STEMReader: hearing maths through technology

Abi James, ECS Accessibility Group, WAIS, University of Southampton

Clare Trott, University of Loughborough

Contents

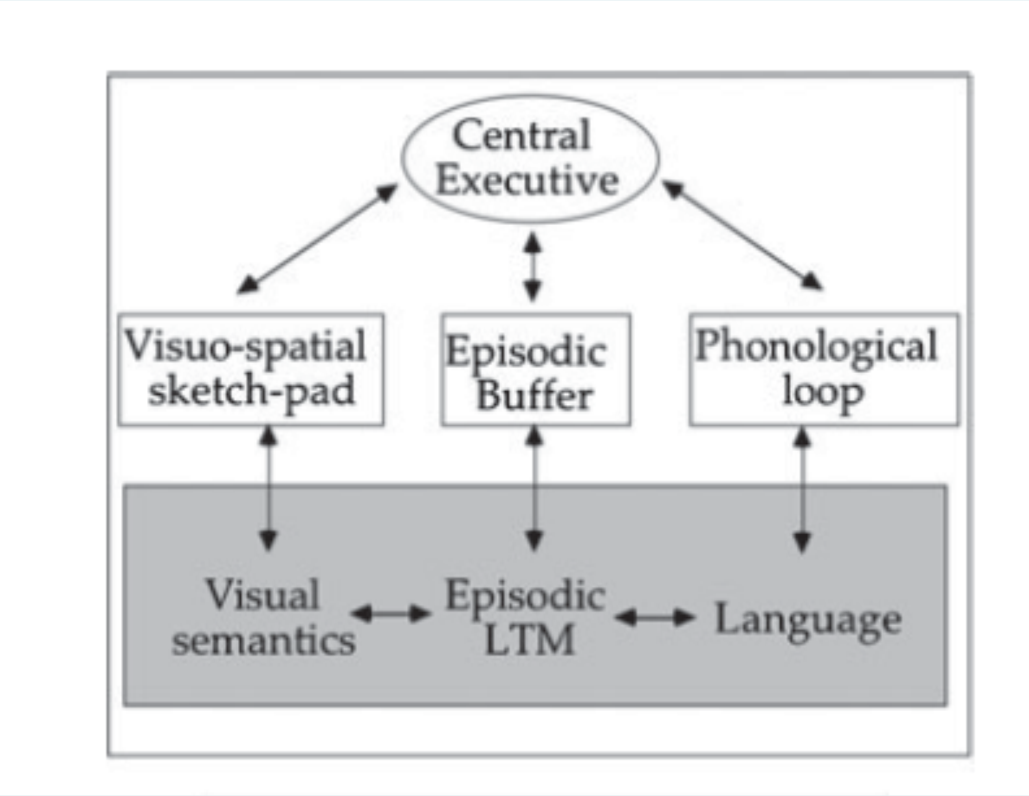
1. Background to reading aloud & maths
2. Computer Readers & maths accessibility
3. Mathematical semantics & implications for computer readers
4. STEMReader project & student trials

Do difficulties with reading impact maths learning?

- Maths is a visual subject…. Learners with impaired sight need additional supported
- But other students impacted by difficulties with reading, with 10% of population estimated to be impacted by a SpLD
  - 55 000 GCSE candidates a year require reading support; 100 000+ receive extra time
  - 161 000 students in FE with SpLD
  - 4% of HE student population receives support for SpLD

Working memory and maths

- Working memory is closely linked to mathematical skills (Alloway & Passolunghi, 2011)



Baddeley (2000)

Attention, anxiety and maths

- Learners with maths anxiety experienced reduced working memory capacity when anxious (Ashcraft & Kirk, 2001)
- Learners with poor spatial processing has been linked to maths anxiety (Ferguson et al, 2015)
- Attention difficulties linked to poor mathematical performance may be due to reducing the ability for the memory to access non-target vs irrelevant information (Passolunghi et al, 1999)

Reading aloud maths, does it help?

Burch, M. A. (2002):

- students with reading disabilities, showed increased performance associated with the computer-read text accommodation

- a larger score boost from the computer-read text accommodation than students without disabilities.

Lack of focus on signs of operation when reading mathematics weakens students' mathematics ability (Adam, 2003)

Lewis et al (2010) showed pupils making twice as much progression in maths with speech enabled maths resources compared to print-based learning materials.

