKt project presented here wants to evaluate effects on children's mathematical competencies of using one particular maths app (MaiKe) in different settings in kindergarten. Currently, the pilot study has been completed. In this paper, design and main questions of the research study are described, and an exemplary insight in the pilot results is given by example of two case studies in a qualitative approach.

## Theoretical Framework

The EfEKt study is embedded in two different broader theoretical research fields. On the one hand, it focusses on learning via ICT. On the other hand, early mathematical learning in kindergarten and its special approaches and topics frame the project.

One important branch of the theoretical background of the EfEKt project is the question how ICT in general and tablet apps in particular may support and provide learning opportunities. For this purpose, research on fundamental attitudes towards learning with ICT and research studies in the field of ICT use are being considered and the position of our own study outlined.

Hereafter, the second relevant branch in the theoretical framework of the project, which lays in research on approaches and content-related considerations about early mathematics education, will be the focus. Consequently, the position taken in our own study is set out.

### *Fundamental Attitudes Towards Learning with ICT*

Süss et al. (2013) distinguishes three basic attitudes concerning learning with ICT: cultural pessimism, media euphoria, and critical optimism.

The perspective of cultural pessimism has been dominating common public attitudes and discussions time and again throughout the last decades and centuries. Buzzwords like 'trash movies' or 'reading mania' illustrate the negative connotation, which is central to this attitude. Nowadays, representatives of cultural

[1] In this paper preschool indicates no special institution but the last year in kindergarten before the children start school.

pessimism focus especially on so-called screen media, in particular on computer and video games. It is assumed that ICT use endangers the psychosocial development of the adolescent or that it at least cannot contribute anything positive to it. Spitzer (2011), for instance, blames screen media to be the reason for obesity and attention deficits, to cause a drop in performance at school, and to lead to more violence in the real world. In this perspective often no distinction is made between certain kinds of screen media or the specific contents offered by them.

The position on the opposite side of the spectrum is called media euphoria. It has become especially famous in the twenty-first century in regard to screen media, i.e., computer or internet. This perspective focusses solely on the positive effects of new media. For instance, growth of children's competencies is attributed to media use. Potential risks are seldom mentioned or discussed. Beck and Wade (2006), for example, applaud the advantages of the 'gamer generation' especially towards social learning and mutual support behaviour: 'Gamers are surprisingly good at teamwork. They love working together and helping each other' (p. XV).

The attitude called 'critical optimism' is a position located between both extremes. So-called secondary experiences via ICT use are regarded as a valuable supplement of primary experiences in the real world, but not as compensation. Moreover, researchers in this approach differentiate between different kinds of media and their specific pros and cons. They also consider the content provided by ICT in evaluative studies. Krauthausen and Lorenz (2008) point out that ICT can be useful in teaching-learning situations. Using digital learning environments, for example, may be a valuable complement in mathematic classroom lessons. However, the digital tool cannot completely replace the interaction with professional teachers and the organization of learning situations through them. Furthermore, Neuß (2013) emphasises that learning support via ICT use depends on quite a few variables. Successful support correlates at least with the quality of the software, the pedagogical involvement, and the individual, additional support by educators. The approach of the EfEKt project presented here is based on the principles of critical optimism.

## *Some Research Studies on Learning with ICT*

Herzig (2014) identifies a research desideratum from the perspective of media education. Researchers often get carried away in theoretical discourses on whether the use of tablets in class has more value than working with traditional concepts. Research studies should focus on evolving teaching and learning scenarios and analyse evidence-based output instead. Empirical research studies show that ICT environments do not always have immediate effects on learning outcomes, but new possibilities and potentials may be opened up, if the use is based on a sound educational and professional concept (e.g. Kerres, 2003).

Different key issues regarding the use of ICT in early mathematics education are addressed in a great amount of current research studies. Some references exemplify the wide range of foci: Pilner Blair (2013) evaluates different kinds of feedback in a freely available iPad app for preschoolers. Lembrér and Meaney (2016) as well as Ladel and Kortenkamp (2013) focus on opportunities offered by interactive tables. Zaranis, Kalogiannakis, and Papadakis (2013) designed applications for kindergarten classrooms based on the concept of realistic mathematics education (RME). The activities are evaluated in relation to ‘their integrity and educational use compared to the traditional method of teaching’ (Zaranis et al., 2013, p. 6). Krauthausen (2012) addresses the issue of mathematical content offered by digital media. He urges experts and researchers to take a clear position in regard to topics and contents used in the digital media while evaluating programmes and software.

The EfEKt project works in line with Herzig (2014) who asks for evaluation studies with regard to potential effects on the development of the mathematical skills of the children. The app at the heart of the project is purposefully designed, and content provided in the app is carefully chosen in regard to the latest research findings in early mathematics focussed on below.

## *Early Mathematics Education: Approaches*

Different approaches are possible to encourage children to think mathematically and to support their competencies. One approach can be identified as programmed learning. In this approach, especially conceived training programmes mostly aim to support specific mathematical competencies. They often focus on practicing skills separately. Because of their highly fixed structure, they usually provide exactly the same learning programme for all participating children (e.g. Gasteiger, 2010). Famous examples of this kind and frequently used training programmes in Germany are ‘Entdeckungen im Entenland’ [discoveries in duck land] by Preiß (2007), ‘Komm mit ins Zahlenland’ [Come to number land] by Friedrich et al. (2011), or ‘Mengen, zählen, Zahlen’ [Quantities, counting, numbers] by Krajewski, Nieding, and Schneider (2007).

In contrast, another approach to support early mathematics assumes potential in everyday situations. Mathematical learning opportunities are provided through everyday life and play situations (e.g. Gasteiger, 2014). In such situations, purposeful impulses and suggestions to communicate about the objects and situations can support mathematical learning. It is challenging for educators to recognise such situations and to use them productively (e.g. Benz, 2016; Ginsburg, Lee, & Boyd, 2008). Communication processes contribute to independent problem-solving competencies and support the development of transferable knowledge. Furthermore, it is supportive and important to offer mathematically rich activities on purpose (e.g. Ginsburg & Ertle, 2008). A large number of research projects underpin the potential of playful learning environments for the development of mathematical competencies, especially in preschool (e.g. Benz, Peter-Koop, & Grüßing, 2014).

