Design and evaluation of Maths related programs for special education

Brigitta Réthey-Prikkel, *rpb@ludens.elte.hu*
Dept. of Media & Educational Technology, ELTE University, Hungary

Márta Turcsányi-Szabó, *turcsanyine@ludens.elte.hu*
Dept. of Media & Educational Technology, ELTE University, Hungary

Abstract

Dyscalculia means the partial lack or error in the counting ability, which is not to be mistaken by acalculia, where these are totally absent. Dyscalculia can occur within any level of intelligence and is a type of disturbance that is typically noticed in school, but is less researched than dyslexia. There is a whole list of syndromes that could indicate dyscalculia and it needs a complex dyscalculia testing by psychologist, neurologist, and logopedia specialist in order to determine the exact type and syndrome of the disturbance, after which any possible treatment could be started. Even though it would be possible to set up diagnosis at the early age of 5, there is no standard dyscalculia test in Hungary, which could determine – with great probability – the fact of being endangered.

TeaM lab provides courses within ELTE teacher training as non-compulsory electives, with relation to developing e-learning materials and running projects in public education, where students develop programs for different curriculum areas, take them out for use in schools and prepare a report about their effects in classes, suggesting some areas of possible modifications for improvement. There is an active collaboration between ELTE Bárczi Gusztáv Practice Elementary School and Methodological Centre for Special Education and TeaM lab since 2003 to develop ICT tools supporting their pedagogical program and hold experiments to evaluate their effective use.

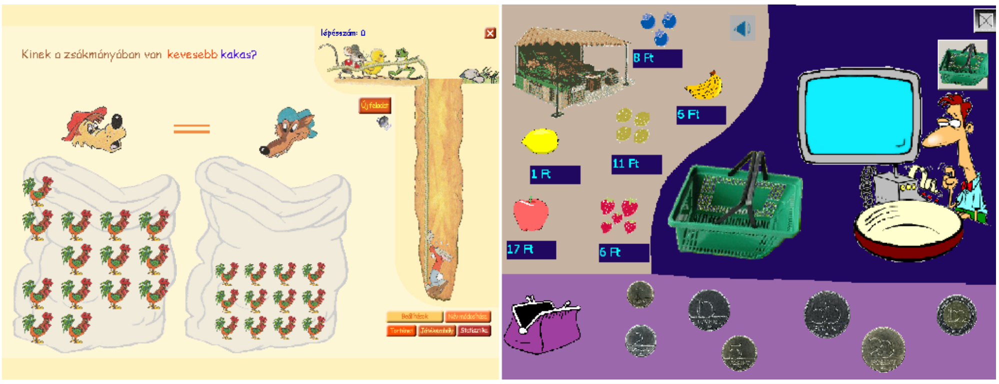


Figure 1. Screen shots of two programs: comparison of quantities and purchase with money.

The paper discusses requirements forced on the developed programs that emerge from practical experiences, the development process is analysed as well as the formal and pedagogical evaluation. Three tests have been used to measure levels of achievement, the Hiskey-Nebraska Test of Learning Aptitude (H-NLAT) and change in skills, the mathematical ability test created at Bárczi Gusztáv Faculty of Special Education, and a general test on fractions. The results are reported and shall be presented at the session.

Keywords

ICT, game design, children with special needs, developing skills

Dyscalculia diagnosis and treatment

Dyscalculia means the partial lack or error in the counting ability, which is not to be mistaken by acalculia, where these are totally absent (Hrivnák, 2003). Dyscalculia can occur within any level of intelligence and is a type of disturbance that is typically noticed in school, but is less researched than dyslexia (Mesterházi, 1996). Due to cultural reasons the society is much more forgiving if a child has problems in maths then if (s)he cannot read properly, or writes with bad spelling (Kulcsár, 2005).

