EARLY MATHEMATICS INTERVENTIONS: Supporting young children with low performance in mathematics

A range of mathematical skills is needed in everyday life. For most of us, applying mathematical skills is an easy routine, but for some people, these tasks are extremely challenging. For example, while shopping, knowing that a 50% discount means the same as getting the item for half price makes the calculation of the final price quite easy – presuming that you understand what the concept of half means, and that you know how to divide the price by two. Another example comes from travelling. In order to travel from A to B on time, you need to know how to read timetables and tell the time, and estimate the total time needed for travelling. Cooking, on the other hand, requires understanding measures used in recipes. How much is one hundred grams of bacon? What about one quarter of a teaspoon? What if the recipe is for four persons, but there are six people coming for dinner? Do they just get smaller portions, or should you do some calculations with the measures in your recipe? Furthermore, a growing body of technological applications provide us with numerical data. For instance, you can track your sport activities. But without understanding the numbers, they may just be meaningless symbols.

About 3 to 6% of the population have severe difficulties in mathematics, namely mathematics learning disability, also called dyscalculia. Even though these people show average intelligence and have received good mathematics education, they have severe difficulties in basic mathematical skills, especially in arithmetic. Instead of being able to give the right answer to an arithmetic problem such as $3 + 5$ or $11 - 4$ quickly, they use slower and error prone strategies, for instance counting with the help of their fingers. Having problems in basic mathematical skills makes it challenging to cope in everyday situations that require using and applying mathematical skills, be it at school, at work, or during spare time. Even milder mathematics difficulties often have a negative impact on learning more complex mathematics. In the school context, in every classroom of around twenty students, there are about four to five students who have significantly weaker mathematical skills compared to their peers, one of them having severe difficulties.
There is already a wide variation in children’s early mathematics performance before formal schooling. The influence of early mathematical skills seems to be strong in predicting mathematics development. The longitudinal studies show that children, who perform low in their early mathematical skills, often show low performance also later on, and the achievement gap between them and their average performing peers also widens.

During their early childhood years, most children learn mathematical skills that will provide a foundation for their later, more advanced mathematics learning. Current research suggests that the foundation for mathematics development is grounded in a nonverbal number sense, identified as two systems for tracking quantity. Subitising, an exact number system for small quantities, allows for fast and exact recognition of small quantities, such as seeing the number of dots on the dice without counting one-by-one. The approximate number system helps us to estimate large quantities approximately, for example, you can quickly say that there are more blue dots (50) than yellow dots (30) in the picture. Furthermore, children learn to make associations between quantities, number words and number symbols. For instance number word ‘five’ can be associated with five fingers or the number symbol five.

The only way to define quantities accurately is to use counting with language. Verbal counting refers to producing a sequence of number words, such as ‘one’, ‘two’, ‘three’ and so on. In object counting, the number of objects in a set is defined with the help of verbal counting. In order to get a correct answer to a ‘How many?’ problem, the child also needs to know some counting principles. For instance, pointing and saying only one number word for one object, knowing that each object can be counted only once, and that the last number word said out loud represents the total number of objects.

By learning counting skills, children are able to compare the difference between two sets of quantities accurately. Ordering skills enable children to arrange quantities and numerals in order, for example from the smallest to the biggest number. Estimation is a process of solving a problem, in which a rough evaluation of a quantity or number is needed. For example, estimation can involve approximating the answer to a measurement problem, such as how many kilometres it is to school.

Early addition and subtraction skills include operating first with small numbers using fingers and objects, and using different verbal counting strategies to find the answer to a problem. Later, more developed strategies, such as retrieving the answer quickly from the memory or deriving the answer through known facts, are used.

This thesis focused on investigating the effectiveness of early mathematics interventions for children performing low in mathematics. Intervention was defined as a planned modification of the environment, done for the purpose of altering behaviour in a pre-specified way. In the context of early mathematics interventions, this means implementing a specific mathematics programme for a specified group, in a specified time frame and of certain intensity, in order to improve mathematics performance. The goal of the early mathematics interventions is to boost early skills, so that these skills allow children to understand better the concepts and procedures needed to attain more complex mathematics later on.

To be considered as evidence-based, intervention should undergo a well-designed and robustly implemented experimental study. This means conducting a systematic experiment with methods that have proved valid, and reliable data, a thorough data analysis, and a detailed description of the participants, setting and methodology. In addition, a study has to be
accepted by an objective review such as a peer-reviewed journal. Based on the evidence gathered from the studies concerning one particular intervention, its effectiveness can be rated, for instance, as having a positive, mixed or negative effect, in order to guide educators in choosing the most effective intervention for their use.

To complement and extend previous research in the field of early mathematics interventions, four studies were conducted. One of the studies focused on reviewing early mathematics interventions, and the other three were targeted on investigating the effectiveness of two early mathematics intervention programmes. In the following, the main findings of these studies are presented.

