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Author

Kortenkamp, Ulrich, Larkin, Kevin, Ladel, Silke, Dahl, Dorothee

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Investigating the effect of learning part-part instead of part-whole concepts using the Fingu App from an ACAT perspective

Ulrich Kortenkamp[1], Kevin Larkin[2], Silke Ladel[3], and Dorothee Dahl[4]

[1]University of Potsdam, Germany; ulrich.kortenkamp@uni-potsdam.de

[2]Griffith University, Gold Coast, Queensland, Australia; k.larkin@griffith.edu.au

[3]University of Education Schwäbisch Gmünd, Germany; silke.ladel@ph-gmuend.de

[4]University of Potsdam, Germany; dorothee.dahl@uni-potsdam.de

In this paper we investigate the effects of the app Fingu on the part-whole understanding of children. Using the Artifact Centric Activity Theory (ACAT) framework, we analyse the externalisation and internalisation processes that appear to occur during one child's use of the app. Our analysis of a 13-minute video of a child playing the app Fingu indicates that the design of the app affected the child's experience of part-whole relationships in ways that were likely unintended by the app designers. We found that the child used less sophisticated part-whole strategies as the gameplay unfolded and suggest that, due to the limitations of the use of one video, further research is required into the experiences of other children whilst playing Fingu.

Keywords: Early childhood education, number concepts, educational technology, video analysis

Introduction

In previous work (Ladel & Kortenkamp, 2016; Larkin et al., 2019), we have argued that the use of mobile applications (apps) is an increasingly common phenomenon in primary school mathematics classrooms. This claim is supported by other researchers (See Moyer Packenham et al., 2019; Tucker and Johnson, 2020) who also found that the use of digital games can lead to positive educational gains, including in children's understanding of part-whole relations (Holgersson et al. 2016), the focus of interest in this paper. We have also suggested that classroom teachers will derive additional benefit from research into mathematical apps that helps them to determine whether specific apps are appropriate for general classroom use.

In this exploratory paper we sought to understand the usefulness of Fingu (Barendregt et al., 2012), a virtual manipulative housed in a game environment, in supporting young children's learning and the development of number concepts and flexible arithmetic competence. More specifically, Fingu targets the understanding and mastering of the basic numbers 1–10 as part-whole relations (Holgersson et al., 2016). Understanding part-whole relations is identified in the research literature as a fundamental concept for children to develop (See, e.g., Fuson, 1990). In the Fingu game, a child is presented with two moving sets of objects (fruit) on a tablet (in Fig. 2 below, three strawberries on the left and two strawberries on the right) and is required to answer how many objects there are in total (five) by touching the screen with the corresponding number of fingers. In Fingu, fingers can be placed anywhere on the screen and there are no restrictions concerning which fingers are used; however, they must be pressed down roughly at the same time, to represent the total number of objects (maximum ten). The game is delivered with progressive difficulty levels and each level is comprised of sets of tasks. To progress to the next level, the child is required to answer a specific number of questions without a certain number of incorrect answers (as shown by hearts in the top right corner of Fig 2).

Artifact Centric Activity Theory (ACAT)[1]

Ladel and Kortenkamp (2011, 2016) have previously outlined the creation of their framework, (ACAT), which can be used to help researchers and teachers understand the various interactions that occur when students use multi-touch environments, such as Fingu (See Fig 1).

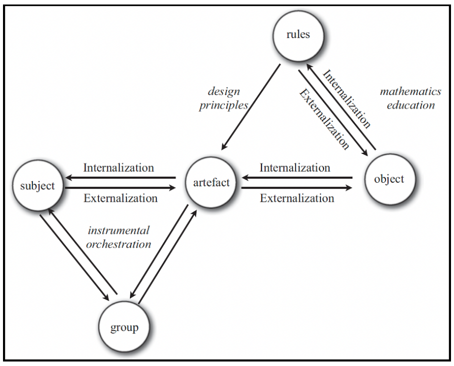

Fig. 1. Artifact Centric Activity Theory (Ladel & Kortenkamp, 2011).

