

Chapter 17

The Learning Potentials of Number Blocks

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1 Introduction

In this paper, we describe an initial exploration of Number Blocks designed to support number learning in mathematics. Number Blocks are based on the generic user-configurable modular robotic system called I-BLOCKS (Nielsen 2008a; (Nielsen 2008b)). The educational goal is to support children's understanding of place value by allowing them to physically play with multi-digit numbers, the pronunciation of which is quite complicated in Danish (Ejersbo and Misfeldt 2011). The target group is children aged 5–8. Development was carried out in an experimental design process actively involving a class of 23 children and their mathematics teacher. This experiment is cross-disciplinary and combines the two scientific areas of robotics and pedagogical research. The tool combines physical interaction, learning, and immediate feedback.

Number Blocks can be labelled as a physical serious game (Majgaard 2009a). The tool is inspired by prior work in the field of physical serious games, e.g. by Papert (1980), Resnick (Rusk et al. 2008) and Majgaard (2009b). Resnick does research in LEGO Mindstorm and Pico Crickets, and he is currently working on how the learning process can become more creative and exploring. In both LEGO Mindstorm and Pico Crickets, the learner must build, program and execute their programs in sequences. During the execution, the robots give feedback and are

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interactive (Rusk et al. 2008). Number Blocks are different; they give direct feedback during the building phase, and the children do not have to program the tool in a separate environment. It is our intension that the tool should support participative, creative and exploring learning processes.

Thus, the questions explored in this paper are: How can technology that combines building block interaction and sound modality, support place value learning? And what are the learning potentials?

The scientific method used is design-based research and action research (van den Akker et al. 2007; Lewin 1946; Majgaard 2010). The empirical foundation of this paper comprises six interventions, which took place in a second grade class during the iterative development of the system.

This paper includes an introduction to numeracy and interaction, followed by a description of the technological platform and an introduction to the way numbers are pronounced in Danish and a description of the iterative development process. Finally there is a discussion of the results and research question.

2 Theory

Comparative investigations have shown linguistically-determined differences in the conception of numbers and in understanding of place value (Dowker et al. 2008; Miura and Okamoto 1989). One of the reasons for these differences is in the extent to which the words used to denote numbers reflect base ten place value system (Dowker et al. 2008).

Danish words for the numbers between 1 and 100 do not reflect the base ten place value system in two ways: (1) the words for the teens (11,12,13 ...) and the decades (20,30,40 ...) do not in any significant way relate to the names of the digits 1–10, and (2) the decades and units are spoken in reversed order compared to how they are written as digits in the base ten system. In Danish you would say ‘fem-og-tres (five-and-threes)’ in order to express the number 65, ‘tres’ (60) is an inflection of ‘tre’ (3), showing how the Danish number-words relate to long gone base 12 and 20 systems (Ejersbo and Misfeldt 2011). The reversed order of pronunciation of numbers between 20 and 100 also affects larger numbers such as 27,000 (in Danish pronounced ‘syv og tyve tusinde’ that is ‘7 and 20,000’). The algorithm to create larger numbers in Danish is described in Fig. 17.1.

It is broadly acknowledged that learning of mathematics can be considered an embodied activity (Johnson 1987; Nemirovsky et al. 2004). Furthermore concept formation in mathematics relates intimately to the representations that are used in work with the specific concept (Duval 2006; Steinbring 2006). The Number Block tool provides an embodied interaction with two representations that are crucial in the formation of a number concept: the number written as digit and the words used for a number. Digital manipulatives have been described as either Montessori-inspired or Fröbel-inspired (Zuckerman et al. 2005). Fröbel-inspired manipulatives are based on aesthetics and allow users to express their ideas creatively and to interact with shape and identity, whereas Montessori-inspired manipulatives allow interaction with

