The dyscalculia simulator: A developmental project targeting teachers


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English abstract: *In this developmental project we present a first version of a dyscalculia simulator. The goal was to support mathematics teachers to better understand the difficulties students with dyscalculia experience in mathematics lessons. We therefore developed a virtual classroom where it is possible to experience some of the same difficulties as a person with dyscalculia would in a mathematics lesson. The simulator was tested on teachers and student teachers. The results show that the dyscalculia simulator has the potential to provide insights and reflections on how students with dyscalculia experience the processing of numbers and numerical information typical of school mathematics.*

Background

Dyscalculia and severe mathematical learning difficulties come with a cost, both for the individual and for society (Mikkelsen et al., 2023). The impact on daily life and academic performance has been documented in several studies on adults (e.g. Vigna et al., 2022) and in interviews with children with severe learning difficulties in mathematics (Egmont, 2023). Research on dyscalculia is relatively limited in a Scandinavian context (Epinion, 2020; Bengtsson & Larsen, 2013). Although there is no clear consensus on a definition on what constitute dyscalculia, there seems to be an agreement that dyscalculia is associated with severe difficulties with understanding and operating with numbers that cannot be explained by other learning difficulties or low IQ (Price & Ansari, 2013). In this project we have been guided by the definition proposed by Bengtsson and Larsen:

> "Dyscalculia is a disability that can have a negative impact on an individual's educational and working life. The condition centres around deficits in numeracy skills that are not matched by similar deficits in other areas. The specific numeracy difficulties include striking difficulties in understanding and dealing with basic number processing, such as comparing numbers and quantities or counting a small number of objects. Subsequently, addition, subtraction, multiplication and division are noticeably difficult. The condition does not necessarily include difficulties with more abstract mathematics skills in algebra, trigonometry, geometry and complex calculations. We do not refer to dyscalculia if the cause of the difficulties is mental retardation or inadequate schooling. However, the condition can include cognitive problems such as poor semantic memory and working memory." (2013: 17, our translation)

People without dyscalculia often cannot comprehend the difficulties a person with dyscalculia experiences. This is also the case for mathematics teachers. If you cannot comprehend the difficulties it can be difficult to spot and act on them as well. With this developmental project we wanted to investigate how we can create a better understanding of the difficulties students with dyscalculia experience, especially in the mathematics lessons in a school context. In this project we seek to answer the following questions:

- Can a simulator experience provide a deeper insight into how a student with dyscalculia experiences a mathematics lesson and the processing of numbers and numerical information typical of school mathematics?
- Can this insight support mathematics teachers in planning and organising classroom teaching to better support these students?

Here, we present a first version of the Dyscalculia Simulator. The process of development is outlined and future possibilities are discussed. The work presented in this paper is based on a bachelor report by four of the authors (Davis et al., 2023).

Teacher empathy and learning

Several studies have found teacher empathy to be important for students' learning (Meyers et al., 2019), therefore supporting teachers in developing their empathy for students with dyscalculia seems promising. Teacher empathy is defined by Meyers et al. (2019: 161) as:

> "the degree to which instructors work to deeply understand students' personal and social situations, feel caring and concern in response to students' positive and negative emotions, and communicate their understanding and caring to students through their behavior."

Simulation can make it possible to learn through experience and create empathy for others' situations. This has proven to be successful using video games (Pallavicini, 2020; Tong et al., 2017) and simulations (Billon et al., 2016). Increasing teachers' empathy for and understanding of students with dyscalculia is important, as students with learning difficulties may also present different behavioural problems such as aggressive behaviour and irritability (e.g. Park et al., 2024).

Simulations as tools for learning

Using practical experience and simulations as tools for learning has proven efficient in several contexts. In the education of health professionals, several studies have shown that simulations can support the teaching of subjects that are difficult or too abstract to experience in practice (Issenberg et al., 2008). One such example is the study of Billon and colleagues (2016). In their study a training course simulation was designed to enhance nurses' understanding of the health needs of patients with intellectual disabilities. Their findings showed that nurses participating in the simulations were able to highlight key issues in their practices and to adjust their practice to better fit the needs of their patients. Although the simulation was designed with persons pretending to be patients, the purpose of the study was very similar to our intention: to support the improvement of communication between the nurse and patient, or in our case, the teacher and student.