Despite the positive effects of different forms of play situations described in the research findings, continually systematic training programmes including strictly prescribed educator-child interactions are being developed still (Gasteiger, 2010).

In German kindergarten practice, unfortunately, these trainings are popular and widely used. One reason for this popularity lies in the missing mathematical education of kindergarten educators (e.g. Steinweg, 2016) and their therefore naive attempt to do the right thing. According to Benz et al. (2014), concepts, which focus on motivational processes and exploit daily learning opportunities, have greater potential for learning success than solely cognitive-oriented and regimented offers.

The app MaiKe, used in the EfEKT project, is understood as an enrichment of play and learning situations in kindergarten. Although the app is a digital learning environment, it is not meant to contribute a programmed approach but offers virtual opportunities to meet mathematical challenges and tasks in play situations.

## *Early Mathematics Education: Topics and Contents*

A useful and early mathematical support should be based on key competencies of mathematics, because first basic skills and ideas found the basis for further development in school mathematics. Key competencies of school mathematics are one possible orientation while choosing specific topics for early mathematics to support solid evolvement in school. Consequently, the German standards for mathematics education in primary school (KMK, 2004) are suitable as one starting point to consider kindergarten topics and contents in order to take connectivity into account (e.g. Benz et al., 2014).

German maths standards list topics in the fields of

Numbers and operations
Space and shape
Patterns and structure
Quantities and measurement
Data and probabilities

Of course, there is no worldwide agreed maths topic catalogue neither for kindergarten nor primary school. Nevertheless, most of the proposals overlap. Even if headings differ, in the end they describe nearly the same contents and topics (e.g. Lorenz, 2012). In literature, a wide range of topic lists for early mathematics education can be found, which are vastly corresponding to the topic lists for primary education (Brownell, Chen, & Ginet, 2014; Montague-Smith, 2002; NAEYC & NCTM, 2010; Sarama & Clements, 2009; Steinweg, 2008; Wittmann & Müller, 2009).

Special attention should be paid to predictive competencies, which have empirically proven impact on performance in the first and the second grade of primary school. Dornheim (2008) identifies the following competencies to be predictive: counting; simultaneous perception (subitising); flexible counting; part-whole relations, e.g. first additions; one-to-one relation; seriation; and certain knowledge about digits. If starting early with supporting the competencies, elements of spatial awareness like redrawing, bilateral symmetry, or pattern are predictive as well.

The design of the app MaiKe, which will be evaluated within this research study, is oriented on fundamental mathematical ideas and essential competencies for early mathematics (Steinweg, 2016; Steinweg & Weth, 2014). Especially predicative competencies, such as those outlined above, which influence performance in the first grades of primary school, are considered (Dornheim, 2008; NAEYC & NCTM, 2010; Steinweg, 2008; Wittmann & Müller, 2009).

The app MaiKe intends to enrich the mathematical learning environment in kindergarten alongside nondigital play materials. The app itself can be provided for free play. All app tasks can be used as suggestions to play the offered ideas with real-world materials, too. Moreover, the app provides a basis for rich mathematical conversations and impulses, if kindergarten educators or parents play together with the children. Benz et al. (2014) note that children benefit from a targeted use of selected board games and mathematical educational games. This is in particular the case, if they are supported by intensive verbal and content-related communication by an adult person.

## The EfEKT Project

The EfEKt project (Effekte durch den Einsatz einer App zur mathematischen Frühförderung auf die Entwicklung mathematischer Kompetenzen) evaluates effects of implementing the early maths app MaiKe (http://sw-software.net/; Steinweg, 2016) in different settings in kindergarten.

The MaiKe app design tries to allow both keeping a playful character and encountering fundamental ideas of mathematics (e.g. Steinweg, 2007) or 'big ideas of mathematics' (NAEYC & NCTM, 2010; Sarama & Clements, 2009). The mathematical topics are framed and embedded in an enriched digital learning environment, to initiate specifically and systematically young children's mathematical thinking and learning processes.

Van Oers (2014) notes that 'it is clear that both creative construction and sensitive instruction are necessary elements for a developmentally productive organization of play and the development of mathematical thinking' (p. 121). The EfEKt project aims for empirical evidence of in what sense the balance of construction and instruction is effective in the special case of playing an app. For this purpose, the implementation of the maths app MaiKe will be evaluated in different settings in kindergarten.

### *Research Questions*

The main EfEKt project research questions, derived from the theoretical reflections considering the current state of research outlined above, are as follows:

1. Will there be effects on the development of mathematical competencies of children who use the app MaiKe compared to a control group?
2. Will there be effects due to the setting in which the app MaiKe is offered on the development of mathematical competencies of children?
3. Which thinking and learning processes can be identified while using the app MaiKe in regard to certain competencies?
4. Do the digital features of the app MaiKe evoke any particular behaviour?

The first two questions lead to quantitative research methods and hypotheses to be tested. The third and fourth questions require a qualitative approach.

## *Methodology and Design*

The EfEKt project aims to evaluate if playing the app MaiKe has any effects on the mathematical competencies of children (question 1). Hence, effects on the learning process and competencies have to be tested by quantitative methods prior and past the intervention phase. For the study, a pre- and post-test design with experimental and control group is used (e.g. Bortz & Döring, 2009). Children in the control group receive no special support apart from the usual kindergarten's daily activities (Fig. 12.1).