ACAT is an evolution of Engeström's (1987) Activity System's model and was devised to closely investigate the pivotal role of tools (apps) in the socio-cultural activity of learning mathematics, including its use by teachers in evaluating the mathematical appropriateness of apps prior to their use (Larkin et al., 2019). ACAT is used in this article as a methodological tool to investigate the learning potential of Fingu. ACAT comprises a complex, causal network of five components (subject, artifact, object, rules, group) that mutually affect, and are affected by, each other. In contrast to Engeström's conceptual model, in ACAT, the artifact (tool) is positioned centrally as it is the focal point of the processes of externalisation and internalisation between subject and object.

Externalisation and Internalisation of part-whole in Fingu

Whilst a complete understanding of a learning experience requires analysis of the interrelationships between all five ACAT components, for specific research purposes, e.g., how the subject internalises the concept of part-whole as presented in Fingu, the overall structure of ACAT can also be considered as consisting of three main sub-structures: the main axis (subject-artifact-object); the upper right triangle (artifact-rules-object); and the lower left triangle (subject-group-artifact) (Larkin et al, 2019). As our focus for the analysis in this paper is the influence of the externalisation of part-whole relations through the app (to be internalised by the child), and on how the child reacts by externalising the solution using his hand, we will only focus on the main axis sub-structure (subject-artifact-object).

Each level of Fingu consists of 20 subtasks, where several objects (fruit) float across the screen for a predetermined period, in one or two blocks on the screen, before vanishing again. The child is tasked with touching the screen with as many fingers as the objects that were shown. As the number of

[1] In earlier versions of our work, we used the term artefact; however, in more recent work we use the more commonly used spelling of artifact. Henceforth we will use the term artifact.

objects can be larger than five, it is sometimes necessary to use both hands; however, for smaller numbers (e.g., 1 + 2) the child can answer using three fingers on one hand, or one finger on one hand and two fingers on another hand. This design feature has significant implications for the subject's learning. It is also essential to note that both the representation shown by the app, and the representation used by the child, include both the total sum and the partition.

Methodology

The video we analysed for this research was recorded as part of a larger project, led by Dr Stephen Tucker, with children approaching the end of the kindergarten school year in an urban elementary school in the USA. The students were introduced to Fingu by two researchers, who demonstrated and explained how to play Fingu. Cameras were used to record the hand movements of the children, with parental consent to participate, as they played Fingu. The data for this paper is a 13-minute video of a right-handed, six-year-old, child's first independent interaction with Fingu. Initially, the four co-authors viewed the video independently to get a sense of the child's activity in ACAT terms. We then met, on four separate occasions, to discuss the child's actions, and to record our developing interpretations of his interactions in a data recording table for later analysis (See excerpt from Table 1).

Table 1. Excerpt from Data Recording Table

Time	Num bers	L	R	SUM	How the number was shown (always in motion)	Answer	Left Hand	Right Hand	SUM Hand	Correct	C-CUM	P-P	P-CUM	Observational Comments
00:03	1 - 2	1	2	3	pears, 2 pears in a diagonal line like \	R2, 3, 4 - firstly just a tap, then trying again - holding	0	3	3	✅	1	❌	0	Has restructured to form 3 on the right hand
00:13	2 - 3	2	3	5	kiwis, two lines \ \	R1, 2, 3, 4, 5 - only holding, no taping anymore	0	5	5	✅	2	❌	0	Appears to have recognised that part + part = whole in that the total is shown on one hand. Or could just be subitising the five and showing with one hand
00:22	1 - 0	1	0	1	kiwi	R1	0	1	1	✅	3	❌	0	Zero right - right hand shows total
00:32	3 - 1	3	1	4	strawberries, 3 in a diagonal line \	R1, 2, 3, 4	0	4	4	✅	4	❌	0	part + part = whole / subitising?
00:38	1 -1	1	1	2	strawberries	R1, 2, 3 - and with no long holding	0	3	3	❌	4	❌	0	part + part = whole / subitising?