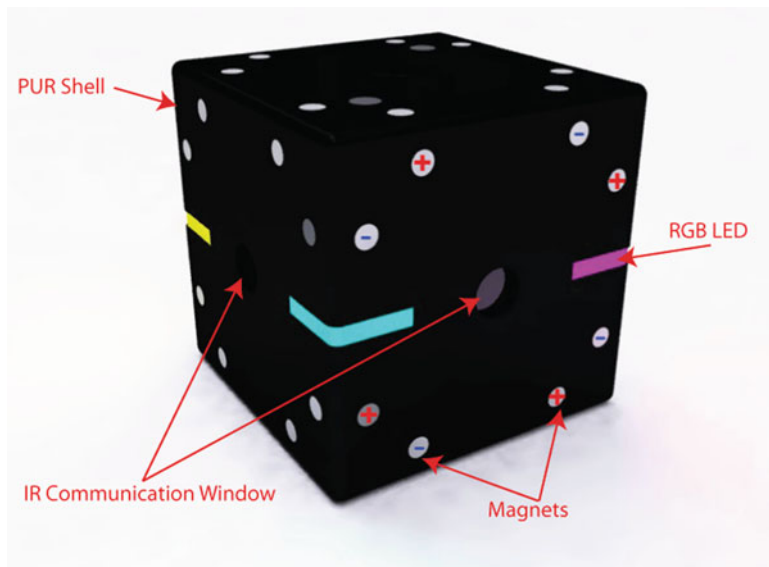


Fig. 17.1 The standard I-BLOCK

theoretical ideas. Number Blocks can be viewed as a Montessori-inspired digital manipulative, because it highlights interaction with the conception of numbers and the place value system (Zuckerman et al. 2005).

3 Technological Platform and the Number Blocks Tool

I-BLOCKS is a user-configurable modular robotic platform developed and tested through several prototype and application generations (Nielsen 2008b). It consists of magnetic cubic modules that can communicate with each other when connected. Each cube can communicate with up to four of its six possible neighbours and is fully self-contained with respect to power, connectors and processing. At the edges of the four communicating sides of a cube are four RGB LEDs, which can light up in 4,096 different colours. The I-BLOCKS communicate locally via infrared light, and in some cases radio (Zigbee), which allow for interaction with a computer. Each I-BLOCK makes use of a 3D accelerometer to detect its orientation with respect to gravity. This makes it able to detect which side is facing upwards.

The I-BLOCKS hardware is encapsulated by a black polyurethane shell that has a soft rubber-like feel, with plastic fittings in top and bottom into which various sockets, connectors, sensors and actuators are integrated, see Fig. 17.1.

The I-BLOCKS have been developed specifically to provide a general platform for exploring physical programming. An I-BLOCKS construction results not only in a physical structure, but also in a particular computational functionality which is dependent upon that particular structure.

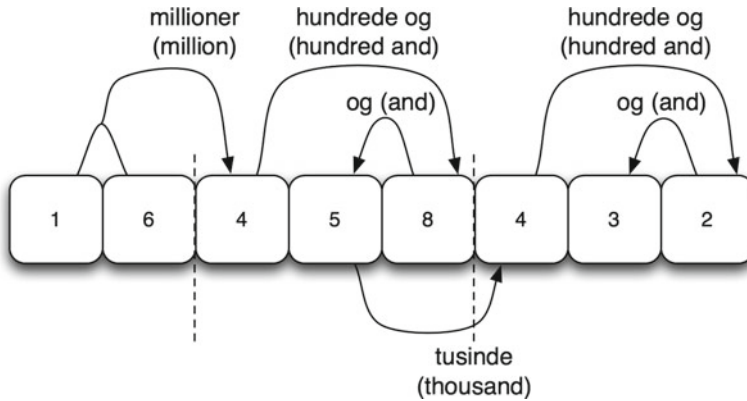


Fig. 17.2 The Danish system of pronouncing numbers

The Number Blocks implementation and instantiation of the I-BLOCKS technology allows children to explore the concept of number and the place value system in a tactile way, focusing on the way large numbers are constructed from digits and on the spoken names of these numbers. To create Number Blocks, each side of every I-BLOCK module is marked with a single digit label. Each I-BLOCK looks like a giant die. Moreover six faces are not sufficient to represent ten digits, so individual modules could only represent a subset of digits. The digit number labels are glued onto specific faces of the cube, so that their value can be registered using the built-in accelerometer. When a module determines which face is currently facing upwards, it also knows which number is represented on that face.

The user connects Number Block modules in lines to create large numbers, which is equivalent to writing digits in lines on paper.

The complete Number Blocks system consists of the above mentioned number modules, a Zigbee radio communication module and a PC with a Zigbee-USB dongle, which serves as an audio playback device that convert incoming numbers into spoken numbers. The spoken numbers are consecutive playbacks of samples of recorded children's voices. A number algorithm plays the samples in the correct order. Figure 17.2 gives the correct spoken order for 16,458,432: by following the arrows from the left we get 16 -> 'millioner' ('millions') -> 400 -> 'og' ('and') -> 8 -> 'og' ('and') -> 50 -> 'tusinde' ('thousands') etc.

