Digital interventions for dyscalculia and low numeracy: Final Report (D2)

For the Becta Research Grant programme 2008-2009

Becta Research Grants are intended for self-contained research grants in the area of technology for learning, and in support of the Harnessing Technology strategy. The overall aims are:

1. To support high quality research in support of the Harnessing Technology strategy
2. To build knowledge and understanding against key research questions relating to the Harnessing Technology Strategy
3. To support the technology for learning research field by promoting development of models, methods, tools, modes of thought.
4. To develop research capacity by supporting the work of those new to the field.

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Summary

Poor numeracy is a serious problem: in 2000 26% of 30 year olds were below Entry Level 2 - knowledge of whole numbers and common fractions. Even now only 53% of learners get C or more in GCSE and *no* help is being given to learners who’ve not built *any basic* understanding, i.e. those with dyscalculia.

Prevalence estimates for dyscalculia are around 6%. It is sometimes termed as ‘a lack of number sense’, and has the effect of making it very difficult for learners to

* recognise number patterns
* memorise number facts
* understand the meaning of basic number relationships

work quickly with elementary calculations.

Dyscalculia is sometimes co-present with disabilities such as dyslexia, but not always. Children and adults who are assessed as normal in all other ways can be dyscalculic. It is not associated with intelligence and can be found also in university students and post-graduates.

SEN teachers have devised teaching strategies for very small groups, or 1-1 tuition, and they work. But this is highly labour-intensive, and does not scale to the thousands of children who need help.

Technology can help in three ways.

1. We have created prototypes for programs that emulate what the best teachers do, selecting and adapting exercises that are personalised for the individual learner, but extending the amount of targeted practice they can do
2. We have designed new forms of interactive task that exploit what is unique to the animation and visual representations of virtual worlds, to complement the tasks being done in the physical world;

The programs can be used and customised by every teacher, so the SEN teaching community can share their best ideas, and continue to develop and share better teaching strategies.

We have found that programs that work for the very weakest learners can help mainstream learners with low numeracy to learn faster, and also help learners at an earlier stage who are beginning to learn the same concepts.

Introduction

The project set out to address the personalisation and social equity aims of the Becta Research strategy. The aim was to personalise the teaching of basic numeracy by developing digital interventions that would adapt to the learner’s needs, and scaffold their social engagement in numeracy.Secondly, we wanted to address social equity by improving teacher and parental support for struggling learners, thereby narrowing achievement gaps in later years.Within the scope of a small project it is not possible to take the research and development very far, but the aim was to demonstrate the feasibility of the approach through at least two prototype programs tested with target learners and their teachers.

As a recent Becta research report concluded:

“Although there are a number of interventions for students who are falling behind with maths, none is specifically aimed at students with dyscalculia and very few of the existing interventions have been formally evaluated. (*Making a Difference*, Changing Media Development).”

The desirable characteristics of interventions for these learners were summarised as

* Start early - early intervention also prevents falling behind in other academic subjects and the development of negative attitudes.
* Personalise learning - general interventions are unlikely to be as effective.
* Use technology to help personalised learning - because not everyone has a weakness in the same area. Technology-based learning can also give the teacher control over a student’s rate of learning, according to the student’s needs.

Design technology-based learning to be used in conjunction with teacher-based learning, not instead of it - because it tends to result in less progress than interventions carried out by teachers. However, teachers are often pressed for time so while not a substitute for teacher learning technology-based learning is valuable and can be used outside school as well as in the classroom.

This project set out to address all these points by developing more effective digital interventions for learners with dyscalculia and low numeracy performance. The main features of the approach are:

1. to start early, by targeting learners in primary school, already identified as having difficulties in maths
2. to personalise the learning, by recording every input and reaction time for a learner, and using an explicit pedagogical model of intervention, so that the program can construct the next task according to their likely level of need
3. to use the capability of the technology to offer novel learning interactions, and to be customised by the teacher, so that they can adjust the parameters and rules used by the program to regulate the pace and level for their own learners

to work with special needs teachers to try to achieve the optimal combination of teacher-based classroom and small-group learning, with technology-based learning that can decrease the gap between schoolwork and homework by using flexible technologies.