As a basis for the pre- and post-test, a school entry test is adapted and extended. As a typical school entry test, it focusses on fundamental mathematical competencies (see above). The realization of the test is adapted to preschool conditions. The test consists of two parts. The first part, a paper-pencil test, is carried out with two children simultaneously. The instruction is given verbally. The second part is a personal interview with each child individually, in order to test verbal counting skills, etc. The test also includes working with manipulatives and material to investigate

| **experimental group** | | **control group** |
|---|---|---|
| pretest | | |
| setting A | setting B | no intervention |
| posttest | | |

| ***MaiKe* available for free use** | ***MaiKe* with personal attendance** |
|---|---|
| Organisation by the kindergarten | Regular play sessions |
| Observation sheets | Guided interview (video recording) |
| Log files | Log files |

**Fig. 12.1** Design of the EfEKt project

various predictive competencies. For instance, printed images of fingers or structured black dots, e.g. like on a dice, are used to determine the ability to perceive quantities simultaneously (conceptual subitising), first arithmetic operations are posed by image stories or with the aid of little cubes or counters, which can be covered under a hand, children are asked to place number cards (from zero to ten) in the correct order, and so forth.

In order to discover whether different settings have an effect on the development of mathematical competencies, the implementation of the app MaiKe takes place in two different settings (A and B) supplemented by a control group (question 2). In setting A MaiKe is made available in the kindergartens for free play. In contrast, regular play sessions organised and participated by the researcher take place in setting B. While playing together and interacting with the children, a deeper insight into their thinking processes and their reactions and behaviour during the play sessions is possible.

Additionally to the pre- and post-tests, log files automatically written by the app provide insight into the use of the app within the intervention phase. Each participant has got their own account for using the app. In this way, it is possible to back up the game progress and to create individual log files. The files document start and end time of each game, the percentages of correct swiping actions and trial-and-error-attempts, and the duration of the time played. The log file data is only available for the researcher and not for children, parents, or kindergarten educators.

In setting A the free use of the app MaiKe excludes the researcher from direct interaction and observation. Hence, observation sheets about each participating child are regularly filled in by the educators. The documentation includes notes about the playing behaviour of the child. The educators note, for example, how self-reliant the children play, if and when adult assistance is needed, or if and when children talk about the app contents with educators or other children.

The researcher-child interaction in setting B is recorded by video and documented in transcripts. The interaction is structured by the individual progress playing the app as well as especially designed interview questions (guided interview). Specific topics are chosen, and standardised questions are theory-based and designed in order to enable comparison between individual reactions and answers of the participating children given in the interviews (question 3). To illustrate this idea, one example (concerning the cardinality of numbers) is given in the following paragraphs.

One of the MaiKe app games shows fields of ten with different amounts of black dots on the left. These are presented in a structured representation regarding the power of five (Krauthausen, 1995). This means the standard representation fills in the first row of five dots before colouring dots in the second row (6 = 5 + 1, etc.). The dot fields in the movable area have to be matched to an egg carton on the right. In this specific game, the eggs are filled in, unstructured, in the carton (Fig. 12.2). Structured and unstructured representations of the same amount of dots or eggs therefore have to be compared. Although the representation in the egg carton is labelled as unstructured in this context, it should be mentioned that the children have the option to use and see individual structures (e.g. Benz et al. 2014).

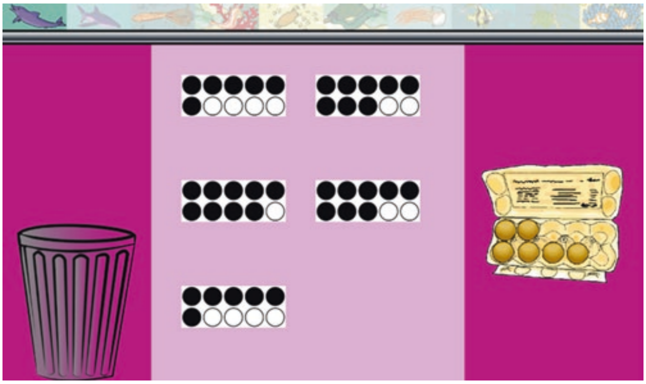


**Fig. 12.2** Exemplary app game concerning the cardinality of numbers

The example in Fig. 12.2 shows two different possibilities to represent a quantity of six, which have to be matched. Whether and how a structure is perceived in one of these representations may vary considerably between the children. This perception may also change over time due to increased experience or due to the task's demands and size of the quantity presented.

The corresponding interview questions focus on special learning opportunities offered in each specific game. While playing the game described above without commenting or thinking aloud, it is not clear, if a perceived structure is actually used to determine the quantity. Consequently, each child is asked to answer the same following question: 'Where can you see faster how many there are?' The interviewer is correspondingly pointing at the black dots and the egg cartoons while posing the question.

Depending on the child's answer, additional questions allow a deeper insight into his or her thoughts, e.g. 'Why can you see it better here?' Thus, it is possible to get some indication, whether or not the individual child perceives the structure of the representations at all and if he or she uses the structure to determine the quantities.

Similar games throughout the whole app allow the pursuing of possible developments, in this case concerning the identification of quantities.

The digital environment provides features impossible in real-world environments. These features may evoke special behaviours (question 4) to be found in a qualitative analysis of case studies. Exemplary results of two case studies, which illustrate the scope of this research question, are presented below in this paper.

## *Pilot Study*

The pilot study has already been carried out. As a matter of course, a pilot study aims for testing the used methods (test, interview questions, structure, and chosen topics). The hope is that the results provide information for improvements concerning design and methodology for the main study. The pilot study uses case studies without a control group in a qualitative approach.

The intervention phase of the pilot was scheduled from October to December, which allows a focus on participating children almost a year before they commence primary school. The participants attended two different kindergartens. Four children participated in setting A. For these children the tablets with the MaiKe app have been available for free play throughout the intervention period. Four children of another kindergarten participated in setting B. Weekly play sessions with the researcher and interviews took place. The intervention phase was framed by the pre- and post-test.

The analysis of interviews indicates that particular digital features of the play environment, like special forms of presentation, have special effects on the children's behaviour (research question 4, see above). Hence, besides the general and concurrent aim of pilot studies (testing the design), two particularities evolved in the analysis of the cases concerning

- Differences in competencies performed in the test vs. the digital environment
- Particular habits exploiting digital features

These two remarkable points are a clear focus in each in the cases of Sarah and Karin.