An example of how a virtual reality game situation can provide the participant with experiences is the FestLab VR application (Vallentin-Holbech & Majgaard, 2020). Here the participant gets first-hand experience of the potential consequences of being drunk at a party. Likewise, a simulation providing the participants, for example teachers, with experiences of having severe mathematical learning difficulties could enhance their understanding of the difficulties and increase their empathy for people with dyscalculia or severe mathematical learning difficulties.

Simulations as learning is related to the four stages of learning in Kolb's experiential learning cycle (Kolb, 1984). The first stage is focused on engaging in a new activity or experience. Here the learners achieve a *concrete experience* with the situation or content of the activity. In the next stage the learners *reflect on and observe* the experiences from different perspectives, for example the emotions and physical and sensory aspects of the experience. The third stage, the *abstract conceptualisation* stage, is where the learners develop generalisations or theories based on the observations and reflections, and this involves developing abstract ideas or concepts that can be applied to similar situations. In the final stage the learners apply their new knowledge and test their theories through *active experimentation* in new situations, thus building on prior experience and refining their understanding of the topic.

The aim of the current developmental project is to focus on the first stage, that is, creating an interactive experience to help teachers reflect on the difficulties of students with dyscalculia or severe mathematical learning difficulties. However, in the trialling of the simulator, the participants will go through stage two and to some extent stage three, as they will be asked to reflect on and observe the experience as well as discuss and develop ideas for teaching that can be applied in real life situations with students in the classroom.

Developing the simulator

The work with the dyscalculia simulator is inspired by similar simulators for dyslexia, such as Dyslexia Simulator (n.d.) by Harvard University and others featured on the PBS website (n.d.). These simulators generally work by scrambling letters shown in a text, requiring a person to concentrate in order to discern what has been written. We chose a similar approach with the dyscalculia simulator.

The aim was to design a simulation that would recreate the feelings and frustrations that a person with dyscalculia can experience when participating in a typical mathematics lesson. The design of the simulator was guided by research on simulations as tools for learning and creating empathy, as described above, and interviews with expert researchers and practitioners as well as two persons with dyscalculia. Based on this we developed a series of tasks typical of a mathematics lesson and manipulated them to simulate the difficulties a dyscalculic person would experience. The tasks concern reading numbers, reading time on an analogue clock, doing simple calculations, paying with cash in a shop situation, measurement and reading a ruler and lastly using a calculator. These tasks were tested in a real-life analogue setting (low fidelity prototype) as described below.

One example is a calculation task written in blue but disguised with red text and drawings making it difficult to find the numerical information necessary to perform the calculations. The participant was given a tool, a piece of red film, which helped highlight the numbers in the tasks (Figure 1A). The calculator on which the partici-

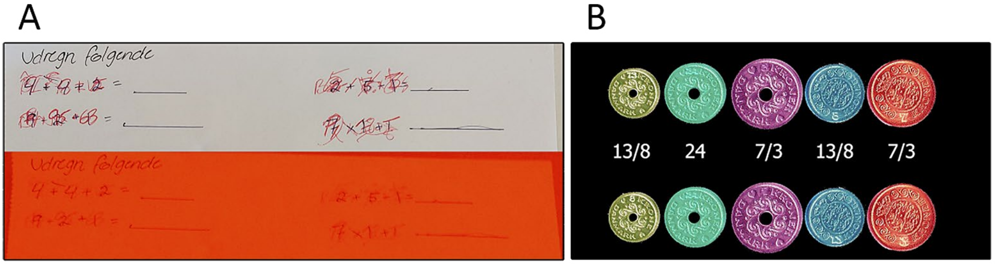

Figure 1. *A: Examples of the arithmetical tasks where the numbers are disguised with red and when the tool 'removes' the red making the blue numbers stand out. B: The coins used in the shop situation. From Davis et al. (2023).*

pants were to do all calculations and provide all numerical answers was manipulated during the participants' work: numbers were randomly assigned and occasionally a random number was duplicated and thus another number disappeared, for example a situation where the calculater had two 2s and no 4. In the shop situation the coins were assigned different and atypical values making it a laborious task to find the correct amount (Figure 1B).

Testing the analogue prototype

The first prototype was tested on seven university students without mathematical difficulties to test whether the simulation provoked the intended feelings. Participants were informed about the aim of the study, that participation was voluntary and that they could stop at any moment during the session. Each participant completed a 25-minute session in a setting simulating a classroom lesson. The participants' actions and responses were videorecorded for further analysis. After the session the participants were debriefed about what they had been exposed to during the session and how they were deceived as part of the simulation. This is standard procedure in experiments where participants are deceived in any way (American Psychological Association, 2017, section 8.07 and 8.08). The debriefing is to allow dehoaxing to occur and to reverse any negative effects the experience may have had (Fanning & Gaba, 2007).