There is a whole list of syndromes that could indicate dyscalculia, just to extract a few problematic areas: perception, recognising numbers, understanding the concept of numbers, leaving out some numbers when calculating, going over 10, understanding and performing functions with fractions, considering signs when subtracting, poor mathematical logic, use of symbols, serialising numbers, grouping, understanding ratios, time, volume, dimension, … etc. (Mesterházi, 1996; Hrivnák, 2003). It needs a complex dyscalculia test administered by psychologist, neurologist, and logopedia specialist in order to determine the exact type and syndrome of the disturbance, after which any possible treatment could be started. There are several motives, which could indicate that a child might be endangered and thus needs to be thoroughly diagnosed, example: when (s)he is late or retarded in speech, lisps, or is dyslexia endangered; in other cases there might be problems with visual or acoustic perception; or even problems with memory, large or fine motoric functions. Even though it would be possible to set up diagnosis at the early age of 5, there is no standard dyscalculia test in Hungary, which could determine with great probability the fact of being endangered and could be administered on a large population for filtering purposes.

Therapy includes developing skills using personalised programs for developing mathematical abilities and increased use of demonstration, e.g.: Montessori-tools, coloured rods, using fingers (Mesterházi, 1996) and should increase levels of perception, concentration, memory, thinking, language skills, establishing basic mathematical concepts on numbers and their use in measurements, functions and symbols, … etc. (Hrivnák, 2003).

The binding situation

The curriculum for special needs schools

Because of the special needs of the pupils, the school's curriculum is different from that of the usual. Here pupils need much more learning time than most children and they are definitely granted extra time. The Hungarian National Curriculum (NAT, 2003) emphasises within the general issues of obligatory schooling for handicapped children's training and teaching:

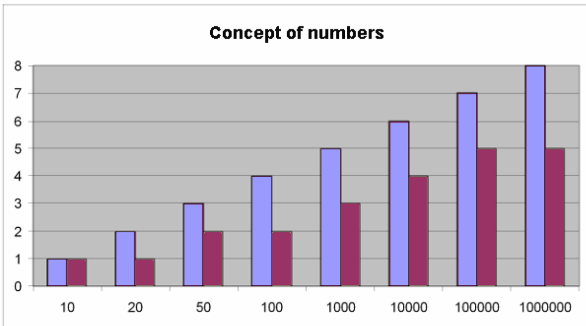
„In case of pupils with special educational needs, the following primary principles must be applied, while being adjusted to individual needs and limitations:

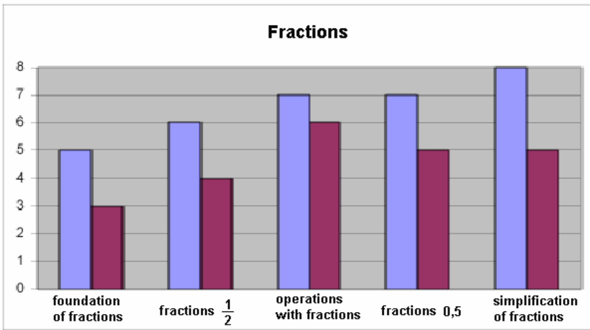
- Extended time periods must be given to accomplishing tasks, as needed;
- If necessary, special content and requirements must be developed and used in accordance with the nature of their disability;
- Schools must use positive discrimination and differentiation with these pupils, providing them with individual help and assess them mainly on the basis of development in light of their condition.

The special tasks required in case of certain disabilities are governed by the guidelines for the curriculum of pupils with special needs as well as examination regulations." (NAT, 2003)

The Hungarian curriculum for special needs children suggests that children with learning difficulties needs two years in order to master the materials defined in first grade, and for the first two grades material three years are suggested, while the schools are free to decide about the terms of progress. Teachers in schools pay attention to the development of each pupil, but the local curriculum does not suggest any further requirements.

For the above reasons, we can only calculate with as much as the maximum of expectations, but always have to have in mind, that class are usually far behind the expected curriculum, which can also be the case with normal children. Nevertheless, classes often lag behind the suggested timing and would be able to fulfil tasks suggested within 6 years of schooling only within the time frame of 8 years. It cannot be predicted how far children can get in development of their skills, abilities and knowledge.





Blue is the schools with learning difficulties, and purple is normal school.

Figure 2. Difference in levels of achievement (in terms of grade) in normal and special schools within different subject areas, based on data available (NAT 2003).