As can be seen in the excerpt, we recorded for each subtask (Column 2), which digits were shown (Columns 3 and 4) and what answer the child recorded via touch (Column 5). In each subtask, both numbers are recorded with their partition as given either by the externalisation of the app (left block and right block – Columns 3 and 4) or the externalisation of the child (left hand and right hand – Columns 8 and 9). In Figure 2, we see the app showing 3 objects and 2 objects and the child touching 5 fingers - 0 [LH] and 5 [RH]. In this instance, the left hand does not touch the screen. NB: Although we cannot always be certain that the child is performing addition in completing a subtask, for the rest of the paper we will use the shorthand (3 + 2) to represent the objects on the screen.

Figure 2. Two externalisations of 5 (video frame at 2.55)

Once this systematic recording of the child's movements was recorded, we commenced the activity analysis, by comparing the total number of objects shown on the screen and the number of fingers touching the screen, and by comparing the partitions of both. As the number of subtasks was only

113, we focused on qualitative changes in the child's answers over the course of the video. Each line of data was colour-coded to quickly see whether the total sum was shown correctly, the same partition was used by the child that was shown on screen (e.g., (2 + 3) shown on the screen was represented with 2 fingers [LH] + 3 fingers [RH]), and whether the left hand was used or not (i.e., the partition was of form $x = 0 + x$). Observations were noted as remarks in the table. During several steps of analysis, we filtered the data by, for example, total sum or certain combinations like (1 + 3). After an initial discussion of our observations, we conducted a quantitative analysis of the data by first excluding all subtasks of the form ($x = 0 + x$), which resulted in 98 observations. NB. These subtasks were excluded as we cannot be sure that the child demonstrates part-whole knowledge as it is impossible to use the touch screen to represent a null amount. For these, we graphed in chronological order, the cumulative number of correct results, as well as the subtasks that were solved using the fingers on each hand that matched the partition shown on the screen.

Results

During the 12:56 minutes of the video, 113 subtasks were presented to the child. The numbers of objects shown generally (due to the random presentation of numbers some earlier tasks were repeated in the app) increased over time, with the first sum larger than 5 (3 + 3) appearing at 2:20, the first sum larger than 6 appearing at 7:41, and a sum of 8 appearing only 4 times from 9:34 on. All subtasks are presented in Figure 3, which also includes the distribution of objects in the left block and right block on the screen (e.g., the first subtask shows 1 object in the left block and 2 objects in the right, and the fifth subtask shows 1object in the left block and no objects in the right block).