## Some Results in the Cases of Sarah and Karin

In this paper, insight in the pilot study is exemplarily given by the cases of Sarah (4 years 10 months) and Karin (6 years 1 month). Nine months after the intervention, they will be starting school. Both participated in the setting B group. Thus, they were taking part in regular play sessions with the researcher.

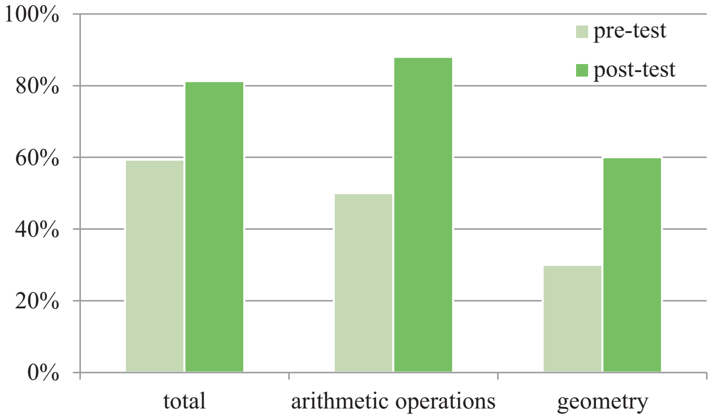
In Sarah's case, the differences in competencies performed in the paper-pencil environment versus the competencies shown in playing the app are striking. Two topic areas are picked out for a more detailed examination regarding the development of her mathematical competencies and her learning process and progress.

The case of Karin illustrates peculiar experiences and habits while playing the app and answering the interview questions. Her handling utilising special opportunities offered by the app is outlined and illustrated by exemplary transcripts.

### *Sarah's Case*

Before considering individual sections and exemplary games in detail, the results of Sarah's pre- and post-test can provide a first impression about the development of her competencies (Table 12.1).

**Table 12.1** Sarah's results prior and post the intervention



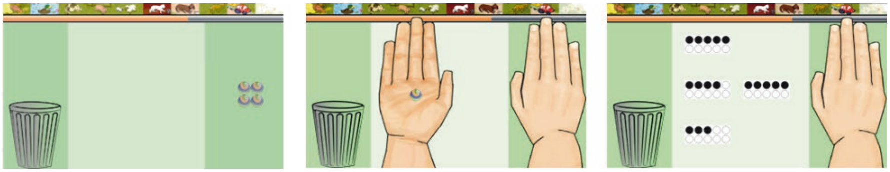



**Fig. 12.3** Covered addition (4 + 1)

Her competencies in the pretest are already fairly high. She solves 59% of the tasks in total. After the intervention the post-test results indicate an increase by 22 percentages points. Sarah is now able to solve 81% of the tasks correctly.

The development in the overall outcome indicates some learning progress. A more detailed analysis concerning content fields shows that the development of Sarah's competencies is especially pronounced and remarkable in two topic areas (Table 12.1).

The topic areas arithmetic operations and geometry examined in the test correspond to certain games in the app MaiKe. These games focus on the part-whole concept, addition, and subtraction in the field of arithmetic operations. In geometry, they require competencies in symmetry, composing shapes, and spatial orientation. For some deeper insight into Sarah's reactions and possible explanations of her progress, first a closer look at *arithmetic operation* is taken.

The addition and subtraction games are designed as so-called covered operations, which have been invented by Spiegel (1992). First, one addend is shown (as a certain amount of marbles) and then covered by a hand (Fig. 12.3). The other hand adds zero to three further marbles. After all the marbles are hidden under the hand, fields of ten with various numbers of black dots are shown. The field of ten, for which the number of black dots corresponds to the amount of marbles under the hand, matches the hand.

Sarah participated in the interviews in setting B. By analysing sections from these interviews, it is possible to trace some of her thoughts and learning processes during her gameplay. In this paper, attention will be drawn to the two topic areas, in which her competencies significantly changed from pre- to post-test (Table 12.1). The following transcript (translated by the authors) describes Sarah's statements and actions during her first encounter with the game covered addition. App actions seen on the screen are indicated by A (app).

| | | |
|---|---|---|
| 1 | A | *Four marbles are shown.* |
| 2 | S | Four. |
| 3 | A | *The four marbles are covered by a hand, and a second hand adds one marble.* |
| 4 | S | And one to it. |
| 5 | I | Mhm. |
| 6 | A | *Fields of ten are shown.* |
| 7 | S | (*5 s pause)*<br>Huh? (*Assigns the field of ten with five black dots. Swipes non-fitting fields to the recycling bin.)* |
| 8 | I | Very good. |
| 9 | A | *Two marbles are shown.* |
| 10 | S | Two. |
| 11 | A | *The two marbles are covered by a hand, and a second hand adds three marbles.* |
| 12 | S | *(Tries to assign the field of ten with four black dots, five times. Questioning gesture.)* Four? |
| 13 | I | You can watch it once again. |
| 14 | S | (*Clicks on the digital image of the hand on the screen.)* |
| 15 | A | *The animation (two marbles, two covered, three added) is repeated.* |
| 16 | S | (*Shows two fingers under the table.)* |
| 17 | I | You can go ahead and do it with your hand. |
| 18 | S | *(Raises two fingers at once. Adds then three times one on the same hand until five fingers are raised. Assigns the field of ten with five black dots.)* |

While the animation is running, Sarah comments on the action (#2 and #4). Thereby she names the amount of the four marbles without hesitation, which indicates that she likely did not count them. Her first correct assignment suggests that she is mastering the task (#7). The next task (2 + 3) challenges Sarah. She tries to assign the wrong field of ten several times (#12). The interviewer encourages Sarah to watch the animation once again (#13). After watching the animation a second time, Sarah uses her fingers hidden under the table (#16). The interviewer invites her to openly show her finger operations (#17). Sarah uses two fingers as starting position and counts on by raising another three fingers one after the other, until she reaches five fingers (#18).