ELTE teacher training specialties

TeaM lab provides courses within ELTE teacher training as non-compulsory electives, with relation to developing e-learning materials and running projects in public education, where students develop programs for different curriculum areas, take them out to use in schools and prepare a report about their effects in classes, suggesting some areas of possible improvements for better use (Turcsányi-Szabó, 2006c). Among courses are the following:

- **Designing educational programs:** Students develop complex educational programs (using Flash or Imagine) to be used in different disciplines practicing experiential and constructivist pedagogy on a specific focused area.
- **Evaluation of educational software:** Formative evaluation and pedagogic evaluation of software (usually developed by other students in previous years), by analyzing the National Curriculum and teaching strategies in order to define a hypothesis for pinpointing the scope of development, designing activity to go through the process, and composing pre- and post test to prove the presumed hypothesis.

ELTE special education school

ELTE Bárczi Gusztáv Practice Elementary School and Methodological Centre for Special Education engages children with learning difficulties, where they can learn to read and write with dyslexia prevention methods, which assures the individual improvement of each child and makes an effort to exclude the usual failures. They also try to assure continuous development of skills and abilities within all classes, for instance mathematic classes. There are special pedagogical services for the first graders, like: generative activities (for attention, memory, orientation in space and time, motion development and motion skills), speech therapies, habilitation and rehabilitation sessions and therapies. For these activities they have special rooms, gym room and a swimming pool. Children can choose different afternoon activities like drama, ICT, journalism, household management, needlework, swimming, table-tennis, singing, playing on the piano and the flute.

Our collaboration

There is an active collaboration between Bárczi School and TeaM lab since 2003 to develop ICT tools supporting their pedagogical program and hold experiments to evaluate their effective use.

The school has so far tried out different software within their classes and just kept a handful of them, since the rest did not suit their special needs. After our established relationship, they provided us with a list of ideas they could use in their developmental work and suggestions for modification of software they have encountered so far. At the same time we prepared for them some skill building programs, which we thought would suit their needs.

Children have now different classes like reading, mathematics, journalism taking place in the computer room. This semester the fourth grade has one out of seven Hungarian language lessons in the computer room, and the seventh grade has two out of four mathematics lessons there too. The fifth grade has four mathematics lessons in a week and they spend two of them in the computer room. 36% of the topics mentioned in the curriculum are covered by different programs. Among the seven main themes in fifth grade a lot of programs used at the school originate from ELTE TeaM lab and were developed using Imagine.

In most cases, programs are used for practicing, showing visual examples, modelling problems, helping to find algorithms for different problems, and conforming constructive learning practices. Of course not all topics can be and should be covered using computer programs, but it can be a motivating alternative. It is also important that making a mistake is not so embarrassing for a child while being involved with a computer than doing it in front of a teacher, and also graphics and animations can be of great help in visual modelling, and creating algorithms.

Case studies of developments

Our courses support program developments both with Macromedia Flash and Imagine, but it must be well investigated which authoring environment to use in each case. In case a closed program is envisioned with need for compact and well compressed media files, then most probably Flash technology would be chosen. But, in case we wish to leave the tool open and transparent for further configurations to be inserted (not necessary done by programming experts) or a possibility to change media elements, then most probably Imagine would be chosen as the environment for development. It is important to note, that while a program originally developed in Flash by one student is **never** changed by any other student, due to the fact that it is hard to figure out another Flash developer’s logic. The situation however is not so difficult to handle in case of Imagine and students are more at ease to make changes according to defined criteria.

To demonstrate the need for configurable programs, we chose two examples. In the first case an existing game was changed into a learning tool, and in the second case a new learning game was developed.

Frogs

The Frogs game (originating from the Comenius Logo package and later redeveloped in Imagine; the task of the game is to order the frogs, but a frog can jump only to a free space if there is one next to it, or only one frog away – see *Figure 3*.) is a very useful, helpful and amusing game, which helps children to practice the order of numbers and the concept of numbers, but it could only handle numbers from 1 to 9 without any changes in the sequence of the numbers and numerical order. Teachers however, needed a tool that also allows the practice of sequences from 8 to 12, or sequences like: 13, 17, 21, or also reverse ordering. After having discussed a framework with the teachers one of our students started to work on its realisation. We decided that the following configurable settings as required:

- Number of the frogs
- Ordering (normal or reverse)
- Starting number
- Steps of the sequence (every number, every second number...)
- Scaffolding (the possibility to see the correct order as a sequence of numbers)

A log file was also required, recording the types of clicks and the time spent on thinking and a visual playback simulation of the log files was also realised in order to trace the process.