4 About the Research Method

The research method is based on action research and design-based research (Lewin 1946; Barab and Squire 2004; van den Akker et al. 2007). Both methods focus on iterative processes. Action research traditionally focuses on the target groups' change in behaviour, while Design-based research was developed for design of educational processes that involve digital media.

There were four steps in the development and research process leading to Number Blocks: (1) Planning and making an overall plan; (2) Iterative interaction design; (3) Interviews and (4) Retrospective analysis.

In the overall planning phase, brainstorming produced many ideas for discussion. During this step it was decided to combine mathematics and I-BLOCKS. We did not decide on a specific learning goal, but a lot of ideas were aired.

Learning goals gradually emerged during the iterative interaction design phase. These were reviewed and adapted to fit national curriculum goals, theoretical hypotheses about the place value system, and to be practical with respect to our technological platform.

We held six sessions with the children, as described below. These sessions ensured that our overall ideas were appropriate for our target group, that the children enjoyed interacting with the Number Blocks, and allowed us to refine the educational content of the study and to investigate the learning potential of our technological platform.

After the six practical sessions, interviews were conducted with some of the children and with their teacher. Finally, retrospective analysis of the learning potential, design methodology, and technology used in this study is still ongoing at the time of this writing.

5 The Design Process

Our iterative design process included several 2 h sessions with our target group. The themes for the sessions were: (1) Getting to know each other and the technology; (2) Brainstorming and decision making; (3) Recording sound; (4) Testing the “Pronounce number Function”; (5) Testing the “Compare Numbers Function”; (6) The final test and putting the teacher in control.

Session 1 (06-15-10): *Getting to know each other and the technology*. The children tried an existing I-BLOCKS music application (Nielsen et al. 2008b). The goal of the session was to evaluate the potential of developing technology based on I-BLOCKS with the target group, and get to know each other, in order to make future cooperation easier for both children and researchers.

Session 2 (06-22-10): *Brainstorming and decision making*. The goal of this session was to generate ideas for the creation of suitable educational tool based on the I-BLOCKS platform. The children had ideas about how to use the blocks for mathematics, e.g. that one could add and subtract using the blocks.

Aside from brainstorming with the children, we also had a session with a group of mathematics teachers from the same school. They suggested that one could use the blocks to help children by saying numbers. They told us that Montessori had some exercises with bricks and positional notation. In an earlier brainstorm the research group had had a similar idea. We decided to design a system that supported place value and to extend the system to include number operations at a later time.

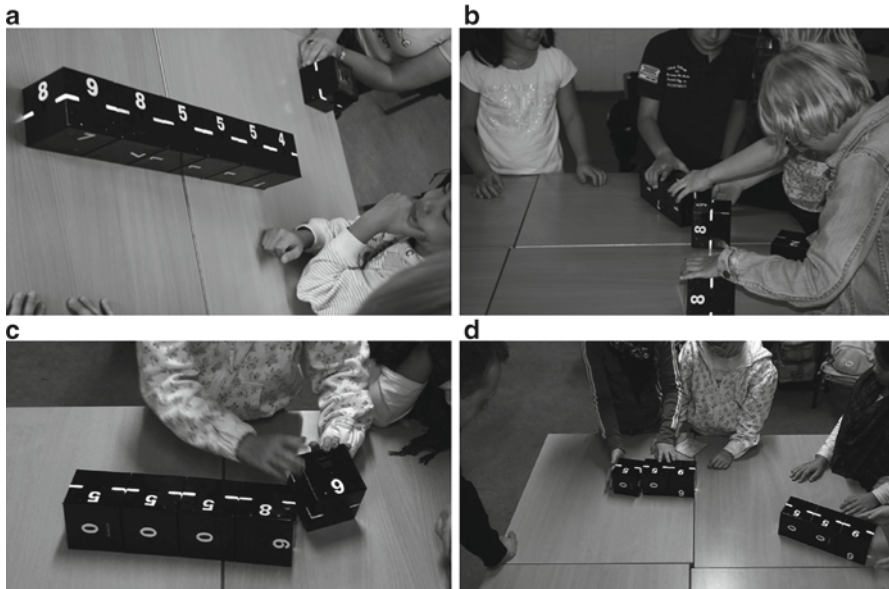


Fig. 17.3 Pictures from our final session. (a) The children enjoyed making large numbers. (b, c) The handy size of the blocks supported collaboration and playful investigation. (d) The children competed about making the largest numbers

Session 3 (08-13-10): *Recording sound and development of the first prototype*. The next step was to record the number elements sufficient to synthesise pronunciation of the relevant numbers. To involve the children as co-creators in the design process, we chose to use the children’s own voices.