The recordings showed that participating in the simulation induced strong reactions, with participants getting visibly irritated and feeling insecure, for example by saying "is this correct? If it is not correct, then I do not know what else to do." Overall, the participants exhibited the difficulties and behaviour very much similar to what can be observed with children experiencing difficulties in a classroom (Park et al, 2024).

To evaluate the use of the simulation with teachers, we asked a group of teacher students to describe what behaviour they noticed in the video recordings of the analogue prototype and reflect on how students with dyscalculia or severe mathematical difficulties could be supported in the classroom based on the observed reactions of

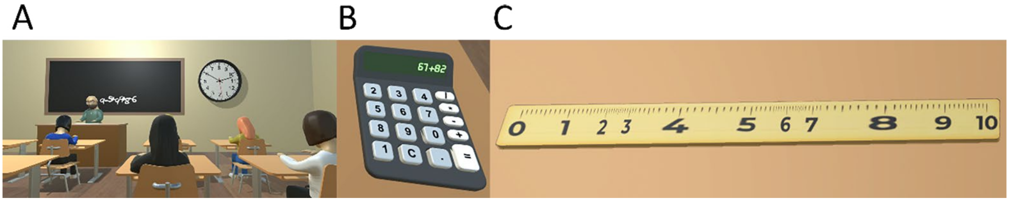

Figure 2. *A: The virtual world: a classroom setting as seen from the participant's 'desk' in the classroom. The teacher is standing by the blackboard, and he gives oral instructions throughout the simulation. The participant can 'look down' on the table in front of them, where the different assignments and a calculator are placed, or 'look up' to see assignments on the blackboard or when asked to read the time. B: The calculator is used to submit all answers. During the session the numbers on the calculator are manipulated. The position of the numbers shifts whenever the participant is navigating to the task (and cannot see the calculator on the screen) and occasionally a number goes missing. In the shown situation, the calculator has been manipulated so 4 is missing and there are two 2s. C: The ruler is used as a tool to read the numbers in a task and for measuring the length of a rectangle. The numbers are constantly moving on the ruler making it difficult to ascertain the correct length. From Davis et al. (2023).*

the participants. The students provided written notes on a) the observed behaviour of the participants in the videorecording of the simulation, b) what elements in the teaching activities and the context enforced or remediated the participants reactions and c) what parallels, if any, they could see to their own experiences with classroom teaching.

Development of the digital prototype

In this phase we focused on developing a virtual world and translating our concepts into a digital interaction. The virtual world is a classroom where the participant is situated in the back of the class and the teacher is standing in front of the class by a blackboard and an analogue clock is pictured on the wall beside the blackboard (Figure 2A). Throughout the simulation the participant is asked to read the time. A calculator and a ruler are placed on the participant's table (Figure 2B and 2C). All calculations and answers have to be submitted on the calculator. The ruler has a double function: it can assist in making numbers easier to read (Figure 3B) and it is used in a measurement task. During the simulation the participant works with different tasks that are manipulated to simulate the cognitive demand of reading and processing numerical information that a person with dyscalculia would experience and the emotions this could inflict.

Figure 3. *Examples of tasks in the simulator. A: During the 'lesson' the participant is asked to read the time on a manipulated analogue watch. B: The tasks written on paper flickered to make it difficult to read the numbers. Placing a ruler underneath the numbers in the task would freeze the numbers. From Davis et al. (2023).*

The first task is a set of arithmetical problems. Here the numbers are manipulated to flicker, making it difficult to read the numbers and operations, and the participant needs to use the ruler to stabilise the numbers (Figure 3B). When asked to read the time, the analogue clock is manipulated in different ways on each occasion (Figure 3A). Other tasks were doing calculations written on the blackboard, where occasionally a number or an operation was changed so the participant would give a wrong answer without realising why. Finally, the participant was asked to count a number of specific objects, for example triangles, on a picture with many different objects. When the participant gave their answer the tasks were manipulated to contain a different number of the objects, so the answer became wrong.

Debriefing was in the form of a video immediately after finishing the manipulation. Here one of the authors and an adult person with dyscalculia describes different aspects of the simulation and how the participant had been deceived in order to provoke the feeling similar to what a person with dyscalculia would experience. This was to ensure that the participant did not get a false understanding of the disability. For example, a person with dyscalculia does not experience numbers as flickering; the flickering is a way of provoke the feeling of frustration and inadequacy similar to what a person with dyscalculia could feel during a mathematics lesson. Furthermore, the video provides information on dyscalculia to support the learning experience of the participant. In this manner the debriefing is intended to enhance the learning outcome of the simulation-based learning (Fanning & Gaba, 2007).