The student that got the program development assignment spent lots of sessions at the special education school to see how children (and teachers) manage to make use of it, where modifications might be needed to enhance the user interface, and what parameters might be useful to be inserted in the log file, that records activities. After a long period of iterated developments, a very useful tool was developed with the satisfaction of both teachers and children. The game thus became a very helpful tool to be used in all areas where sequencing numbers is required. It also proved to be a helpful tool for children for self-reflection, in order to construct a more useful algorithm for solving a problem.

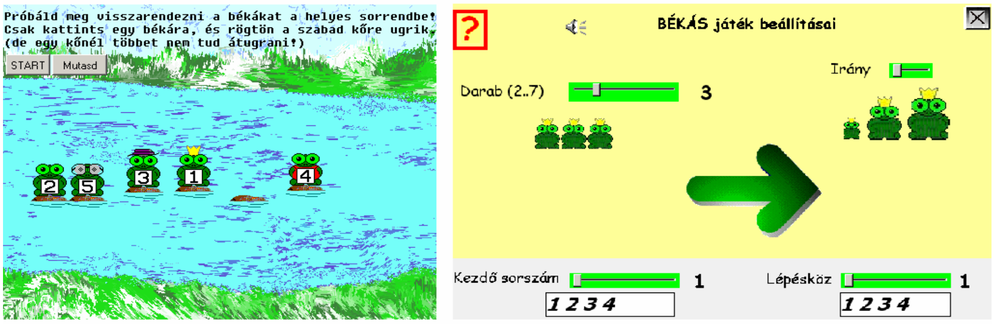


Figure 3. Screens of the Frogs program: original game and configuration page of our version

Grouping

Once teachers have pointed out to the student teachers the need for a program that helps understand the concept of grouping numbers, which is actually a preparation for understanding division. They explained the difficulties in the use of small plastic discs (within the official maths package for elementary schools): they always get lost, it is not interesting enough for children, and it is also difficult to check the result of each child's work. So they asked for such a test like program with configurable number of discs and distribution parameters. Small coloured discs would appear in a given number, which can be dragged, grouped as a visual aid for distribution exercises. So one student teacher made a first version to cover the draft of the ideas, this is shown in the picture on the left of *Figure 4*. Later an idea for an interesting metaphor emerged from another student: distributing acorn or hazelnut among chipmunks, and so the other students re-designed it with the new user interface. Then, after some trial period, teachers suggested that chipmunks could give the children tips when they went wrong, and what is already solved correctly. Later the problem of bigger numbers appeared, and finally a division part was also requested, where remainders can be handled step-by-step in the process of division.