**Fig. 12.4** Exemplary app games concerning geometry

Finger use can be observed in this game only two times out of six tasks (3 + 2 and 2 + 3). If one addend is 1, the sum can be determined by identifying the successor. Likewise, counting strategies are leading to the desired result quickly. Possibly, the relation between predecessor and successor (ordinal number aspect) may be anchored as factual knowledge. The tasks, where Sarah uses her fingers, need a mediator (fingers) to determine the sum by counting-on strategies. However, if the sum is being worked out, no counting processes can be observed, while the correct field of ten is assigned promptly. The immediate assignment indicates that Sarah is able to match the five dots in the field of ten with five as a finger number (#18).

Finishing a game is rewarded by a progressively completing illustration as in a jigsaw puzzle in the starting screens. Because of the relatively high trial-and-error rate in this first round, the reward picture of this particular game is not fully coloured. Sarah therefore starts a second round. This time, she uses her fingers implemental while solving three tasks (3 + 2, 3 + 1, 2 + 3). For solving the task 4 + 1, she decided to watch the animation a second time via tapping on the image of the hand.

In the EfEKt project, playing the MaiKe app with or without interaction with the researcher is accompanied by recording background data in log files. These files offer quantitative data which can be compared to the qualitative data and validate or indicate similar findings. Overall, Sarah's solution rate in the covered addition game increases from 30% in the first round to 75% in the second round. This becomes visible in the log files documented by the app. In the first round, Sarah needs 5:17 min to solve the six addition tasks. In the second round the time is nearly halved (2:39 min).

During the game session a week later, Sarah is playing the game on covered subtraction. In this first subtraction game, the amount of the marbles covered by the hand first (minuend) is not more than four. Then, the second hand takes zero to four marbles away (subtrahend). Sarah solves these eight tasks in 3:34 min with a solution rate of 85%. She is not using her fingers at any time.

As mentioned above, the second content area in which Sarah's progress is remarkable is *geometry*. In the topic field geometry, games on symmetry, composing shapes, and spatial orientation (Fig. 12.4) are presented.

The analysis of Sarah's test answers and her behaviour and success playing the game reveal one striking point in her case: Although Sarah scores low on spatial orientation and geometry tasks in the pretest, the log file data from the corresponding games in this specific topic show high solution rates between 84% and 100% often even combined with fast processing. Sarah solves especially the symmetry games with an above average speed. The time required for the other games can be classified as average.

During the post-test, Sarah shows higher competencies in geometry (increase by 30 percentage points now to 60%). She solves the tasks focussed on symmetry correctly for the first time. She still has difficulties to assign building blocks to a given construction in the post-test, although she masters the matching app game very well with a solution rate of 84%.

### *Karin's Case*

As mentioned above, Karin also participated in setting B and, therefore, in the interviews during the pilot study. She is already 6 years old at the beginning of the study and scored quite well in the pretest (86.6%). Although, her scores in the post-test increase to 94%. The particularity in Karin's case is her handling of the digital features of MaiKe.

The following interview (translated by the authors) portrays her reaction to a part-whole-relation game in the app MaiKe. In this game a certain amount of black dots in a row (whole) and another amount of red dots (part) in the second row below is given. The parts are framed, and the whole amount is shadowed in grey. The part pieces appear as if they have been cut (straight line on one side of the frame) to underline the fragment characteristic. Potential matching parts are presented in the moveable area (Fig. 12.5).

1 A *First row with five black dots (whole) and second row two red dots (part).*
2 K Funny, how should this work? No clue. (*Swipes a four dot part to the gap.*) Like this?
3 I Aha, good.
4| K (*Swipes the second four dot part towards the bin.*) Recycling bin? Ah. (*Lifts her finger.*)
5| A *The first four dot part is faded out, and the gap is empty again.*
6 K Huh? Where is that again?
7 I That matched. Now you can have a look, if another one matches.
8 K That there? *(Swipes the second four dot part to the gap.*) Yes, fits.
(*Tries to swipe a three dot part several times to the gap*) Does this match?
9 A *The three dot part bounces back.*
10 K No. (*Tries to swipe a different three dot part to the gap.*)
11 A *The three dot part bounces back.*
12 K Anything has to match still. (*Tries again to swipe the three dot part to the gap.*) Then, into the bin. (*Swipes both three dot parts to the recycling bin.*)

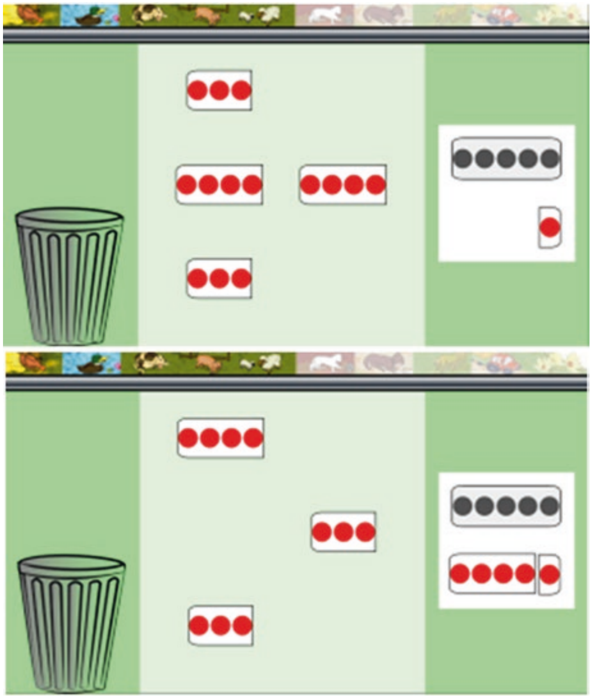


**Fig. 12.5** Part-part-whole app game

In Karin's first encounter with this game, she expresses her lack of knowledge (#2) but finds a matching part nevertheless. It is unclear, whether this first match is found accidentally, because she tries to swipe the second fitting part to the recycling bin first (#4). She feels uncertain doing so, which is indicated by her question, her interjection, and the fact that she does not finish her assignment but lifts her finger again (#4). She, therefore, takes advantage of the digital learning environment which allows tentative and uncertain trials without any consequences, if the swiping process is not finished.