Session 4 (08-31-10): *Testing the initial prototype and the “Pronounce Numbers Function”*. The goal of this session was to conduct usability testing and to assess whether there was sufficient potential in the design to go ahead. Our initial observations suggested that the children were interested in creating large numbers (Fig. 17.3a). They were clearly interested in using the blocks to make as large a number as possible, either with all the cubes or with a specific selection.

Our initial concerns about the Danish number names mainly concerned the first 100 numbers but the session showed children found large numbers appealing. This came as a surprise for the teacher, since the class was only using two-digit numbers at that stage.

Another observation was that the children managed to play with Number Blocks. The session showed that the children (in groups of four) were able to create small games and competitions with the blocks (see Fig. 17.3d), without assistance from the investigators. They competed about who could make the largest number. This was a surprise in the sense that this prototype version of Number Blocks was designed without intended gameplay.

Our observations suggest that the size of the blocks supported physical play including group interaction and cooperation (see Fig. 17.3b).

Session 5 (11-2-10): *Testing the “Compare Numbers Function”*. We tested two versions for comparing numbers. If the children put a “Compare” block between two numbers, the system could tell which number was larger. This worked well, and was easy to use and understand. We also tested another version. This version could explain the difference between the two numbers. This function was too complicated for the children, because they had not yet been introduced to subtraction at that point.

Session 6 (07-12-10): *Final test and putting the teacher in charge*. This session was mainly held to confirm the findings of the previous interventions. We worked with groups of four children. In this intervention, the mathematics teacher participated in, and organized, the children’s work with the blocks. The teacher did identify a number of potential uses, and spontaneously developed didactical activities involving the blocks. The pupils responded in a very natural way to these activities, did what the teacher asked just, as if it was any other form of didactical activity. This was unsurprising in that, the class seemed very positive and hard working and showed much respect for the teacher.

6 Summary of Interviews

Six of the children and their mathematics teacher were interviewed about the design process and learning potentials. The first two children were interviewed individually and after that we interviewed them in pairs, which made the more talkative. Different groups were represented in each interview. They were asked whether they had felt involved in the design process and how they perceived their participation in the technological design processes. In addition, they were asked how one could learn about the place value using the blocks. The teacher was asked about learning potential and how the blocks could be incorporated into daily lessons.

The children thought it was exciting that their voices were used as a part of the prototype. When the children were asked how they had influenced the study, it was particularly the use of their voices they mentioned. The use of their own voices gave them a special ownership of the project, which their teacher also underlined during the interview. The children could also recognise their own and each others’ voices:

Child 2: “... You have listened to our ideas, to use our voices I can hear my own voice and it’s fun ... I say something with a 100 in the game” (6:44)

The teacher: “They’ve been looking forward to this enormously, there is no doubt about that. It has been on the top of their wish list. The children have also experienced it as exciting and rewarding to be part of the process.” (teacher 1:02:52).

The children were asked how one could learn about the place value by using the blocks. This was difficult for them to explain, but they gave examples, of how they had pronounced large numbers, and how they had compared the number sizes. They also explained how they had competed to make the largest number.

The teacher thought that one obvious use of the blocks was as part of the so-called ‘math workshop’, where the children work in groups with physical artefacts, practical exercises, and games to improve their skills.

The teacher was asked about learning potential and if the blocks had some benefits over pen and paper. He emphasized that the blocks could ‘communicate’ on several channels: “They (blocks) speak to many channels at once; they (children) are faced with blocks and feel them. So it’s something tangible for them, they get it aurally because they hear the sounds ... It is so immediate – it is so easy to switch (the blocks) around.”(Teacher, 1:06:10)

The teacher felt that the blocks appealed to both auditory and tactile channels, as well as the visual channel through the string of digits that the blocks have in common with printed representations of number. In addition, the blocks’ physical form provided the teacher a good opportunity to talk with the children about figures, and the modularity made it easy to swap the digits around.