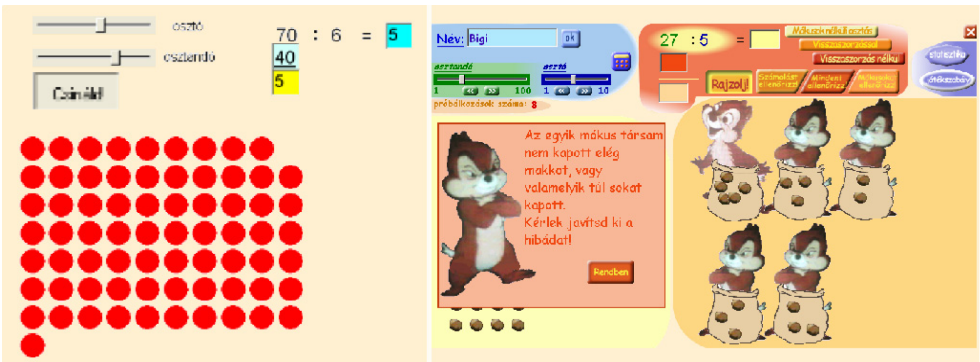


Figure 4. Screens of two iterations of the Grouping program

Evaluation of programs developed

The design process

During the long process of cooperation, we both gained knowledge on requirements for development of effective learning tools. It was and is a win-win relationship. Teachers at Bárczi school have deep knowledge on the needs of children and effective pedagogic methods, at TeaM lab we have many years of experiences in developing learning games for children, besides we bring up a new generation of developers, that are sensitive also to the practical needs of children. It is a fortunate bind between the two institutions as our student teachers are able to experience the use and effects of developed programs by visiting school classes from time to time, chatting with children on their preferences and consulting with teachers on their needs. Programs developed by student teachers (as developers) in such a situation are of much higher quality then if they would be just a normal course deliverable, since it not only has to comply to the course requirements, but also has to fulfil all needs required by school teachers (as customers making the orders) and most of all that of children (as individual users) who are the most critical factor. Student teachers are much more motivated in producing quality work for children, since children are absolutely honest and immediately give feedback if they like it or not. For the past (more than ten) years, we have been practicing this process of program development, having close ties with several types of schools and kindergartens and have experienced the benefits in terms of quality and overall attention of student teachers towards learners (Turcsányi-Szabó, 2006c). Thus TeaM lab has already come out with hundreds of such small educational programs developed within such a process and has produced two considerable learning materials in both English and Hungarian language. These materials also provide learning paths for constructivist developmental learning for children, and for teachers to learn how to configure the programs themselves , one using Comenius Logo (Turcsányi-Szabó, Abonyi-Toth, 1999; Turcsányi-Szabó, 2004) and the other using Imagine as authoring tool (Turcsányi-Szabó, 2006a; Turcsányi-Szabó, 2006b).

Special design elements

At the moment Bárczi school uses 36 different programs developed at our university 34 of which were developed at TeaM lab. 28 of these programs are built into the curriculum and are used in classes. From the 36 programs 15 are built to suit the mathematic curriculum and 11 are designed for the ICT curriculum from fifth to eighth grade. Among the programs 18 produces different kinds of log files, 9 saves the final image when a task has been finished and 9 records the whole process.

The main features of the package so far developed for Bárczi school are:

- **Motivation**: programs are highly motivating and amusing for children.
- **Focus**: all programs focus on a specific theme handled with flexible perspective.
- **Personalization**: programs can be set for the different needs of children concerning level of difficulty, complexity, visual needs, background knowledge and interest.
- **Learning curve and feedback**: activities can be flexibly set in terms of time frame, repetition, feedback, scaffolding, and applicable rewards in order to support the learning curve.
- **Traceability**: activities of children are recorded and can be traced later by checking the log files and saved screen-shots to evaluate the development of the child and the the user interface.
- **Transparent and open**: all programs are developed with the Imagine authoring tool and have similar internal structure that helps further re-developments if needed or media re-configurations by teachers themselves if requested.

The design of log files are of great importance as they are to be used by student teachers during school evaluations in order to monitor progress and pinpoint deficiencies of the program itself.

Most of the log files record the whole sequence of the working process, but it might not be necessary to produce such detailed trails in all cases. E.g. in the program for comparison of quantities, it is enough to record when and which answer was chosen and what the question and the right answers were (see *Figure 5.*). Statistics can also be made immediately and can be stored in files for a quick summery. But in case of the program for using money other events could be more important, since the answer is not a single click, but a sequence of clicks and drag & drops. In this case all clicks that start drags and stop drags are important and are stored in the logs, but as mentioned previously in case of the Frogs program, the visual process can also be reconstructed.

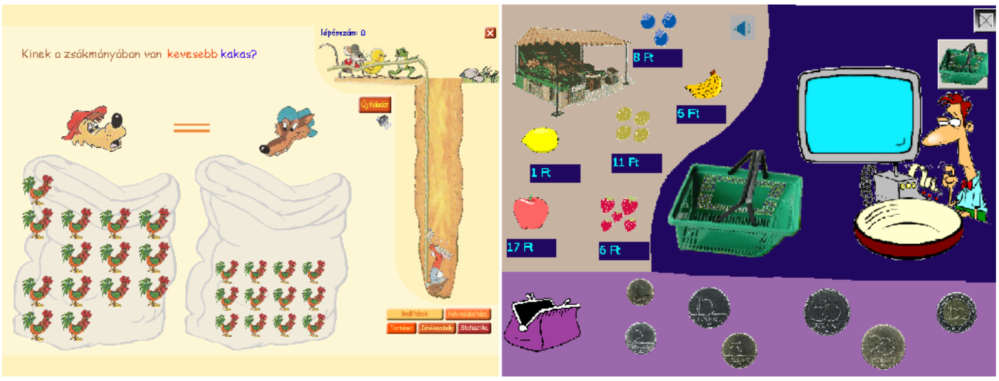


Figure 5. Screen shots of two programs: comparison of two numbers and purchase with money.