In synch, the animation fades out the first correct match, to offer the gap again for possible other correct objects (#5). This function is irritating Karin (#6) and is being explained by the interviewer (#7). Now it looks like Karin has understood the game, and she assigns the second fitting part (#8). But again, she is unsure and tries to assign a non-matching three dot part several times (#8–#11), before she gives up and decided to swipe the last two parts to the bin (#12). To summarise her first solving strategy, she finds correct answers by trial and error.

While playing the second task, the interviewer gives impulses by posing questions. Karin solves the other four following tasks in this first round independently and without any problems. The following interview transcript shows one of these four tasks:

13 A *First row with three black dots (whole) and second row with two red dot (part).*

14 K *(Swipes a one dot part next to the two dot part.)* One more can fit, I keep this. *(Swipes the other two and three dot parts into the recycling bin. Swipes the second one dot part next to the two dot part.)* Exactly!

This short transcript shows furthermore that Karin is able to change between the different possibilities of swiping. First, she swipes one of the two correct parts to the right side. She spots the second correct part immediately but decides to 'keep this' and to swipe the non-fitting parts into the recycling bin before she matches the remaining one to the right side, too (#14). This scene indicates that she is handling the opportunities of swiping flexibly and confident.

Karin plays this game a second time. The following transcribed part shows that she is now using even more extensive opportunities, the digital playground offers.

15 A *First row with five black dots (whole) and second row with one red dot (part).*

16 K Five. *(4 s pause)*
Need to be actually four more, or what? *(Swipes a four dot part next to the one dot part but she does not lift the finger to finally place it there.)*
Are they? 1, 2, 3, 4, 5. Yes*! (She lifts the finger to fix the part.)*

17 I Yes, this fits. Good.

18 K *(Swipes the non-fitting parts into the recycling bin and identifies another four dot part.)*
And that may fit, too. (*Assigns the part.) Five, again. (And lifts her finger immediately.)*

At the beginning of this scene, Karin presumes that the four dots are fitting next to the one dot part, but she is not entirely convinced. This becomes evident because she swipes the four dot part next to the one dot part without releasing it finally (#16). The app makes it possible to move the dot parts, which are placed in the middle, anywhere on the screen. Only when releasing through lifting the finger or the pen, the dot part is either fitting or bouncing back to the original position in the middle of the screen. Holding the parts next to each other, without releasing her finger, gives Karin the opportunity to check her presumption by counting the dots of both parts (#16). Reaching five by counting, her presumption is confirmed. Therefore, she lifts her finger now (#16). After swiping the non-fitting parts into the recycling bin, she identifies the second four dot part. She considers this one a suitable solution, too. She assigns the four dot part next to the one dot part. This time, she recognises the amount of the five immediately and lifts her finger (#18). At this, she does not need to count anymore to assure herself.

The log files of this game show a solution rate of 84% for Karin's first round. Her few mistakes mainly result from her trial-and-error strategy in solving the first task (see above). In the second round, she exploits the possibility of the digital learning environment, e.g. by swiping the movable dot part next to the given ones in order to check her intuitive attempt. She is verifying her presumption by using a counting strategy to gain confidence. Afterwards she does not use any tentative or counting strategy. The solution rate of 100% in this second round of playing validates the process data identified in the transcripts. The period of time, Karin needs to solve all tasks in this game dropped by one third; first she needs 3 min and in the second go 2 min. This quantitative data can be interpreted as another indicator of her growing mastery.

## Discussion

The case of Sarah indicates some substantial difference between the abilities and competencies shown in the test versus the digital play environment. One possible explanation for the diverging results might be the forms of presentation, which have to be interpreted differently by the children in the paper-pencil test and in the digital playground MaiKe. In the first case, immobile printed images (building blocks, mirror images, etc.) expect mental rotation and reconstruction. By contrast, the app provides animated representations and allows concrete (though virtual) actions. For example, building blocks can virtually be moved, or line patterns in a matrix are actually drawn by the app, so that the children can imitate this action directly.

The app offers opportunities a paper-pencil learning environment does not. The meaning of movability of the elements and the explicit option to tentatively match objects is a special value of the digital learning environment. To have a whack at solving the task is not considered makeshift, but a possibility and customary way of behaviour in gaming situations. The case of Karin reveals and exemplifies these opportunities in the part-whole game.

Fixed and, therefore, immobile printed images in a paper-pencil learning environment do not allow movable features exploited by Karin. The same task would require more mental activity and mental moving of the representations. Furthermore, the children do not have the chance to check their presumptions in a real-world environment without any consequences, like Karin.

Of course, it is conceivable to create a task like this with real-world materials like cube strings or something like that. In principle, all of the app tasks can be used as suggestions to pose analogue tasks with real-world materials. Working with manipulatives and real-world materials usually requires support by an adult. In the part-whole relation example, the cubes have to be placed in suitable rows. If this silent impulse is not sufficient, only a question posed by the educator or parent can initiate the problem-solving. To find a solution, the child then has the option to change the position of the cubes presented or add other ones. In contrast to the digital environment, the attempts to find missing parts mainly depend on counting processes because cubes and other manipulatives are usually presented in units. The app allows and asks for more sophisticated approaches like simultaneous perception.

The materials sometimes enable the children to check their solutions self-reliantly. If the task demands to compare parts and the whole, the parts can be placed beneath the given whole and be compared by length. Though, this elaborate idea does not come to every child. Thus, often support by educator feedback is needed or demanded by the children. The automatic feedback of the app can, therefore, be regarded as another special feature of the digital playground. At least a distinction between correct and incorrect solutions is made by the app directly. Children do not take offence at the digital feedback and are not intimidated at all. On the contrary, they try another solution or a wrong solution again and again, as long as it takes them to figure out the mathematical relation and the correct interpretation of the task. One may object that this feature encourages children to stick to trial-and-error strategies. Our findings – like in Karin's case – dissent this fear. Karin needs the trial-and-error phase to become confident in the task's demands and overcome it quite fast in the second attempt. Of course, for a more detailed response and individual support during the learning process, adult assistance is useful while playing the app as well.