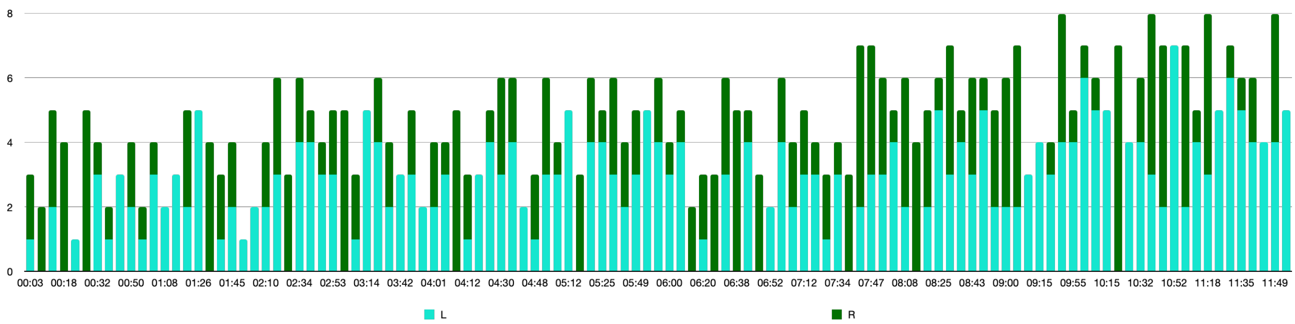

Figure 3: Distribution of Subtasks in the video

The time used for each subtask, including the time to skip to the next subtask or level, is shown in Figure 4. Apart from some longer measurements due to changing the level, the answer time normally lies between 3 and 10 seconds. There is no correlation between the sum and the answer time.

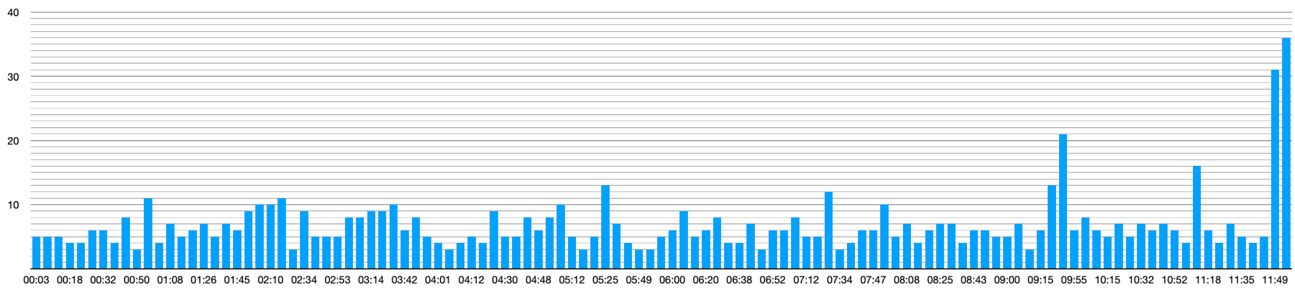

Figure 4: Answer time in seconds for each subtask, including time to move to the next subtask.

The distribution of totals is shown in Table 2. The subtasks generated by the software are approximately normally distributed, with a modal value of 5. Only 31% of the subtasks require a partition, as only these have a sum larger than 5, however, some amounts of 5 or less were represented by the child using other than an ($x = 0 + x$) form.

Table 2: Subtasks with a given number of objects (fruit)

Number of objects	1	2	3	4	5	6	7	8	Total tasks
Subtasks	2	9	17	22	28	21	10	4	113

The quantitative analysis provides evidence that in the beginning, the child used only his right hand to show the sum, regardless of the partition that was presented on screen. Almost all initial subtasks were answered correctly in this way. This approach had to fail at subtask #23, time 2:20, when (3 + 3) was shown. In this subtask the child appears to struggle, uses his left hand, and produces (2 + 2). While this is incorrect, the child partitions his answer into two equal parts. The next time six objects are shown (4 + 2, [#25, 2:34]) the child appears no longer surprised and produces (5 + 1). This suggests to us that the child knows the sum is 6 and furthermore, that this sum is first internalised and then externalised, using a different partition.

As the total sums presented in the following subtasks from [#26, 2:43] to [#42, 4:21] except for [#32, 3:23] are again less than or equal to 5, the child continues to use the right hand only to produce a solution. The one exception, subtask #32, presents (4 + 2), and the wrong answer is (0 + 2). Here it seems that he tries to at least match the right part of the solution. Subtasks [#43, 4:30], [#44, 4:35] and [#47, 4:54] show (4 + 2), (3 + 3), and (3 + 3), respectively. The child answers (1 + 5) for each, correctly, and appears to be enjoying his success. We claim that all these representations show part-whole understanding, as the partitions in the child's answers differ from the subtask partitions shown.