The project has also been able to include a number of additional features, designed to build on existing work and relevant research:

1. SEN teachers have devised some highly specialised and effective small group learning tasks for these learners, so the design of digital interventions begins by emulating some of these tasks, making explicit the pedagogic models of intervention in terms of: the design of the task presentation, the required action by the learner, the form of feedback, the cognitive reflection elicited, and the construction of the next task.
2. Low attaining learners need more intensive and explicit teaching, more practice to achieve mastery, more examples to learn concepts, more experience of transfer, and more careful checking for preparedness for the next stage of learning. Digital interventions are designed to motivate learners to attend to the different representations of number, to carry out many repetitions of exercises, and to keep rehearsing component concepts and skills as they need to, in tackling more complex tasks.
3. The identification of a congenital condition usually called Developmental Dyscalculia (DD), has enabled researchers to show that as many as 6.5% of learner population could be affected. The theory suggests that these learners have not been able to build their own representation of the concept of number, and cannot easily make sense of the idea of counting, except as a rote sequence. Without these foundational concepts, they will always struggle with the progressively more complex ideas and procedures in arithmetic. The individual activities for the digital interventions are therefore chosen to assist these learners in building the foundational concepts and forms of representation essential for understanding number, and then arithmetic.

SEN teachers are a small and thinly distributed professional group in our schools, and yet are often very innovative in their approaches to specialist pedagogy. They would benefit greatly from being able to communicate problems and solutions more easily, especially if they have some shared experience. Part of the focus of the project, therefore, is to bring these teachers together in an online community, where they have access to the software we have developed, as well as links to other relevant software, and where they can exchange ideas and suggestions for improving their practice, and perhaps also for developing further software.

Project activity

We worked with five expert SEN teachers as ‘informant practitioners’ (IPs) who give specialised help to children identified as needing it (2 in a state primary, 3 in providing specialist help in private schools, 1 who works as a consultant to state and private schools).

For each of three terms we worked with small groups of learners in Nursery, and Years 1 to 4, to observe lessons, observe the use of commercial numeracy software, and to trial initial versions of interface designs and prototype activities. We held workshops with the teachers once a term to discuss progress, designs, and further requirements. The work carried out is described for each of the planned activities.

# Design TEL pilot interventions.

We have observed learners using CrickWeb’s Place Value Calculator, to determine the problems with the approach, and design an alternative; various other games used by the schools for practice of basic arithmetic. None of these provide teaching of the concepts needed, only rehearsal of what has already been taught.

*Dots2Digit* has been fully developed and tested.

*Dots2DigitsFace-up/Face-down* are interactive games for one or two players, which is based on a card game devised by the specialist teachers. The latter ‘face-down’ version rehearses memory and strategy as well as pattern recognition.

*Dots2Track* has been fully developed and tested. It uses animation to provide intrinsic feedback on both correct and incorrect inputs - counting the dots onto a number track to confirm the total value.

Each program begins with a teacher preferences screen, enabling them to customise parameters such as (i) starting values for an activity, (ii) the number of exercises that have to be correct for an item to be considered as ‘mastered’, (iii) colours, (iv) shapes of dot patterns, etc. Further descriptions are given below under Project Findings.

# Test current software against adaptive software.

Interface designs were tested through observation of individual children. In most cases the interface designs have been easily understood and interpreted by the learners. Specific difficulties have occurred with:

The number ten has to be input using two keys, not one, as for all the other numbers up to ten, and ‘0’ comes after ‘9’ on the keyboard, which can be confusing. Learners are surprisingly able to deal with this because of their familiarity with the keyboard, but the uncertainty over how to input ‘10’ affects the validity of the reaction time data for this number.

Observation of dyscalculic children and those with low numeracy showed that they do not seem to learn from commercial software, relying mainly on guesswork, which is possible because of the multiple choice question formats that are so common.