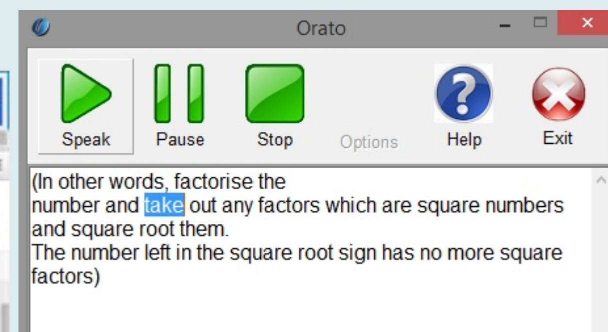
Reading aloud maths, does it help?

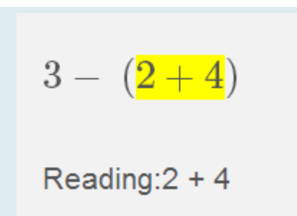
Lewis et al (2014) found with students aged 13-14yr:

- average student error rate for reading math symbolic content was almost twice that for reading plain math text
- 96% of the students surveyed preferred reading math on computer instead of on paper.
- 100% of teachers & 79% of students said synchronised highlighting of symbols & text helped.
- 80% of students reported easier for them to read their math materials on the computer,
- But time to access materials and technology issues reduced impact and confidence of the students and instructor

Working memory & text to speech

- Text to speech offer multi-modal support for reading maths
- Reduces demand on phonological loop
- Synchronised highlighting aims to support visual spatial processing





Computer Readers & Accessibility

- Screen readers for non-sighted users
  - reads all screen elements & allow navigation by keyboard & audio
- Text to speech tools (TTS) for sighted users
  - Control speech by selecting text or toolbar buttons
  - Often with colour highlighting to assist with tracking text
- Accessible content is compatible with TTS or computer reader

Accessible Content (or not)

function of math anxiety, especially on tasks that require intensive processing within working memory. We do not test the specifics of Eysenck and Calvo's (1992) prediction here, which states that it is intrusive thoughts and worry (in this case, about math) that detract from available working memory capacity. Instead, we assess the more general prediction that math anxiety disrupts working memory processing when the cognitive task involves arithmetic or math-related processes. In this sense, our prediction is not appreciably different from simpler models of attentional or working memory disruption, for instance, Kahneman's (1973) prediction that stress will disrupt processing that depends on attentional (working memory) factors.

Where were the children?"). At the end of the set, the participant must then recall the final word in each of the presented sentences (e.g., harvest, ice cream), in serial order. Three trials are presented at each span length, with testing continuing until the participant fails to respond correctly to at least two of these trials (note that each sentence or problem in the block must also be answered correctly). For the C-span test, simple arithmetic problems replace the sentences (e.g., 5 + 2 = ?, 9 − 6 = ?). Participants give the answer to each problem (7, 3), one by one, and then must recall the last number (2, 6) in each of the several problems within that trial, in order. Thus the span tasks require both on-line processing for sentence comprehension or problem solution simultaneous with storage and maintenance of information in working memory for serial recall.