A closer investigation reveals several interesting subtasks in the neighbourhood of the subtasks discussed immediately above. In the subtask [#46, 4:40] the objects shown are partitioned into (1 + 2), and the child answers with the exact same partitioning of fingers (1[LH] and 2[RH]). This is different from the child's earlier answers, where the total was only shown with the right hand, in this case, (0[LH] + 3[RH]). Subtask [#48, 5:02] can be seen as a crucial turning point: the subtask presents (3 + 1), and the child answers (3[LH] + 4[RH]). While this seems at first glance to be completely wrong, it can be interpreted, based on previous finger patterns, as showing the total of 4 [RH] and just adding the part of 3 [LH] by mistake. It seems, that the child switches to showing the given partition with the left and right hands. This might also be reinforced by the time pressure created in the game, as time is almost up for the level at this point in the game.

The following subtasks, which are mostly using small numbers totalling less than six, are again solved mostly correctly. Starting with subtask [#75, 7:41] large numbers are presented more frequently, and we appear to see the child's strategy change: instead of using either the right hand alone, or a partition different to what is represented on the screen to represent numbers larger than 5, the child simply matches the two on screen parts using the same number of fingers on the respective hands. For example, subtasks (#85, #86, and #88) [8:43 to 9:00] are solved by repeating the onscreen partitions (3 + 3; 5 + 1; 2 + 3; and 2 + 4) directly with (3[LH] + 3[RH]; 5[LH] + 1[RH]; 2[LH] + 3[RH]; and 2[LH] + 4[RH]) respectively. What is remarkable for us is that subtask #87 (4+1) is now solved as (4[LH] + 1[RH]), and not as how it was solved earlier at (#32, #38, #43, or #47) as (0[LH] + 5[RH]). This representational pattern continues in the following subtasks, where it appears that the child discovered (or the app has taught the child), that it is not necessary to touch the total in a standard representation (either $0 + x$ for $x \leq 5$ or $y + 5$ for larger numbers), but that it is more efficient (perhaps for gameplay reasons) to use the exact partition that is shown on screen for their fingers as well. To support our claim, we removed the subtasks of the form $0 + x$ from the data and graphed the cumulative number of correct answers (C-CUM) as well as the cumulative number of answers using the same partition (P-CUM), see Figure 5.

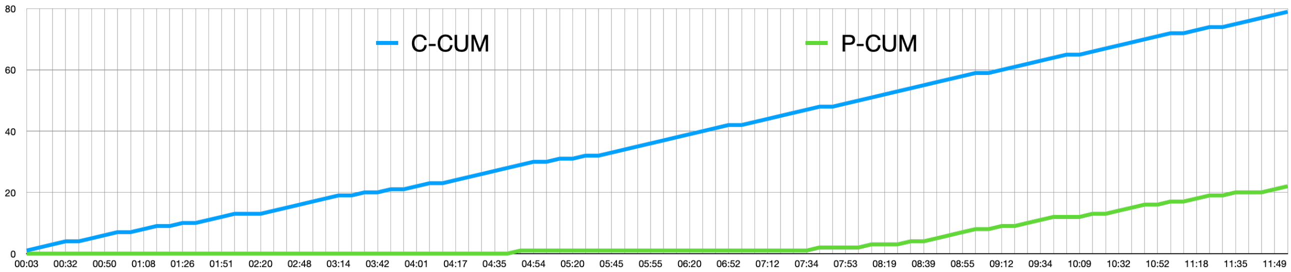

Figure 5: Cumulative number of correct totals and correct parts

In Figure 6, the ratio between these two values is shown. We can see how the subtasks around 8:39 start to evoke the alternative strategy, supporting our claim that the app play has modified the representational strategy of the child. Instead of internalising the sum, the child internalises the partition, as we can see by the externalised form.