Digital versions emulating highly labour-intensive one-to-one teaching tasks can complement the one-to-one work for many more learners.

As the activities are simple to learn, and instructions are spoken as well as written, and tasks are progressed according to the learner’s performance, it appears that even learners who are easily distracted are able to attend for up to 20 minutes.

#  Build a collaborative environment for teachers and parents

A free online collaborative environment has been used to create an interactive website for the project (<http://low-numeracy.ning.com>). Main features are:

* a list of the programs developed, with brief descriptions and links for downloading
* a forum for teachers to post comments and discussion on each of the programs
* relevant links to other SEN websites
* feedback quotes from teachers who have tried the programs

events of interest for SEN teachers and professionals.

The website will also potentially provide an area for parents to offer feedback on home use of the software, and to exchange experiences with other parents. However, we cannot yet implement this service as it needs funding for promotion and management.

# The role of technology

The programs track learners’ performance and progress by recording reactions times (RTs) and accuracy data.

We have not been able within the funding for this project to investigate linking the programs to digital manipulables. Given the importance of physical manipulables for these learners, and their delight in using and controlling digital programs, it is likely that this kind of investigation could be very fruitful.

We have built in teacher preferences at the start of each program, and have sought the advice of teachers on how best to do this. The preferences have been trialled successfully in a workshop environment, but really need further testing with teachers in the standard classroom.

The programs give SEN learners more practice to achieve mastery, more examples to learn concepts, more experience of transfer, constructionist learning activities, a motivating and rewarding environment that holds learners’ attention.

Project staffing and budget

The project employed Hassan Baajour as the Research Officer, Grade 7, half time for one year. In addition, Professor Diana Laurillard contributes 2 hours per week. We also had Dr Fukumi Kozato working on an internship at LKL associated with the project. She designed and revised a storyboard on place value, with guidance from the Informant Practitioners.

The project was delivered on time and within budget.

Project findings

Current digital interventions are unsuitable for low numeracy learners

We carried out an initial search on the software being used in primary schools for numeracy. Teachers were appreciative of many of the characteristics of these products:

* Engaging animation and interactive qualities, so learners are motivated to use them
* The option to set up the task under teacher preferences

The collection of scores against pupil names.

They were used much less for failing learners, however, because

* The screens were too busy and confused them,
* The tasks were too difficult for these learners, and

The programs only rehearsed already understood concepts.

Investigating the commercial software on offer to schools, we found very few that targeted low numeracy learners, and the best of these exhibited all the negative characteristics that teachers had mentioned. Figure 1 shows an (anonymised) example of such a program.

Figure 1: In ‘*How many dots’* the screen display is confusing because the answer conflicts with the learner’s input displayed (3), and with the numbering of the tasks they have to do (shown on the right); feedback is extrinsic, not meaningful, and does not elicit reflection.

The initial survey of commercial software showed the following characteristics, from the perspective of their value for failing learners:

Teachers appreciate:

* lively, colourful screens

scoring and/or motivating feedback to keep pupil on task.

Problems for failing learners:

* Screens are too busy for pupils to focus on number concepts
* Tasks rehearse known facts rather than support learning
* Feedback is only extrinsic, not intrinsic to enable learning
* Learner input promotes guessing, not prediction or reflection
* Next task is randomly generated, not adapting to learner performance
* Complexity of interface requires teacher supervision

Teacher preferences are very limited.

It would be very difficult for commercial companies to develop the interventions needed for other than mainstream learners, as the profit margins of developing for the schools market are already very low. The project therefore set out to explore what can be done with technology in areas where the market is unlikely to provide, in order to understand how best to assist these learners.

Modelling the pedagogy of the best teachers is feasible in part

The programs developed within the project attempted to emulate the expert SEN teacher by modelling their practice. This requires precision in the teaching requirements analysis for the programs, in order to build the rules by which each program operates, and so develop effective pedagogic models that can be repurposed in other similar contexts.