We also learned how important it is for children to get immediate feedback on their final answers before pressing the OK button. So we put checkpoints into the programs to allow self-checks before submitting answers. We were interested to learn how often children use these checks and we found out that after working out a solution, they indeed used the self-check every time before submitting a final solution. This feature gave them self-assurance of their thinking process. When such features were not available, children would ask teachers themselves for feedback, which would acquire considerable time from teachers. This is one good reason for the teachers to use such programs in their classes and it also supports self reflection by children and thus provides a more effective learning process.

Scaffolding was also a feature that was required by teachers, e.g. in practicing multiplication, after two wrong answers the multiplication table was shown, and after another wrong answer, the line and column to be used were also highlighted, and next time the needed number was highlighted as well. We had to think of workable algorithms to help the children solve different problems within their abilities, algorithms that provide clear solutions for them as learning skills.

Formal evaluation

The programs developed in earlier semesters were evaluated by student teachers also within course work. During the past ten years we have constructed and refined a rubric for the formal evaluation of educational programs, which has been later adapted by Schoolnet (Sulinet) in Hungary to evaluate the learning objects developed for their repository (SDT). This rubrics contains more than 400 items for check, which seems to be an alarming number, but once a single program is tested in such details, the important features for consideration at the evaluation of any educational tool definitely sticks into the head of the evaluator and next time the main titles of check will automatically retrieve in mind the overall feeling of the features to consider. Thus, student teachers could become good advisors for educational programs in other subject areas as well.

All 34 programs were also tested for usability against pedagogical criteria (Nokelainen 2006): learner control, learner activity, cooperative/collaborative learning, goal orientation, applicability, added value, motivation, evaluation of previous knowledge, flexibility and feedback. From these, the teachers rated 29 as usable, 14 were found to have creative challenges, 25 could be used with an interactive white-board, 25 were found to be suitable to practice everyday life's problems, 18 were rated to be flexible enough for easy configuration to suit the needs of pupils.18 of these produced different kinds of log files (pictures, statistics or step by step logs) that could be used for evaluation later and 6 of them had text logs on the whole working process.

Among the general programs for maths classes: 15 were built into the mathematics curriculum and teachers are absolutely satisfied with 11 of them; 12 have explicit goals, and 14 allow explicit goals to be given by teachers; 11 are flexible to suit children's needs, 5 have complex settings also for the different special needs of the pupils; and 9 produce log files, 3 create statistics, and 6 have text logs recording the whole working process. Among the programs 6 give direct and immediate feedback to the children, and 6 have motivating feedback animations if the exercise is solved correctly.

The Visual Fractions microworld is a program where exercises (activities) can be designed and integrated as interactive workbooks (scripts). For the fifth and sixth grades 22 scripts have been created, with different tasks and difficulties, starting from tests like distributing a whole, reading out values and pairing values with representations (for the fifth graders) and comparing, up to ordering and notations of fractions (for the sixth graders).

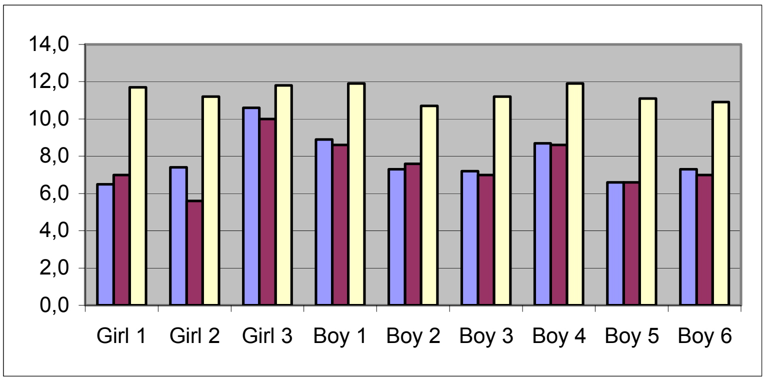
Evaluation of children's progress

Standardized tests do not exist in Hungary to measure dyscalculia or dyslexia, and there are also no tests devised to measure progress of special needs children. So, we had to search for alternative measurement systems that might suit these special circumstances. We found two such to be useful in our inquiry.