7 Learning Potential

In the following section we describe the learning potential of Number Blocks. We will argue that Number Blocks fruitful can be a way to integrate play and fun into mathematics education, and they can play an including role to support and engage pupils who typically find little or no interest in mathematics. Furthermore, the blocks’ relation with the sound of number names sparked an interest to utter larger and larger numbers, and finally, the size of the blocks made them very useful for collaborative activities and allowed a different context for mathematical activities.

1. Play. The children obviously enjoyed to play with the blocks, and to put them together to form structures. The children also liked to create larger and larger numbers and to compete with each other. Children in the second grade usually work with hundreds and thousands, but in our sessions they produced much higher numbers just for the fun of it.

It is obvious that the block format helped the children to create numbers. This came up consistently throughout the session. The children described the process as: “It is so immediate – it is so easy to switch the building blocks around” (child, 1:06:10). One of the children described the building process like this: “You can put the numbers together in new ways and go on and on” (child, 8:44).

The playful aspect fits nicely with Vygotsky’s ‘zone of proximal development’ in play. In play, the child can pronounce bigger numbers than s/he can when not playing and the child will behave “as if it was older”. The zone of proximal development is the distance between what the child can learn by itself and what can be learned in collaboration with peers or with a teacher (Vygotsky 1978, p.86). The playful approach in Number Blocks has the potential to bring the children to play and learn in their zone of proximal development.

2. Inclusion. During the interventions, it seemed that children developed an interest in mathematics when they played with these ‘digital blocks’. This is no surprise, since the interventions in the classroom represented something new and different from the typical mathematics class. The teacher’s evaluation supported the impression that the blocks directly supported the so-called “weaker” pupils:

“It has helped them, I’m quite sure it has. xx finds it really hard to pronounce numbers and we get assistance from the learning support center to identify what is wrong. (...) But here she realized that if she placed a new digit in front of the number it became larger...it became so real for her when she interacted with the blocks (...) Some of the brightest pupils, such as yy and zz, they could pronounce any of the major numbers but the rhythm has now given them a structure.” (Teacher, 38:39)

Our observations and the teacher’s judgment suggest that Number Blocks can be an efficient way to support mathematical activities because the typical power structure in the mathematical classroom is turned on its head, which supports the “weaker” students.

3. Rhythm and number names: by allowing an interaction with the sound of number names, the blocks sparked an interest in saying larger and larger numbers. The teacher pointed out the special rhythm in the application: “They (the blocks) have such a rhythm, take for example 99.999, it becomes quite clear for them (the children) what are thousands hundreds and so on ... and they start to use the rhythm, when they say the numbers. And I think it’s good for them, it becomes real for them and then they use the rhythm too ... and the rhythm that has given them a structure for pronouncing big numbers. ... The (system) has helped them to structure the pronunciation.”(Teacher, 52:00)

The rhythm is a direct consequence of the consecutive playback of the bits of the children recorded pronunciations of the individual numbers – such as “one”, “two”, “ten”, “twenty” and “hundred” along with the binding word “and”. The software combines these different recorded bits into a structured sequence, which makes the computer’s pronunciation much more predictable (rhythmic) than that of an adult.

Maybe the rhythm became important because the digital spoken numbers had a very transparent and rhythmic structure. The combination of the visual representation and the transparent rhythm of the number words, made the combination of these two semiotic registers natural when playing with the blocks.

4. Collaboration, Gesticulation and Building. The size of the blocks invited to play as a group activity. Experimentation was a big part of the overall design idea. We observed children who used their body/hands as part of a reasoning process; several times where a group of pupils were given three blocks with fixed digits, and told to find the largest possible number. Some of the children would use their hands to show how to move the blocks around, while they uttered the target number for their manipulation. This shows that the blocks can facilitate a mathematical activation of the bodily register in a structured way.

5. Bridging contexts. Creation of numbers from blocks was a new context for the children. In a ‘normal’ block context the children would have used blocks to build towers or quirky LEGO constructions; this can be described as a playful context. The new context for the numbers gave the children an opportunity to combine numbers and make them larger or smaller simply by manipulating the blocks. It made it clear to children that the digits were specific components. The learning tool combines a playful context and a mathematical context, and this connection between these contexts help the children to work in a new and fruitful way.

The children in second grade work normally with pen and paper. In this project, the children used their knowledge of numbers in a new context. This new context was tactile, interactive and auditory. Using knowledge in a new context made children adapt. Adaptive learning means that the child uses its knowledge in a new context. The child adapts to the new context in an optimizing manner. Bateson describes this as learning to learn or “Deutero-learning” (Bateson 2000, p.159). In this process the learner’s learning strategy improves subconsciously. This is the most common form of learning, and planning and implementing of courses will often be based on this type of learning. The core elements in this type of learning are: adaptivity, optimization, new contexts, collaboration, processes of change, and qualities of interaction.