Testing the digital prototype

To test the effect of the digital prototype we tested the simulator with six groups (72 students in total) of teacher students from UCL in Odense (students were in their first to fourth semester) and with 12 teachers from Bork Havn Efterskole. The test session involved pairing individuals, and one person went through the simulation (group A) while the other (group B) observed the reactions of the person participating in the simulation. Immediately after the session, the observer group B reported their observations and reflections on the participating person's (group A) reactions and any changes in behaviour or mood throughout the simulation. Group A participants completed a questionnaire after the test session wherein they were asked about their experience and mood during the session. Additionally, we ran a test with a group of 18 student teachers from VIA in Nørre Nissum, where all 18 student teachers participated in the simulation and completed the questionnaire. Participants were informed about the study before the testing, that participation was voluntary and that they could stop at any moment during the session.

The digital prototype was also tested in a similar manner by Pernille B. Sunde with a group of teacher students. After the simulation the teacher students discussed the experience and reflected on which aspects of the simulated teaching session and the teacher's behaviour triggered the different behavioural responses, and also whether they themselves had experienced similar behaviour with students in the classroom. The teacher students were then asked to discuss and suggest possible solutions and activities that would support students with dyscalculia and how teachers should engage with these students to meet their needs.

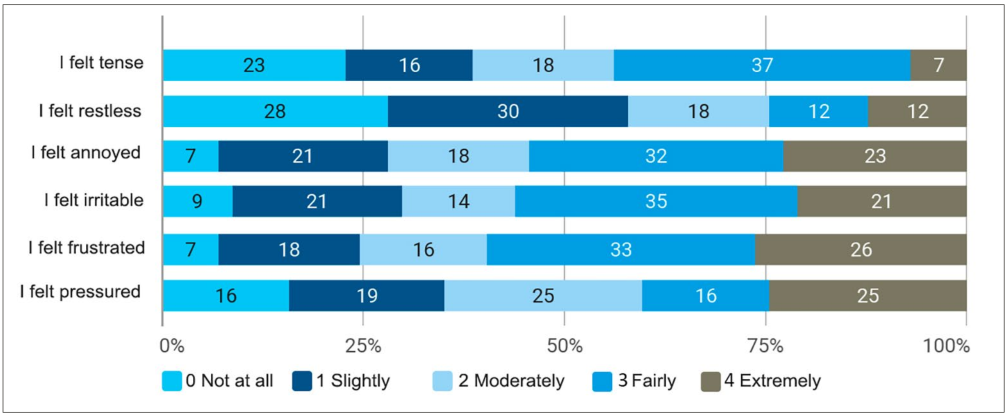

Figure 4. *The distribution of answers for 59 participants on their experienced emotions during the simulation on a scale from 0 (not at all) to 4 (extremely). The introduction to each question was: Please indicate how you felt going through the simulation for each of the questions. From Davis et al. (2023).*

Results of the questionnaire

The responses to the questionnaire showed that the simulation affected both those who participated in the simulation (Figure 4) as well as those observing a person doing the simulation (Figure 5).