Study one reviewed early mathematics interventions aimed at 4 to 7 year old children. In the majority of the interventions, the mathematical skills of the participating children improved more than the skills of the children in control groups. Progress in mathematics learning was evident when instruction included one or more of the following instructional features: explicit instruction, peer-assisted instruction, concrete-representational-abstract sequence, computer-assisted instruction or playing mathematics games. Explicit instruction means that mathematics concepts and strategies are modelled for children step-by-step, and this is followed by opportunities for guided and independent practice, and continuous feedback. Peer-assisted instruction involves pairs of students working collaboratively, and enables peers to provide an answer or suggestions that help them solve the problem. The concrete-representational-abstract sequence is a three-phase process that involves first using concrete objects, gradually advancing to pictures that represent objects, and finally to the abstract level using numbers and symbols. Playing mathematical games either as board games or on the computer were also found to be beneficial.

In the second study, RightStart Mathematics instruction was provided for kindergarteners in general education classrooms. First, the material was translated into Finnish. Kindergarten teachers used RightStart Mathematics approximately twice a week during seven months, and it replaced the typical mathematics instruction provided. Children’s mathematical skills were measured before the instruction phase and immediately after the instruction phase, and in the first grade. The results showed that RightStart instruction was as effective as the typical Finnish kindergarten mathematics instruction received in the control groups. The counting skills of the initially low-performing children improved to the level of their typically performing peers. Follow-up in the first grade revealed performance differences between the initially low- and typically performing children,
highlighting the importance of remaining continuously aware of the children’s mathematics performance level, and of providing them with opportunities for slowing down and practicing skills that are challenging.

Children with specific language impairment, SLI, often have difficulties in learning mathematics. Surprisingly, there are hardly any mathematics interventions targeted for this group of children. In the third study, RightStart Mathematics instruction was provided for children with SLI, in special education classrooms. The study procedure was similar to that of the second study. Children with SLI began their kindergarten year with significantly weaker early mathematics skills compared to their normal language-achieving peers. After the intervention phase, the counting skills of children with SLI had improved to the level of their peers without language impairment. In the first grade follow-up, the children with SLI performed similarly to their peers in addition and subtraction accuracy skills and multi-digit number comparison, but showed weaker skills in arithmetical reasoning and in matching spoken and printed multi-digit numbers.

At the moment, there is a lack of research-based mathematics programmes in Finland. In study four, an intervention programme Improving Mathematics Skills in the Second Grade was developed. Its effectiveness for second graders identified as performing low in mathematics was examined. Intervention was given in small groups of five to six children, in twelve 45-minute sessions over eight weeks. Mathematics skills were measured three times: before the intervention phase, and immediately and three months after the intervention phase. A two-month training, concentrating on counting skills and conceptual place value knowledge, did not improve the mathematics skills of the second graders participating in the intervention more than those of the low-performing children in the control group. However, this study provided valuable information about the functionality of the programme’s intensity and content that can be taken into consideration in future development work.

This thesis provides several theoretical and practical implications. The results indicate that rather than waiting for children to fail in mathematics, mathematics interventions can be used successfully to promote the early mathematics skills of children with low performance, already before the onset of formal schooling and in the early grades. Therefore, I argue that identifying low performance in mathematics and providing sufficient support should be emphasised already in early childhood education, in order to reduce the emergence of mathematics learning disability later on. Effective instructional features in mathematics, such as explicit instruction, were identified. These can be used in mathematics instruction for young children with low performance in mathematics. Furthermore, the effectiveness of two mathematics programmes were investigated, for the first time in Finland. In future intervention studies, more attention should be paid to having larger sample sizes, using active control groups in addition to passive ones, and especially to the fidelity issue. This means that observations, such as video recordings, should be made in the classrooms, in order to find out if the teachers implement the intervention programme as initially intended.

Using follow-up measures in intervention studies provided a longitudinal approach for examining the effectiveness of the interventions, which has been rather neglected in previous

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mathematics intervention studies. Finally, this thesis demonstrated the complexity of interpreting and comparing the effects of different interventions, and conducting interventions in kindergartens and in schools. These were mostly related to methodological issues, such as, the type of reference group and participants, and the measures used. There were also practical issues that have to be taken into consideration while doing field research in schools together with teachers, such as training teachers to use assessment and intervention materials.

Educators should have easy access to mathematics intervention programmes that have been shown to improve mathematics learning outcomes. However, it takes time to include evidence-based practice in everyday school practice, because developing and investigating the effectiveness of an intervention programme is a slow research process. There is evidently a need for evidence-based mathematics intervention programmes in Finnish kindergarten and school practice, and therefore, further intervention studies in this field are needed.