In summary, the pilot study indicates that the interviews, like in Sarah's and Karin's case, allow interesting insights into thoughts and learning processes in a qualitative way. The findings can be compared and related to quantitative data gained by the test results and the individual log files, especially concerning solution rate and duration of time playing a certain game, as exemplarily shown above.

The participating children benefit from playing the app and their mathematical competencies increased. The pilot study implies that the competencies performed in the app are even higher than the ones shown in tests in some cases. Of course, the results are only first indications and tentative. Deeper insight into the effects and evidence for dependencies of results will only be made possible by the main study.

Furthermore, the pilot study expertise leads to important implications for the main study design regarding:

Sample size
Age of the children
Tasks used in the tests
Interview impulses and focus

The experiences gained during the pilot study allow a sound estimation regarding the possible amount of participants manageable in the main study. The sample, of course, will be extended. Sixty-six children from six different kindergartens will participate. The design of settings A and B will be maintained. The main study will be complemented by a control group, which enables reliable interpretation of effects as well as attribution to the intervention.

Additionally, the chosen sample will be widened with respect to the age of the children participating in the main study. The pilot study indicated that several of the preschool children master the pretest – which is a school entry test – already quite successfully. Likewise, the app tasks are worked on with ease and very well by some. Hence, younger children (aged 4–5 years), who's school start is going to be 1.5 years ahead, will be included in the main sample.

The preschool children, who constitute half of the sample, participate for half a year, before the post-test is taking place shortly before they start school. The younger children participate 1.5 years in the intervention. During this period, one intermediate test is taking place half a year before the children's school entry. This intermediate test makes it possible to compare the results with the results of the preschool group. Both groups consist of children of the same age and utmost equal experiences in the same kindergarten but different experiences concerning the app. Finally, the post-test is carried out shortly before their school beginning, too.

The questions and tasks used in the pre- and post-test are improved and complemented by some further tasks for the main study in order to receive additional information on specific competencies. Moreover, the guideline for the interviews in setting B is elaborated and refined. In particular the guidelines and impulses are focussed on two specific topics rather than broaching the issue of every possible topic sketchily. Because of the longer intervention period over 1.5 years, regular meetings with the educators in the setting A kindergartens are scheduled. This allows for maintaining an overview of the progress playing the MaiKe app, e.g. by checking the log files. Furthermore, it enables the researchers to present an intermediate result to the educators to keep them informed about the current game status of their children.

The adaptations have been worked on and the design of the main study has been completed. The pretests were actually already carried out in spring 2016. At the moment, the intervention phase in the two different settings is currently running.

## References


Beck, J. C., & Wade, M. (2006). *The kids are alright. How the gamer generation is changing the workplace*. Boston: Harvard Business School.

Benz, C., Peter-Koop, A., & Grüßing, M. (2014). *Frühe mathematische Bildung [Early mathematics education]*. Heidelberg, Germany: Springer.

Benz, C. (2014). Identifying quantities—Children's constructions to compose collections from parts or decompose collections into parts. In U. Kortenkamp et al. (Eds.), *Early mathematics learning – selected papers of the POEM 2012 conference* (pp. 189–203). Heidelberg, Germany: Springer.

Benz, C. (2016). Reflection: An opportunity to address different aspects of professional competencies in mathematics education. In T. Meaney et al. (Eds.), *Mathematics education in the early years – results from the POEM2 conference* (Vol. 2014, pp. 419–435). Heidelberg, Germany: Springer.

Bortz, J., & Döring, N. (2009). *Forschungsmethoden und Evaluation: Für Human- und Sozialwissenschaftler [Research methods and evaluation: For human- and social scientists]*. Heidelberg, Germany: Springer-Medizin-Verlag.

Brownell, J., Chen, J.-Q., & Ginet, L. (2014). *Big ideas of early mathematics: What teachers of young children need to know*. Boston: Pearson.

Dornheim, D. (2008). *Prädiktion von Rechenleistung und Rechenschwäche [Prediction of numeracy competence and numeracy difficulty]*. Berlin, Germany: Logos.

Feierabend, S., Plankenhorn, T. & Rathgeb, T. (2013). *miniKIM* 2012*: Kleinkinder und Medien* [miniKIM 2012: Young children and media]. http://www.mpfs.de/fileadmin/miniKIM/2012/PDF/miniKIM12.pdf. Accessed 05 Sept 2016.