8 Technological and Interaction Insight

The development of the Number Blocks application added a few new features to the existing software framework for the I-BLOCKS. To be useful for this experiment the Number Blocks had to support a higher degree of structure recognition than earlier applications. This structure recognition is the system’s ability to determine the sequential structure that a user has built. The solution was to make the ‘result’ or ‘master’ I-BLOCK record this structure when it was connected at the end of the structure, so it would transmit the correct number to the PC for playback. This solution also paves the way for new applications, such as work with letters, words, musical notes or other sequential material. Our experiments demonstrated that it is possible for the users to ignore the PC. This means that, in the case of the Number Blocks application, the PC is merely a playback device, with which the user has no direct contact – it might be placed at the opposite end of the room because of its radio connection to the master block. Conceptually speaking, the user might actually find it more natural if the actual feedback came directly from ‘the master’ block. We did however not get any indications on this through our experiments. Making ‘the master’ block do the actual audio narrative feedback would demand an electronic audio extension that would have the ability to play back sampled audio. Such an expansion is already planned and will in the future provide the possibility of working with many kinds of sample-based audio feedback.

Our studies demonstrated that the I-BLOCKS as a solid physical building-block platform has the potential to embody abstract learning material through playful interaction and collaboration. The children obviously enjoyed connecting and disconnecting I-BLOCKS, and appreciated the freedom and flexibility that the building-block approach offers through its inherent modularity. From the first intervention, we learned that the children were very curious about the actual electronic and mechanic functionality of the I-BLOCKS. They even asked us if we would take apart one of the I-BLOCKS, so they could see the components inside, which we did right away. This request showed us that the children's curiosity was not limited to play only with the content we provided them, but that they wanted to explore and understand as much about the system as possible – perhaps to be able to better exploit its functionalities. In our view, the children's extensive exploration of the system was a natural consequence of the interactive hands-on experience. The fact that the system is physical makes us relate to it in a very concrete way and to investigate it in a very concrete way – by taking it apart or handling it so as to experience its weight, material feel, smell, temperature and other physical features. The I-BLOCKS could be compared to a hand tool and it can be described as “a device for performing work on a material or a physical system using only hands”. Similarly the I-BLOCKS are a tool for performing work on digital material using only hands. The digital material is immediately instantiated as physical feedback, in this case audio, and thus gives the user the feeling of working with genuine physical material.

When we work with computers, the user's curiosity is stimulated by the visual feedback provided by the screen. The screen of the screen-based technology is a window to the very soul of the device. In the users' mind the screen directly reflects the capabilities of the device – there is little point in a physical investigation of the device. All interactions are fed back through the screen. The screen is the main medium towards which we must direct our attention.

With the I-BLOCKS, the lack of a screen reduces emphasis on the user's visual senses and thus gives more importance to other senses such as touch and hearing, and it allows the user to collaborate better with other users through a common interaction with the system.

9 Summary and Conclusions

The questions explored in this paper are: How can technology that combines building block interaction and sound modality, support place value learning? And what are the learning potentials?

The I-BLOCK technology combines audio and physical interaction. This gives the learners hands-on experience with place value learning. The interactive blocks gave the children new opportunities for active participation. We believe that active participation is closely related to successful learning processes, which is supported by Wenger and Schön, who also believe that new knowledge is developed through

active participation in a social context (Wenger 1998; Schön 1983). Reflection during and after the interactive learning activity also plays an important role in the learning process (Schön 1983). That's why the mathematics teacher has an important didactical role. The blocks can add new ways of participation and the teacher can add to the learning process by helping the children reflect. Our teacher felt that he did so when he guided the children through the I-BLOCK activities.

We found that I-BLOCKS contributed to the learning process in several ways: (1) The blocks combines mathematics and play; (2) They included and supported children at different academic levels; (3) The sound as a representation and the rhythm helped the children pronounce large numbers; (4) The size of the blocks made it easier for the children to collaborate and for the teacher to intervene, and the modular block concept gave the children a new perspective on building and combining digits; (5) Bridging contexts. The children were playing, interacting, building, and learning about place value at the same time. This created a new context for the learning of mathematics.

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