The pedagogic models instantiated in the programs also draw on learning theory, which provides the pedagogic rationale for:

1. the design of the task,
2. the way the task is constructed for the learner in terms of representation of the goal, nature of learner action, nature of feedback,
3. sequencing rules, based on learner performance for successive trials on each task,
4. sequencing rules, based on learner performance for choosing the next type of task,

what counts as mastery in terms of learner performance.

Different theories of learning, such as behaviourist, or constructionist, provide different instructional strategies (Gagné & Merrill, 1990). The behaviourist approach is common to many existing educational software programs, and relies on *extrinsic* rewards, such as scores, or animations to motivate further activity. The motivation to repeat tasks until they become very familiar and well mastered is appreciated by teachers, as we have seen, but these programs assist only in the rehearsal of understood concepts, not in the development of understanding, which is what struggling learners need.

The constructionist approach is much less common, as it requires the program to model an environment with which the learner can interact (Papert & Harel, 1991). This enables them to make sense of the relationship between the goal and their actions through *intrinsic* feedback, i.e. showing the result of those actions in relation to the goal. This approach relies on the intrinsic satisfaction for the learner of refining an action to achieve a given goal to motivate further activity. The contrast between the main pedagogic features of the two approaches can be summarised as follows:

A behaviourist approach defines the task in terms of the action as selecting a response to a given stimulus, and feedback as either information about the accuracy of the response, or reward/absence of reward. Mastery is described in terms of degree of accuracy on the task. The task will state the goal, but may or may not represent the goal. Figure 1 shows an example of this approach.

A constructionist approach defines the task goal in terms of something to be constructed, the action as an operation on elements contributing to that construction, and feedback as a representation of the result of those actions. Mastery is described in terms of how the goal was achieved. Figure 2 shows an example of this approach, used in the project program ‘Dots2Track’, and applied to the same task as that in Figure 1.

Figure 2a: In ‘Dots2Track’, when the learner inputs an incorrect digit (5), they are shown the dot pattern that matches their input; Figure 2b shows that both sets of dot patterns have been counted down onto a number line so that the difference between them can be related to the counting sequence, offering more meaningful feedback on why the input was incorrect than a statement of the correct answer.

Figure 2a shows the task presented in the same way as the one in Figure 1 (though with fewer competing visuals). Figure 2b shows how the feedback on the learner’s input represents the task in an additional way, by animating the movement of the two dot patterns onto a number line - clarifying the result of the learner’s action in relation to the goal, which helps to make the feedback more meaningful. They can then ‘construct’ the match to the goal by using the ‘Add 1’ or ‘Take 1’ button, which shows whether their line changes to match the target, or not.

The program checks the speed and accuracy of the learner’s input, and moves on to higher numbers only if they have answered correctly, and quickly enough to show they are recognising the dot pattern, and not counting it. Teachers want these learners to recognise and remember patterns, rather than relying always on counting.

In this way, the program is modelling the actions of the teacher, in helping to make the task and actions of the learner meaningful, to give them encouraging and helpful feedback, and to adjust the pace of the task development to maintain them in their ‘zone of proximal development’, challenged just enough, and not too much.

All the programs developed emulated the games the SEN teachers use with their pupils to help them manipulate and practice the representation and interpretation of basic numbers.

Where interactive programs fail to emulate the teacher is in the talk that is such an important part of these lessons. Teachers frequently ask learners to describe what they do, and predict what they think will happen, and then reflect on what they did, enabling them to rehearse the language of basic arithmetic. Computer programs can use voiced instructions, encouragement, and descriptions, such as counting, but cannot interact in natural language, and cannot easily elicit mathematical language from the children. However, they work very well as an adjunct to the teacher, enabling learners to practice the tasks for much longer, at their own pace, and wherever they have access to a computer.

Technology is used best when its full capabilities are exploited in service of the most difficult problems in education. By tackling the problem of learners who are failing in the basic skills areas it becomes apparent that the predominant designs in educational software are not properly exploiting the potential of digital technologies. Explicit modelling of the teacher’s role in helping the learner to focus on key concepts, manipulate them, and apply them, necessarily makes use of digital methods such as alternative forms of verbal, visual, audio, and dynamic representations, and adaptive interaction. When the teacher’s role is made explicit in this way, it becomes more amenable to investigation, testing, and re-design, and therefore, eventually, improved learner support.