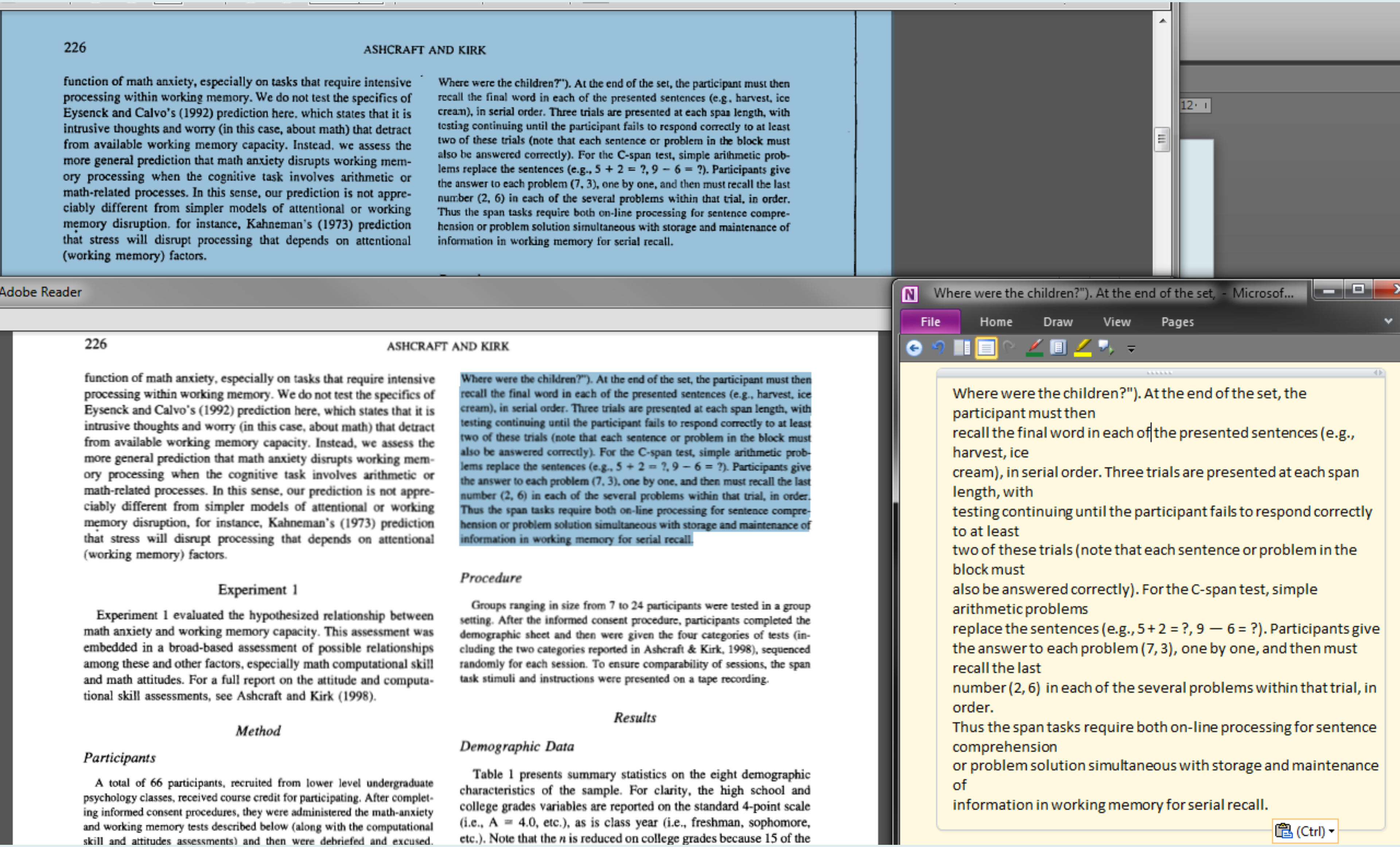
Adobe Reader

226 ASHCRAFT AND KIRK

function of math anxiety, especially on tasks that require intensive processing within working memory. We do not test the specifics of Eysenck and Calvo's (1992) prediction here, which states that it is intrusive thoughts and worry (in this case, about math) that detract from available working memory capacity. Instead, we assess the more general prediction that math anxiety disrupts working memory processing when the cognitive task involves arithmetic or math-related processes. In this sense, our prediction is not appreciably different from simpler models of attentional or working memory disruption, for instance, Kahneman's (1973) prediction that stress will disrupt processing that depends on attentional (working memory) factors.

Where were the children?"). At the end of the set, the participant must then recall the final word in each of the presented sentences (e.g., harvest, ice cream), in serial order. Three trials are presented at each span length, with testing continuing until the participant fails to respond correctly to at least two of these trials (note that each sentence or problem in the block must also be answered correctly). For the C-span test, simple arithmetic problems replace the sentences (e.g., 5 + 2 = ?, 9 − 6 = ?). Participants give the answer to each problem (7, 3), one by one, and then must recall the last number (2, 6) in each of the several problems within that trial, in order. Thus the span tasks require both on-line processing for sentence comprehension or problem solution simultaneous with storage and maintenance of information in working memory for serial recall.

Accessible Content (or not)



Accessibility barriers to maths notation

- Most electronic maths is represented as images (PDFs, JPEGs, SVG)
- PDFs provide particular difficulties with for typesetting maths

Questions 4: Simplify: (a) $\frac{10}{\sqrt{5}}$ (b) $\frac{\sqrt{5}}{\sqrt{3}}$ (c) $\frac{2\sqrt{3}+5}{\sqrt{3}}$

(d) $\frac{3\sqrt{6}}{\sqrt{3}}$ (e) $\frac{12\sqrt{21}}{\sqrt{6}}$ (f) $\frac{2\sqrt{15}}{\sqrt{12}}$ (g) $\frac{12\sqrt{3}-6\sqrt{2}}{\sqrt{6}}$

Clipboard output….