Friedrich, G., Galgóczy-Mécher, V., & Schindelhauer, B. (2011). *Komm mit ins Zahlenland [Let's visit Numberland]*. Freiburg, Germany: Herde.
Gasteiger, H. (2010). *Elementare mathematische Bildung im Alltag der Kindertagesstätte [Elementary mathematics education in daily routine kindergarten]*. Münster, Germany: Waxmann.
Gasteiger, H. (2014). Professionalization of early childhood educators with a focus on natural learning situations and individual development of mathematical competencies: Results from an evaluation study. In U. Kortenkamp et al. (Eds.), *Early mathematics learning - selected papers of the POEM 2012 conference* (pp. 275–290). Heidelberg, Germany: Springer.
Ginsburg, H. P., & Ertle, B. (2008). Knowing the mathematics in early childhood mathematics. In O. N. Saracho & B. Spodek (Eds.), *Contemporary perspectives on mathematics in early childhood education* (pp. 45–66). Charlotte¸ North Carolina: Information Age Publishing.
Ginsburg, H. P., Lee, J. S., & Boyd, J. S. (2008). Mathematics education for young children: What it is and how to promote it. *Social Policy Report: Giving Child and Youth Development Knowledge Away, 22*(1), 3–22. http://files.eric.ed.gov/fulltext/ED521700.pdf. Accessed 05 Sept 2016.
Herzig, B. (2014). *Wie wirksam sind digitale Medien im Unterricht?* [How effective are digital media in class?]. Im Auftrag der Bertelsmann Stiftung. https://www.bertelsmann-stiftung.de/fileadmin/files/BSt/Presse/imported/downloads/xcms_bst_dms_40521__2.pdf. Accessed 05 Sept 2016.
Kerres, M. (2003). Wirkungen und Wirksamkeit neuer Medien in der Bildung [Effects and effectiveness of new media in education]. In K.-S. Reinhard (Ed.), *Wirkungen und Wirksamkeit neuer Medien in der Bildung* (pp. 31–44). Münster, Germany: Waxmann.
KMK [Kultusministerkonferenz]. (2004). *Bildungsstandards im Fach Mathematik für den Primarbereich [Education standards in mathematics for primary school]*. München, Germany: Wolters Kluwer.
Krajewski, K., Nieding, G., & Schneider, W. (2007). *Mengen, zählen, Zahlen [Quantities, counting, numbers]*. Berlin, Germany: Cornelsen.
Krauthausen, G. (1995). Die „'Kraft der Fünf' und das denkende Rechnen [The 'power of five' and thoughtful numeracy]. In G. Müller & E. Wittmann (Eds.), *Mit Kindern rechnen* (pp. 87–108). Frankfurt, Germany: Grundschulverband e.V.
Krauthausen, G. (2012). *Digitale Medien im Mathematikunterricht der Grundschule [Digitale media in primary school mathematics education]*. Heidelberg, Germany: Springer Spektrum.
Krauthausen, G., & Lorenz, J. H. (2008). Computereinsatz im Mathematikunterricht [Computer use in maths classes]. In G. Walther (Ed.), *Bildungsstandards für die Grundschule: Mathematik konkret*. Berlin, Germany: Cornelsen Scriptor.
Ladel, S., & Kortenkamp, U. (2013). Number concepts - processes of internalization and externalization by the use of multi-touch technology. In U. Kortenkamp et al. (Eds.), *Early mathematics learning. Selected papers of the POEM 2012 conference* (pp. 237–256). New York: Springer.
Lembrér, D., & Meaney, T. (2016). Preschool children learning mathematical thinking on interactive tables. In T. Meaney et al. (Eds.), *Mathematics education in the early years. Results from the POEM2 conference* (Vol. 2014, pp. 235–254). New York: Springer.
Lorenz, J. H. (2012). *Kinder begreifen Mathematik [Children understand mathematics]*. Stuttgart, Germany: Kohlhammer Verlag.
Montague-Smith, A. (2002). *Mathematics in nursery education*. London: David Fulton.
NAEYC (National Association for the Education of Young Children) & NCTM (National Council of teachers of mathematics) (2002/updated 2010). *Early childhood mathematics: Promoting good beginnings.* https://www.naeyc.org/files/naeyc/file/positions/psmath.pdf. Accessed 05 Sept 2016.
Neuß, N. (2013). Medienkompetenz fördern [Supporting media competence]. *DGUV (Deutsche Gesetzliche Unfallversicherung) Kinder Kinder, 4*, 4–5.
van Oers, B. (2014). The roots of mathematising in young Children's play. In U. Kortenkamp et al. (Eds.), *Early mathematics learning – selected papers of the POEM 2012 conference* (pp. 111–123). Heidelberg, Germany: Springer.

Pilner Blair, K. (2013). *Learning in Critter Corral: Evaluating three kinds of feedback in a preschool math app. Proceedings of the 12th International Conference on Interaction Design and Children (pp. 372–375)*. New York: ACM.

Preiß, G. (2007). *Leitfaden Zahlenland [Guideline Numberland]*. Kirchzarten, Germany: Zahlenland Preiß.

Sarama, J., & Clements, D. H. (2009). *Early childhood mathematics education research. Learning trajectories for young children*. New York: Routledge.

Spiegel, H. (1992). Was und wie Kinder zu Schulbeginn schon rechnen können [What and how children are already able to calculate at the time they start school]. *Grundschulunterricht, 39*(11), 21–23.

Spitzer, M. (2011). *Anhörung im Hessischen Landtag zum Jugendmedienschutz am 04. Mai 2011* [Consultation in Hessian state parliament about youth media protection]. http://www.hessischer-landtag.de/icc/Internet/med/f60/f6060b4c-0f03-9031-6875-17672184e373,11111111-1111-1111-1111-111111111111.pdf. Accessed 05 Sept 2016.

Steinweg, A. S. (2007). Mit Kindern Mathematik erleben [Experience mathematics with children]. In S. B. Bayern (Ed.), *Das KIDZ-Handbuch. Grundlagen, Konzepte und Praxisbeispiele aus dem Modellversuch* (pp. 136–203). Köln, Germany: Kluwer.

Steinweg, A. S. (2008). Grundlagen mathematischen Lernens vor der Schule [Foundations of mathematical learning before school]. In É. Vásárhelyi (Ed.), *Beiträge zum Mathematikunterricht* (pp. 273–276). Münster, Germany: WTM.

Steinweg, A. S. (2016). MaiKe – a new app for mathematics in kindergarten. In T. Meaney et al. (Eds.), *Mathematics education in the early years – results from the POEM2 conference* (Vol. 2014, pp. 341–357). Heidelberg, Germany: Springer.

Steinweg, A. S., & Weth, T. (2014). Auch das noch? Tablets im kindergarten [Really? Tablets in kindergarten]. In J. Roth & J. Ames (Eds.), *Beiträge zum Mathematikunterricht* (pp. 1167–1170). Münster, Germany: WTM.

Süss, D., Lampert, C., & Wijnen, C. W. (2013). *Medienpädagogik. Ein Studienbuch zur Einführung [Media education: An introductory textbook]*. Wiesbaden, Germany: Springer VS.

Wittmann, E. C., & Müller, G. N. (2009). *Das Zahlenbuch - Handbuch zur Frühförderung [The number book – Handbook of early support]*. Stuttgart, Germany: Klett.

Zaranis, N., Kalogiannakis, M., & Papadakis, S. (2013). Using mobile devices for teaching realistic mathematics in kindergarten education. *Creative Education, 4*(7A1), 1–10. https://doi.org/10.4236/ce.2013.47A1001. Accessed 05 Sept 2016