Modelling learners’ pedagogic needs is feasible

Both constructivist and constructionist pedagogies are built on the idea that humans learn about the world through interactions, the former with people, the latter with materials or, in the case of Logo, with the virtual materials of a microworld. In each case, goals, actions, feedback, reflection, adaptation, and revised actions, are critical. Cognitive neuroscience gives remarkably similar accounts of how the brain learns through prediction:

[The brain] makes predictions about the world and then checks how well these predictions work. Through this process of prediction the brain discovers which causes go with which effects. These causes and effects are then bound together to form units which, in this case, are actions performed by agents. (Just as colour, shape, and motion are bound together to form objects) (Frith, 2007: 153).

and through communication:

“I can know that my communication has been unsuccessful when my prediction about what you will do next is not quite right. But the process does not stop there. If I know that my communication has not been successful, I can then change the way I communicate. I should also have a clue as to how I should change the way I communicate. I compare my idea and my model of your idea and I see that they are different. This is the prediction error. But I can also look at the nature of the error. Where precisely are the differences between my idea and my model of your idea? The nature of the prediction error tells me how to change my communication.” (Ibid: 171)

This iteration between interlocutors enables the social construction of a shared idea, and thereby accounts for the social construction of knowledge (Vygotsky, 1978). The constructionist account “shares constructivism's connotation of learning as "building knowledge structures" [and] then adds the idea that this happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the universe” (Papert & Harel, 1991). In both cases, the process being described is an *iterative sequence of goal-oriented actions with meaningful feedback enabling reflection in order to adapt the action to achieve a closer approximation to the goal*. The model of the learner, therefore, has to represent the task goal, and how the learner’s action relates to achieving the goal, and how they need to be helped to reflect on the feedback in relation to the goal, in order to refine their next action (Laurillard, 2009).

In the context of the programs in the current project, the learner model is represented in terms of what counts as progress towards mastery, e.g. in the case of the *Dots2Track* program, the accuracy of their responses, and their reaction times to each dot pattern. The degree of accuracy required can be determined in teacher preferences as ‘the number of correct responses in a row’. The reaction times that count as recognition, rather than counting, are a matter of empirical test. Collecting data from learners over several weeks shows clear differences in reaction times, as in Figure 4, where the response times for one learner show they are recognising low number dot patterns, with uniformly low reaction times, but do not yet have reliably low reaction times for higher numbers, and are probably counting these patterns; however, a second learner is recognising all numbers with very low reaction times. The pattern is similar to that found in cognitive neuroscience experiments with adults tested on canonical dot patterns, where patterns for low numbers are ‘subitised’ faster, and there is a discontinuity in the slope as they begin counting for the higher numbers (Piazza, Mechelli, Butterworth, & Price, 2002).

Figure 4: The red line shows the difference in reaction times between recognising numbers up to 5 and counting some numbers higher than that. The data from a second learner who has low reaction times of less than 2 secs for all numbers, i.e. is recognising all the patterns, is superimposed on the same graph.

The reliable collection of data for each individual learner is not possible within the funding of this project, as it requires controlled conditions to ensure that the learner who types their name into the program is the one who enters the data. Data is collected by the program, and can be used by the teacher, and in the course of classroom teaching that is valuable. A scientific analysis of change within individual learners needs stricter conditions, which are highly labour intensive and beyond the scope of this project. The aim was to achieve working programs through an iterative design process that involved expert teachers at every stage, and revised the design according to observations. The programs were continually changing, therefore, and within the timescale of the project, do not provide a consistent basis for establishing individual improvement.

What we have been able to show is that the speed and accuracy data can be analysed to assess the current ability of the learner on the current task, and that this can be used to determine the optimal next item in the task (e.g. which dot pattern to include next), or the next optimal task (e.g. move on to rehearsing dot pattern recognition in a matching game.