Questions 4: Simplify: (a) 10 5 (b) 5 3 (c) 23 5 3 +

Accessibility barriers to maths notation

- Mathematical mark-up MathML designed for accessibility but limited support in browsers and applications

$a+b/2$

```
<mml:math xmlns:mml="http://www.w3.org/1998/Math/MathML">
<mml:mfrac>
<mml:mrow><mml:mi>a</mml:mi><mml:mo>+</mml:mo><mml:mi>b</
mml:mi></mml:mrow>
<mml:mn>2</mml:mn>
</mml:mfrac>
</mml:math>
```

- MathML support is improving in e-books (epub3) and increasing number of apps support it (Sorge et al , 2104; Holden et al, 2014; Bahram et al 2014)

Mathematical semantics & computer reader issues – visual structures

Maths is a 2-deminsional notation. Location of a symbol affects its meaning.

GCSE question:

Circle the expressions that is equivalent to $4 \times x$:

$x \uparrow 4$ $\quad$ $4x$ $\quad$ $4 \uparrow x$ $\quad$ $x \times x \times x \times x$

text read as: “x 4” “4x” “4x” “x times x times x times x”

Quadratic Formula:

$x = -b \pm \surd b \uparrow 2 - 4ac / 2a$

Read as “x = b square root b 2 4 ac slash 2 a”

Mathematical semantics & computer reader issues - ambiguity

Maths when read aloud can mean different things

Example 1: “a plus b over 2”:

$$a+b/2 \quad \text{or} \quad a+b/2$$

Example 2: “3 plus 2 minus 4”:

$$3+2-4 \quad \text{or} \quad 3+(2-4)$$

Note:

- inconsistency of language: minus/subtract
- Importance of prosody & context

Mathematical semantics & computer reader issues - accuracy

Example: “a plus b over 2”   / “a plus b all over 2”

$$a+b/2 \qquad\qquad a+b/2$$

Accurate but verbose alternatives

“a plus open fraction b over 2 close fraction” $a+b/2$

“open fraction open bracket a plus b close bracket over 2 close fraction”

$(a+b)/2$

Pitch, earcons, spearcons a have been proposed to replace elements that represent hierarchical structure (Bates & Fitzpatrick,2010; Gellenbeck & Stefik, 2009)

Mathematical semantics

A mathematical expression or equation is like a sentence. It has a grammar and semantic structure.

Simple expressions are like simple sentences:

“I can run” …… $x+2$

Complex expressions can contain sub-clauses and conjugates

"I can run like the wind if the grizzly bear chases after me‟…

$(x+2)\uparrow 2\ /x+2$

If sighted readers can drill down into the semantics of an equation then audio representation of the notation may be more valuable.

STEMReader project

Develop a usable, sustainable tool for reading aloud maths notation to use alongside their current support strategies.