The Hiskey-Nebraska Test of Learning Aptitude (H-NLAT) is an individually administered, nonverbal test of learning ability developed for and standardized on a population of children with hearing impairments. This is the only test system on learning abilities which is standardized on individuals who are deaf. The test is suitable for children between ages 3 and 17 and is activity oriented, thus it can definitely not decrease performance if applied with children having reading, writing or communication disorders.

The mathematical ability test (Dékány, 2003) has been used successfully for many years now and was created at Bárczi Gusztáv Faculty of Special Education. According to experiences (not published yet) all children diagnosed to underscore, were later proven to suffer from dyscalculia.

H-NLAT



Graph is scaled by age where:

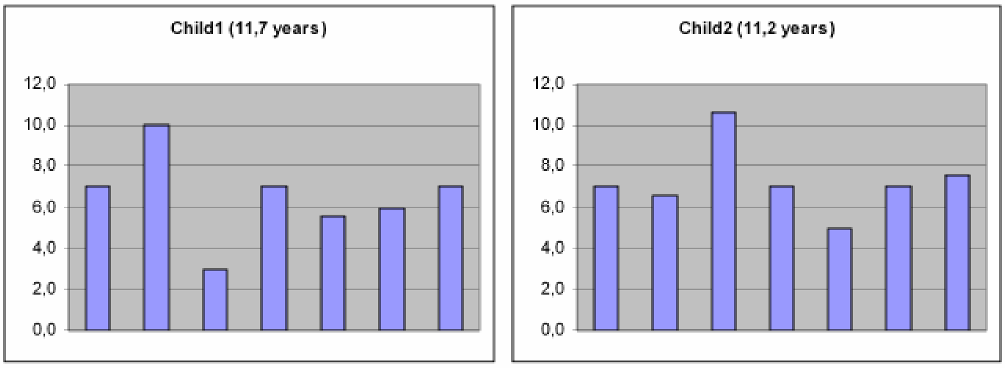
Blue: average sub-test age in years

Purple: median age in years

Yellow: real age in years

Figure 6. H-NLAT test results of administered group of children

Most children with special needs have big differences between their real age and their mental age. At first we administered the H-NLAT test in 2004 September for the fifth grade (9 children) (Hiskey, 1966; Watson, 1982), where we found out that with an average of 11,4 years of real age of children, an average of 7,6 years in median mental age could be detected (see *Figure 6*.), and there was also a big difference between each individual child, as well as their mental age in different attitudes, as can be seen in *Figure 7*.



Titles of skills tested are (from left to right): recollection of colours, recognition of pictures, association of pictures, paper folding, extent of visual attention, building out of cubes, completion of drawing.

Figure 7. Individual differences in attitudes

Because of the big difference between individual children's skills and abilities, differential teaching is needed. At this point it is a big help for teachers that they have only a small amount of children in their classes, although these days the situation is worsening and the average number is increasing to ten.

However, the curriculum is not suitable either for the pupils real age nor their mental age, it is somewhere in between the two, and the teacher also needs to take into account the skills and abilities of each individual child to be able to find suitable methods for personalised development and enhancement of the learning process.

Thus it is clear that there is a great need for educational tools that can be customised sensitively enough to suit several levels and stages of knowledge acquisition, where the tools allow the tracing of each child's activities in order to pinpoint any development that might increase level or force some change in configuration to ease its use.