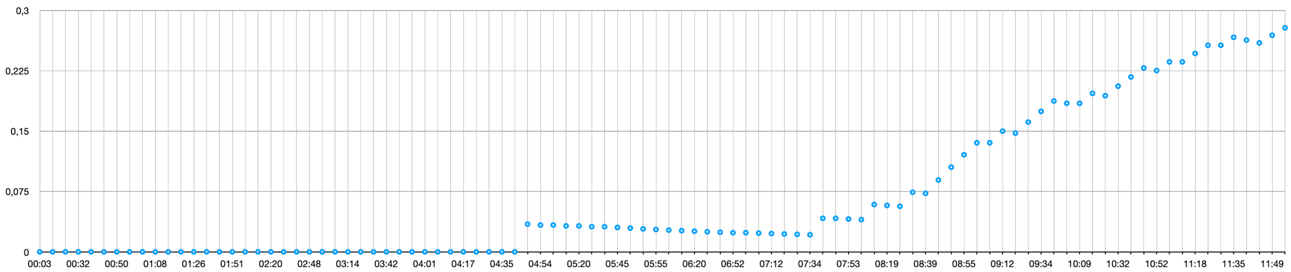

Figure 6: Ratio of cumulative correct totals and correct parts by subtask

Discussion

Our investigation of the use of Fingu, as seen in the video we analysed, suggests that using the app might have an unintended, adverse effect on part-whole understanding. From our analysis, we see certain signs that indicate a potential flaw with the design of Fingu, whereby a child might be discouraged from using finger patterns configurations, which clearly indicate that the child has completed an addition process and thus understands part-whole relations (e.g., representing 1 + 3 or 1 + 4 as shown on the screen, with four fingers and five fingers respectively on the right hand – clearly indicating addition), to a situation later in the game where they represent the same sums, when encountered again, using finger patterns that correspond directly to the arrangement of objects on screen (i.e., 1[LH] + 3[RH] or 1[LH] + 4[RH]). This indicates to us that the child no longer is focusing on part-whole relations, but more likely is simply representing the pattern of on-screen objects with the matching number of fingers on their respective hands. This regression to a pattern matching rather than a clear indication of a part-whole understanding may be caused by the increasing level of difficulty in the game (e.g., 3 + 4 or 2 + 4), as well as the time-limiting elements in the gameplay, where the child is rewarded as having completed the subtask by merely repeating the pattern of objects respectively on the left and right hands, without any need to add the numbers. Thus, when re-presented the earlier tasks, where the child demonstrated an understanding of part-whole, he now just represents the onscreen objects using the required number of fingers on each hand.

We can hypothesise that this is caused by the onscreen representation and the similarity of the externalisation of the app showing the sum as a partition, and the child begins to use both hands to show a total, whereas earlier he had used only one. Even in the case of the larger numbers, there is no instance where the objects on the screen are represented by other than the matching fingers on the respective hands. For example, (6 + 1) or (4 + 3) are never represented by, for example, (5[LH] + 2 [RH]). In our view, a better approach to teaching part-whole would be to force a switch between representing the partition and the whole, for example, by providing two modes of the app: In the part-to-whole mode a partition is shown (similar to how it is currently implemented), and the answer must be given by tapping the corresponding point on a number line or a cardinal representation of the whole. In a new whole-to-part mode, a sum is shown (i.e., a set of 0 to 10 objects) and the child can choose two partitions, which add to the sum shown, by tapping with either the left or right hands (or both). For example, nine strawberries are shown, and the child represents this amount with either (5[LH] + 4[RH]) or (4[LH] + 5[RH]), or four apples are shown, and the child represents this amount with, for example, (4[LH] + 0[RH]) or (2[LH] + 2[RH]) etc.