Learner requirements need repeated iterative development

During the course of the iterative design-test-redesign process observations were made by both researchers and teachers, which were recorded as learner requirements for changes in the design of the program. As the basic pedagogic design of the tasks came from the teachers’ existing methods, these changed little.

The main difficulty in attempting to emulate the teacher’s individual support for a learner lay in the interface design. Not all children were experienced computer users, so the development of primary software has to take this into account. Observation notes recorded three main categories of design problem:

* Representation of the task
* Instructions for learner actions

Representations of feedback.

All of them were important aspects of the pedagogic design that can only be refined through repeated observation of how learners react.

Some problems were due to the learners’ lack of familiarity with mouse and keyboard, but these quickly resolve with practice. The programs were redesigned and new versions tried out over two terms at the school. The labour-intensive nature of the initial work with teachers to clarify the underlying pedagogy, and the repeated trials and observation with learners demonstrates how difficult it would be for commercial companies to produce comparable programs. It suggests that these pedagogic designs must begin with research studies, if we are to develop digital interventions that both exploit the technology, and succeed in not just rehearsing concepts already understood, but helping to develop them as well.

Learning patterns can be repurposed for similar tasks in other topics

The programs based on games were designed for learning the digit symbols in relation to the dot patterns. These are essentially arbitrary triples – there is no reason why the shape of ‘2’ is related to two dots, or why its name should be ‘two’– so for learners who are not familiar with the digits, or with how the names sound, this is essentially trial-and-error learning. The program can, however, adapt the sequence and range of numbers involved, according to the learner’s performance on accuracy and reaction time. Once the pedagogic rules were optimised, the same program was easily converted to the equivalent problem of learning the capital letter-small-letter-sound triples for the literacy curriculum. There could be many more such applications of the basic learning patterns developed for these tasks.

Project outputs

Prototype programs

During the project we developed, tested, and redesigned five programs (although only two were planned in the proposal), and a further storyboard. As part of the design process, we ran three workshops with the expert teachers to work through design ideas and propose further requirements on existing and potential software development.

Trials were conducted with learners in two schools, from Years 1 to 4, as well as with Nursery children for two of the programs. All the programs have been through observed trials with at least 6 learners, and have been revised as a result. Data collected is used to determine appropriate parameters for the rules, and to test the extent to which performance can be judged to be improving over the successive trials. Analysis of the results will be published in a paper being prepared for a journal.

Dots2Digit (FaceUp)

This program displays a set of face up digit cards and a set of face up dot patterns (1 to 10). The learner is asked to click on a digit card and then the matching dot pattern. If the cards match they are moved down into the bottom of the screen, in numerical order. If they do not match, they stay in the same position.

The teacher can set the game preferences as follows: the initial number of pairs, the initial highest number, and the number of times a pair has to be identified correctly before new digit-pattern pairs are added.

The program will repeat the task, increasing the level and the number of cards until all pairs up to 10 are matched. The cards chosen are voiced, to help learners new to the digits, but the sound can be turned off once they are known better.

The aim is to help the learner to make the link between digits and patterns.

Dots2Digit (FaceDown)

This program displays face down pairs of digits and dot patterns, in random order. When the learner clicks on a card it turns face up. To pair the digits and patterns learners must therefore try to remember where matching pairs are located, which means they have to hold the image of each pattern and each digit in mind, as well as their location. If the cards match they are moved down into the bottom of the screen in numerical order. Otherwise they stay in the same position and are turned face down.

The teacher can set the game preferences as follows: the initial number of pairs, the initial highest number, and the number of times a pair has to be identified correctly before new digit-pattern pairs are added. The program will repeat the task, increasing the level and the number of cards until all pairs up to 10 are matched.

The aim is to help the learner with memorizing the number patterns.