Tests

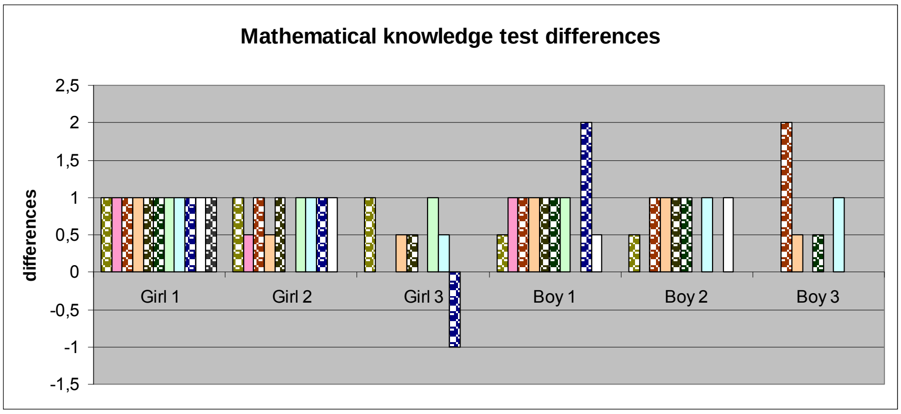
Mathematical ability tests

Fifth graders were tested on mathematical ability, using rubrics developed at ELTE Faculty of Special Education (Dékány, 2003). These were administered twice, once in September 2004 and then in February 2005. The six children were tested for 11 different skills and abilities (1. attention; 2. graphomotorium; 3. visual perception; 4. acoustic perception; 5. serialisation; 6. thinking functions; 7. thinking in terms of time; 8. speech and language; 9. addition, subtraction, multiplication, inclusion; 10. learning ability; 11. motivation). All aspects were rated from 1 to 5. Part of these tested skills are expected to produce improvements using computer programs (1, 3, 5, 6, 8, 9, 11), and the use of the mathematics programs proved to have effect on five items from the 11 (1, 3, 5, 6).

From the 6 children in the experiment 5 were dyscalculic, and one was found to be endangered. After half a year of using the described programs in classes 33 scores within the test have changed, 20 did not and 16 of the changed scores were in the categories that could have been affected by computer programs. Only one negative change was noted within numerical operation, but it turned out to belong to the only non-dyscalculia child. It is worth mentioning that in two cases significant changes took place in the results, both in the skills area which could have been affected by the computer programs. There was one pupil whose every score has improved by one. It is also important to note, that all children were very well motivated. In

September 5 children got 5 in motivation, and in February all of them got such results in motivation.

As we can seen from these results, computer programs had a very good effect on children, helped to keep up their motivation and developed their skills.



Titles from left to right:
Attention,
graphomotoric skills,
visual perception,
acoustic perception,
serialisation,
thinking functions,
thinking in terms of time,
speech and language,
basic mathematical functions (addition, subtraction, multiplication, inclusion),
learning ability,
motivation

Figure 8. Judit Dékány's test results

Fraction's test

After using the Fractions program for two years in classes, in May 2006 we tested all senior grades (from fifth to eighth), that is 48 children with a written test for understanding and using fractions.

At the time of the testing, fifth and sixth graders learned fractions with the Fractions program, while seventh and eighth graders without it. The 15 test questions were on: 1. reading values (same denominator), 2. inserting relational symbols (same denominator), 3. giving values (by colour), 4. reading the smallest value (nominator is 1), 5. reading the biggest value (nominator is 1), 6. inserting values within their main categories (nominator is 1), 7. reading values on number lines (nominator is 1), 8. inserting relational symbols (nominator is 1), 9. reading values (on scale, same denominator), 10. text assignment on pairing, 11. reading missing values, 12. addition of 2 values (to one whole), 13. taking notes on counting, 14. difference between two numbers, 15. taking notes on counting.

As result, we found 3 questions (3, 7, 11) where the smaller children had a better solving rate then the bigger ones. In the 3rd exercise they attained 96% to 95%, in the 7th exercise 77% to 73% and in the 11th 50% to 45% respectively. These were questions concentrating on reading out values, and understanding values. So we can say that the use of the Fractions program was helping children to develop better models of fraction values for themselves.

Figure 9. Fractions test results on the different exercises solved by all classes (1,2,3,4,5,6,7,8,11,12) Left is for the fifth and sixth grade, and right is for the seventh and eighth graders

Conclusion

Children with learning difficulties need much more time and practice to learn new bits of knowledge. They need much more experience, representations, experiment, explanation, example to extend their knowledge.

As we can see personalise-able programs provide adequate help for teachers working with special needs children. It helps to achieve differential teaching. The motivating effect and the direct feedback of computer programs is also of great help, that makes children more self-confident. Unlimited exercises generated with these programs give children the opportunity for the practise they individually require, to develop new mental models and the ability to be able to extend their own knowledge.

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