Limitations and Future Research

A major drawback of this study is the fact that only the interaction data of a single child was available, and thus we cannot claim that the use of Fingu by other children will demonstrate the same effect as is the case of the child in this video. In addition, Fingu has a range of settings, for example, how long the objects are displayed on the screen, how quickly the objects are moving across the screen, and how long the children must hold down their fingers on the screen to record a response. There are also “motivational’ settings for the app, for example, the number of lives, a progress indicator, music, sound effects, and (non-informational) feedback. How these settings are set in Fingu almost certainly influences the way a user responds. For example, due to time limitations, a child may save time by merely repeating with their fingers the pattern of objects on screen, instead of working out the total and representing the total in a novel way. As we used the video provided, we did not have the scope to change these settings to see how they impacted on how this child experienced Fingu. Later levels of Fingu also use partitions into three parts, so the two hands of the child would not be sufficient to represent the parts. It would have been interesting to see how the child handled that situation; however, we have no access to later interactions of the child with the app.

Finally, it is likely that Fingu is most commonly used in classrooms, where the teacher will influence app use (e.g., a teacher might give a direction that the part-whole answer should be represented using a finger combination different to how the objects are presented on screen). This would prevent children from merely copying the pattern and would support them in representing their thinking using a novel part-whole structure. In future work we would like to analyse the use of Fingu, by several different children, to determine more clearly whether the design features built into the app contributed to the child in this video changing from how he represented part-whole understanding early in the gameplay, to the use of simple pattern recognition strategies in latter stages of gameplay, as an apparent consequence of playing Fingu.

Acknowledgement

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References

Barendregt, W., Lindström, B., Rietz, E., Holgersson, I., Ottosson, T. (2012). Development and Evaluation of Fingu: A Mathematics iPad Game Using Multi-touch Interaction. Conference: Interaction Design and Children. 10.1145/2307096.2307126

Engeström, Y. (1987). Learning by expanding: An Activity - Theoretical Approach to Developmental Research. http://communication.ucsd.edu/MCA/Paper/Engestrom/expanding/toc.htm

Fuson, K. (1990). Conceptual structures for multiunit numbers: Implications for learning and teaching multidigit addition, subtraction, and place value. Cognition and Instruction, 7(4), 343-403.

Holgersson, I., Barendregt, W., Emanuelsson, J., Ottosson, T., Rietz, E., & Lindström, B. (2016). Fingu-A Game to Support Children's Development of Arithmetic Competence: Theory, Design and Empirical Research. In P. S. Moyer-Packenham (Ed.), International Perspectives on Teaching and Learning Mathematics with Virtual Manipulatives, 7. Springer.

Ladel, S. and Kortenkamp, U. (2011). An Activity-Theoretic Approach to Multi-Touch Tools in Early Maths Learning. In: Proceedings of ATATEMLO 2011, Paris.

Ladel, S., & Kortenkamp, U. (2016). Artifact-Centric Activity Theory-A Framework for the Analysis of the Design and Use of Virtual Manipulatives. In P. S. Moyer-Packenham (Ed.), International Perspectives on Teaching and Learning Mathematics with Virtual Manipulatives, Mathematics Education in the Digital Era, 7. Springer. https://doi.org/10.1007/978-3-319-32718-1_2

Larkin, K., Kortenkamp, U., Ladel, S., & Etzold, H. (2019). Using the ACAT Framework to evaluate the design of two geometry apps: An exploratory study. Digital Experiences in Mathematics Education, 5(1), 59-92. https://doi.org/10.1007/s40751-018-0045-4

Moyer-Packenham, P. S., Lommatsch, C., Litster, K., Ashby, J., Bullock, E., Roxburgh, A., Shumway, J., Speed, E., Covington, B., Hartmann, C., Clarke-Midura, J., Skaria, J., Westenskow, A., MacDonald, B., Symanzik, J., & Jordan, K. (2019). How design features in digital math games support learning and mathematics connections. Computers in Human Behavior, 91, 316-332.

Tucker, S. I., & Johnson, T. N. (2020). Developing number sense with Fingu: a preschooler's embodied mathematics during interactions with a multi-touch digital game. Mathematics Education Research Journal, 34(2), 393–417. https://doi.org/10.1007/s13394-020-00349-4