Dots2Digit (2 players)

This program is a game for two learners competing to match a set of face down digit cards and number patterns. When the learner clicks on a card it turns face up. To pair the digits and patterns learners must therefore try to remember where matching pairs are located, which means they have to hold the image of each pattern and each digit in mind, as well as their location. If the cards match they are moved down into the bottom of the screen in numerical order. Otherwise they stay in the same position and are turned face down. Every time a learner matches the cards their score increases by one and the turn passes to the other player.

The aim is to help the learner with memorizing the number patterns, with the added motivation to concentrate on images and locations, by competing against the other player.

Dots2Track

This program displays a number pattern (1 to 10) and asks the learner to input (with a key press) how many there are. If they get it right, the pattern is transferred instantly to a number line. If they get it wrong, it is counted onto the line one by one (visually and with sound). If it is wrong, they can see their response next to the correct response, and then fix their own by adding or taking away, until it matches the target.

The aim is to rehearse the recognition of the number patterns, and to make the link between patterns and digits meaningful by counting the pattern onto a number line

Navigating the number line

The program attempts to give the learner a sense of being able to ‘navigate’ to find a target number. They do this by ‘steering’ backwards and forwards, and zooming out to see only tens or hundreds or thousands marked, or zooming into find the units marked. Whenever the learner clicks on the target number, they are awarded a flower and a new target number is displayed. The program gradually increases the difficulty of the task, to more distant numbers, as the learner’s performance improves.

In a second version of the Numberline program the teacher can set the game preferences as follows: the maximum and minimum numbers, the sequence of numbers to be displayed as targets, in case there are particular types of numbers they want the learner to rehearse.

The aim is to give the learner an experience of how the number line is organized.

Initial storyboard for PlaceValue

Uses 3d animation of blocks, lines and squares shapes representing units, tens and hundreds. Generates tasks for the learner to (i) match a given set of shapes by assembling their own set of shapes; (ii) interpret shapes as digits, (iii) interpret digits as shapes, progressing from one to two to three digit numbers. The learner can tell if their input is correct by visual matching of the result.

This storyboard has not been programmed and has not yet been trialled.

Website

An interactive website has been created for teachers, providing links for downloading the programs, and a Forum for discussion of the programs, comments on what design features need to be changed, and suggestions for further program designs.

Part of the purpose of the website is to trial the extent to which teachers find it valuable to have an online collaboration environment with other teachers, and whether the comments they provide in relation to the programs can be of value to the developers.

Papers and presentations

Diana Laurillard, ‘Computational approaches to learning: The educational perspective’, *Workshop on Concepts of Learning*, UCL/IOE/Birkbeck Centre for Educational Neuroscience, October 2008

Diana Laurillard and Hassan Baajour, ‘Understanding teachers’ needs in the use of e-learning’, *Becta Symposium for CAL 09*, Brighton, March 2009.

Hassan Baajour and Diana Laurillard, ‘Using New Technology to improve Learning of Children with Dyscalculia and Special Needs’, by *E-Learning Today*, Sept 2009 (forthcoming).

Brian Butterworth and Diana Laurillard, ‘Low numeracy and dyscalculia: identification and intervention’, presentation at *Educational Neuroscience Symposium*, Rovereto, Italy, October 2009.

Brian Butterworth, Diana Laurillard, and Hassan Baajour, ‘Using adaptive learning technologies for low numeracy and dyscalculia’, Special Issue on "Cognitive neuroscience and mathematics learning" in the *International Journal on Mathematics Education (forthcoming).*

Partnerships

We have had several discussions with a publisher, Continuum, and their software development arm, LearningMate, about collaboration on the development of specialised software for numeracy. It would be valuable to be able to build a relationship with a publisher who could take any effective designs to market. However, the amount of material that can be researched, developed and tested within the scope of this project is very limited. We are therefore looking for further funding opportunities for support for this type of research and development. Ideally, we would be looking for a continuing relationship with a software house and publisher that could attract sufficient market interest from teachers, schools, and local authorities, and therefore sufficient license-based funding to sustain continued development of the programs alongside further research on learners’ needs in this area.

We have established an initial trial partnership with LearningMate to test whether research prototypes of this kind can be developed as school-oriented products.

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