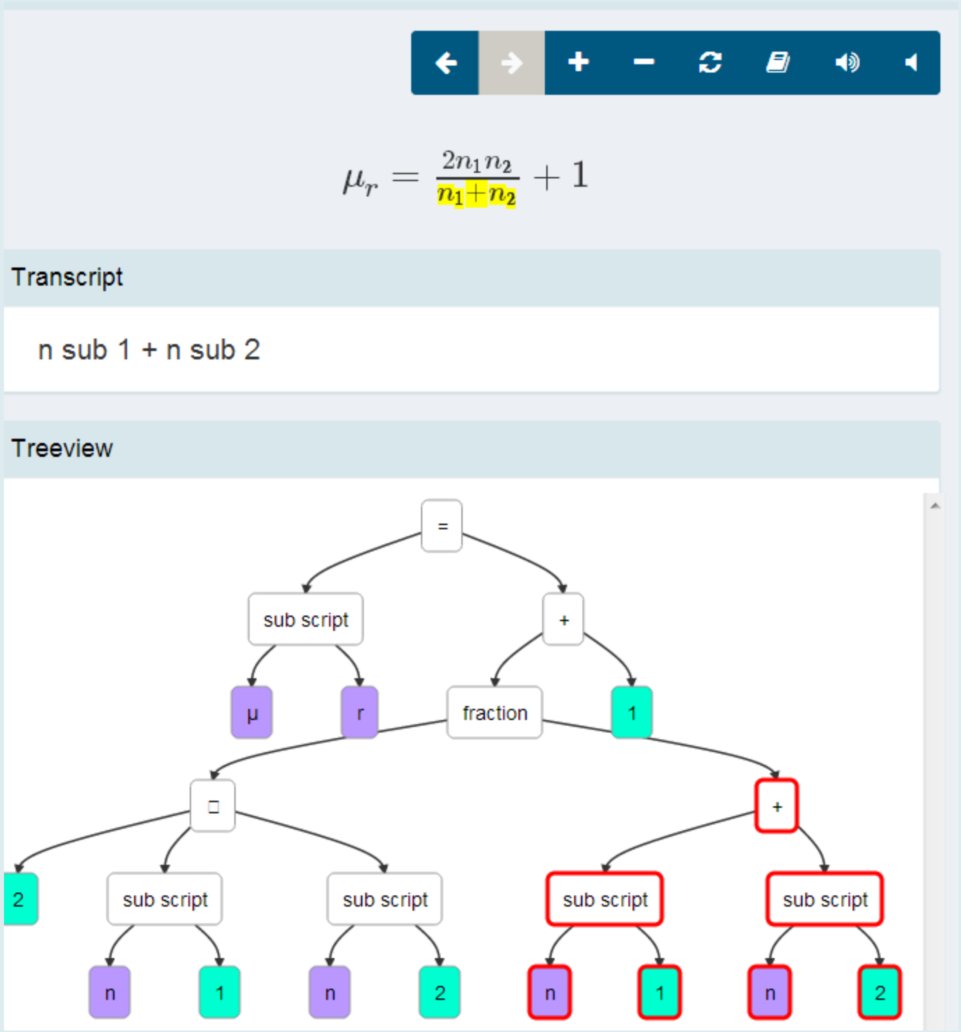
Goals:

- Improve solutions for reading aloud maths notation for students studying from functional skills through to degree level maths and science
- Platform independent tool for rendering & speaking MathML with definitions and suitable reading rules
- User-centred design throughout user trials throughout development
- Due to launch May 2016

UNIVERSITY OF Southampton
The Higher Education Academy
Department for Business Innovation & Skills
Innovate UK Technology Strategy Board

STEMReader

- Read aloud maths in accurately but without overloading user
- Highlight the equation as it is read
- Provide users with different options for speaking equations
- Investigating different ways of displaying the semantic relationships within the notation



Student trials – use of maths TTS in Higher Education

Loughborough Students:

- February & March six students from maths support department were interviewed and had access to STEMReader.
- Four students interviewed following using STEMReader
- Additional meetings with students and professionals at schools, FE colleges, universities & in the workplace

Student Profiles

A: 1st yr Economics, Dyslexia

- Reading comprehension
- Writing speed
- Working Memory
- Information processing speed

B: SEFS,

Dyslexia, Dyspraxia, Dyscalculia

- Phonological processing
- Working Memory
- Information processing speed
- Organisational skills
- Hand-eye coordination
- Handwriting speed
- Read comprehension
- Numeracy

Student Profiles

C: 2nd yr Maths/Computing, Dyslexia

- Reading comprehension
- Reading speed
- Writing speed
- Working Memory
- Information processing speed

D: 3rd yr Maths/Physics Dyslexia (IQ top 5%)

- Reading accuracy/speed
- Writing speed
- Working Memory
- Information processing speed
- Specific difficulties with mathematical information processing

Student Profiles

E: 2nd yr, Physics

Dyslexia

- Working memory
  - number sequencing
- Retrieval of information from long term memory
- Rapid naming.
- Phonological processing

F: 3rd yr Economics

Dyslexia

- Reading comprehension
- Reading speed
- Short Term Memory
- Information processing speed
- Underestimates her mathematical ability

Self reported difficulties with maths

- Of 4 students using text-to speech, 3 reported being frustrated that they couldn’t read aloud maths & needed this for proof reading. (C, D, E)
- Students A, B, C, D reported mixing up numbers or writing them down incorrectly.
- Students A, B reported concerns of how long it took them to process information & equations
- All students wanted support with revision with D, E, F wanting audio support, C wanting visual support