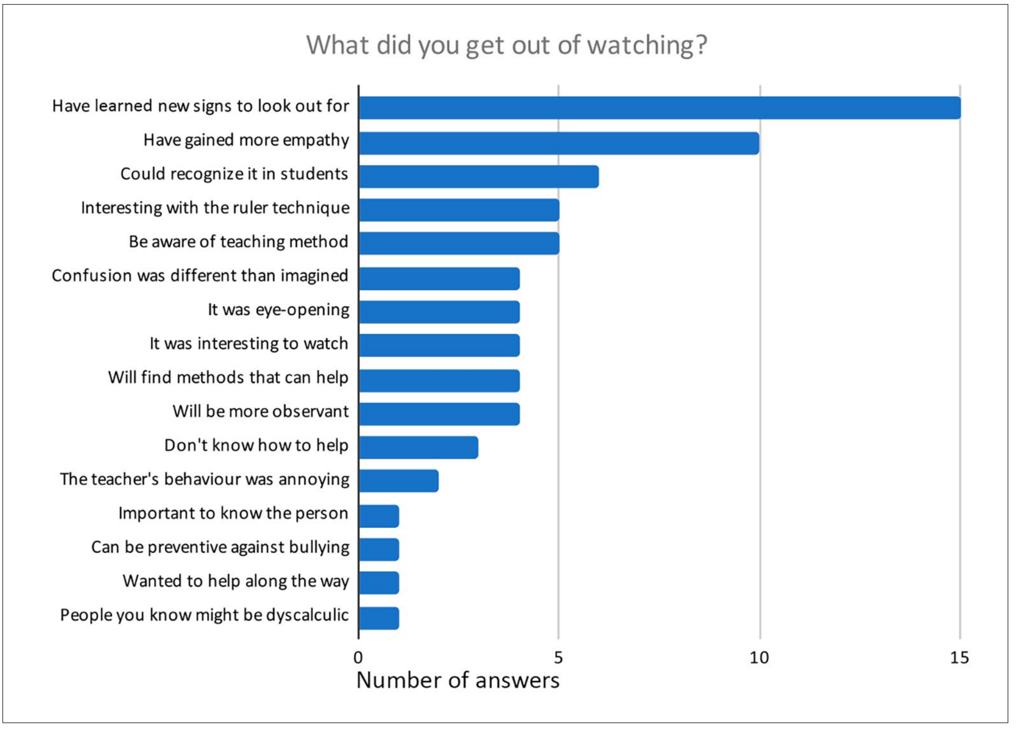

Figure 5. *The authors' categorisation of the observes' (n = 70) open answers to what their outcome and reflections were after watching another person participate in the simulation. From Davis et al. (2023).*

Overall results and discussion

From the video recordings of the testing of the analogue prototype we observed a range of behaviour typical for students in mathematical difficulties, such as frustration, loss of trust in own ability, resignation and indifference towards the tasks. This indicated that it was possible to construct a simulation with the desired effect. From the testing of the digital prototype with the teacher students we found that the video recordings provided them with an insight into what a student with dyscalculia endures during a normal mathematics lesson. The teacher students engaged vividly in discussions on what aspects of the tasks and "the teacher's" behaviour enforced or remediated the participants' experienced difficulties. This led to suggestions on how to support students in the classroom and reflections on their own experiences with students in the classroom as well as different aspects of their own teaching practice. From these results it seems that a dyscalculia simulator has the potential to provide insight into how students with dyscalculia experience a typical mathematics lesson, which can potentially influence teachers' teaching practice. It is important to be aware that what is presented here is the first steps in the developmental process. Although the digital prototype seems to work as intended, we need to perform more detailed observations of and interviews with teachers going through the simulation and the debriefing video.

Next step and perspectives

The next step is to develop an online platform where the simulator will be made available together with background information on dyscalculia. We further plan to investigate the effect of engaging with the content of the platform through a largescale study where we will measure the effect on teachers' attitudes towards students with dyscalculia as well as changes in the teachers' approaches to teaching these students. It would be particularly interesting to gain insight into the teachers' and also teacher students' possible solutions and activities to support students with dyscalculia. With this dyscalculia simulator we hope to be able to give teachers and future teachers a better insight into the difficulties a person with dyscalculia experiences in working with numbers and mathematics in school, and thereby be able to give these students the help and support they need.

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Author contributions

The idea and development of the dyscalculia simulator is the work of the four co-authors, Jacob Frølund Davis, Johan Kørvel Sørensen, Nina Genster and Simone Lindhøj Rasmussen, as a bachelor project in Science in Engineering (Game Development and Learning Technology) at Syddansk Universitet (Davis et al. 2023). They all contributed equally to all aspects of the project. Pernille Bødtker Sunde has provided feedback on the development and trialling of the simulator and assistance in writing the paper.

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Dansk abstract

I dette udviklingsprojekt præsenterer vi en første version af en dyskalkuli-simulator. Målet var at støtte især matematiklærere til en bedre forståelse af de vanskeligheder, elever med dyskalkuli oplever i fx matematiktimerne. Vi udviklede derfor en simulation, et virtuelt klasseværelse, hvor fx en matematiklærer, kan opleve nogle af de samme vanskeligheder, som en person med dyskalkuli oplever i en matematiktime. Simulatoren blev testet på lærere og lærerstuderende. Resultaterne viser, at dyskalkuli-simulatoren har potentiale til at give indsigt i og refleksioner over, hvordan elever med dyskalkuli oplever det at skulle arbejde med tal og udføre almindelige regneoperationer i en typisk matematiktime.