Feedback 1. audio rendering of equations

- Distracted by audio pitch changes. Used in some tools to communicate equation structure
- Equations must be spoken correctly & consistently

$$\mu_r = 2n_1 n_2 / n_1 + n_2 + 1$$

2 n sub 1, n sub 2

2 n subscript 1, n subscript 2

2 n 1, n 2

- Felt like it was taking longer to read equations. Student A, B reported improved accuracy in tests.
- Student C & D talked about the advantages of chunking the equation

Feedback 2. text & visual representations of equation

- Students reported text version of equations helpful to confirm contents
- Students confused by semantic map of equations
  - Already comfortable with standard notation
  - Map too large with complex expressions
- Tool included example definitions for a few symbols. Students reported that they would find this useful to have access to simple definitions & examples.

Feedback - overall lessons

- Accessible maths content is key
  - students concerned about time it took to get maths into the right format
- While it took longer to read equations, students reported improved accuracy
- Positive response to including speech feedback within revision strategies for those preferring audio strategies
- Using student feedback to redesign tree & navigation approach (also considering non-sighted users)

Maths Reading Rules

- Current reading rule set based on non-sighted users
  - Verbose & use of terms derived from US Braille rules
- Students have reported inconsistent use of language is confusing
- Concerns about matching reading to assessment criteria if used in exams
- Building symbol dictionary combining reading rules with definitions. Multiple rule sets e.g.
  - Level 2 maths
  - Assessment environment
  - Degree level maths

Further work

- Improve navigation through maths equation
- Guidance on creation and access to accessible maths content
- Dictionary and reading rules sets to match user requirements
- Support for different platforms

Contact email:

a.james@soton.ac.uk

References

Adams, T. L. (2003). Reading mathematics: More than words can say. The Reading Teacher, 56(8), 786-795.

Alloway, T. P., & Passolunghi, M. C. (2011). The relationship between working memory, IQ, and mathematical skills in children. *Learning and Individual Differences*, *21*(1), 133-137.

Ashcraft, M. H., & Kirk, E. P. (2001). The relationships among working memory, math anxiety, and performance. *Journal of experimental psychology: General*, *130*(2), 224.

Baddeley, A. (2000). The episodic buffer: a new component of working memory?. *Trends in cognitive sciences*, *4*(11), 417-423.

Bahram, S., Soiffer, N., & Frankel L. (2014) Understanding Mathematical Expressions through Interactive Navigation. In 29th *Annual International Conference on Technology and Persons with Disabilities, Northridge, California, USA.*

Bates, E., & Fitzpatrick, D. (2010). Spoken mathematics using prosody, earcons and spearcons. Computers Helping People with Special Needs, 407–414.

Burch, M. A. (2002). Effects of computer-based test accommodations on the math problem-solving performance of students with and without disabilities. Dissertation Abstracts International: Section A. Humanities and Social Sciences, 63(3), 902.

Ferguson, A. M., Maloney, E. A., Fugelsang, J., & Risko, E. F. (2015). On the relation between math and spatial ability: The case of math anxiety. *Learning and Individual Differences*, *39*, 1-12.

References

Gellenbeck, E., & Stefik, A. (2009). Evaluating Prosodic Cues as a Means to Disambiguate Algebraic Expressions : An Empirical Study, 139–146.

Holden, W., Sunnes, M., & Graffe, S. (2014) The Next Generation Text to Speech Program. In 29th *Annual International Conference on Technology and Persons with Disabilities*

Lewis, P., Noble, S., & Soiffer, N. (2010, October). Using accessible math textbooks with students who have learning disabilities. In *Proceedings of the 12th international ACM SIGACCESS conference on Computers and accessibility* (pp. 139-146). ACM.

Lewis, P., Lee, L., Noble, S., & Garrett, B. (2013). KY Math Etext Project-A Case Study: Math Curriculum Digital Conversion and Implementation. *Information Technology and Disabilities*, *13*(1).

Passolunghi, M. C., Cornoldi, C. &De Liberto, S. (1999).Working memory and intrusions of irrelevant information in a group of specific poor problem solvers. Memory and Cognition, 27, 779–790.

Sorge, V., Chen, C., Raman, T. V., & Tseng, D. (2014, April). Towards making mathematics a first class citizen in general screen readers. In *Proceedings of the 11th Web for All Conference* (p. 40). ACM.