From design experiments to innovation at scale: potential and challenges for research in mathematics education

Professor Dr Celia Hoyles O.B.E

London Knowledge Lab, Institute of Education, University of London

Director of the National Centre for Excellence in the Teaching of Mathematics

Vielen Dank für die Einladung

Ich liebe Münster

structure of my talk

1. design experiments in mathematics education: some general issues
2. design experiments that embed use of digital technologies
3. some ongoing research
4. factors in scaling up

different ‘types’ of research

‘science’ & ‘engineering’

design research

starts with “big ideas” in mathematics that are identified by research (theory or empirical experiment) as hard to teach and learn (they are ‘obstacles’)

theoretically & empirically-driven task design & task progression to

- address these obstacles
- align with ‘local’ curriculum & assessment practices

iterative design experiments to test with teachers as co-designers

Design research often reports ‘dramatic’ impact on student outcomes

need more caution about reporting results of design experiments?

- innovations in and of themselves do not innovate
- maybe other options explain positive results of implementing the innovation or design experiment that do not privilege one part of the innovation

Temptation to pick one area as reason for change///

XXXXX has demonstrated that attainment can be dramatically improved by using XXXXXXXXX to improve students' learning

But many caveats

intervention groups relatively high attaining in relation to matched comparison

different timings of the student tests for intervention and for the comparison group

teachers involved in the interventions self-selected volunteers and very enthusiastic

the intervention involved professional development for teachers

professional development undertaken by the design team

BUT cumulative evidence of effects of design research is dramatic

Design research: a framework?

Some conjectures:

1. recognise importance of design & complexity of implementation
2. make explicit the
   - epistemological basis of the intervention
   - and the design decisions made

4. be clear about the need for evidence-based, expert **teacher professional development & materials**

Design research: a framework?

And recognise the limitations of what can be achieved by teaching: e,g

"difficulty of multiplicative reasoning and mastering proportionality is not simply engendered by teaching---huge conceptual step to be taken by students in order to master proportional (or, more generally, functional) reasoning". (Nunes & Bryant)

need to revisit in spiral way?

and bridge to 'standard' curriculum?

A note about context?

- mathematics carries considerable social capital
- But in a world of digital images, animations, easy information retrieval & communication students can dismiss mathematics as irrelevant, boring and hard
- importance of tapping into youth culture to motivate students to sustain their engagement with mathematics

We try to build **engaging** environments for learning mathematics where mathematics is

- **needed** for students to achieve the goals of the activity
- **compelling** for students
- the **actions in** the environment help students engage in mathematical thinking: shift from pragmatic to epistemic use of digital tools

Design research that embeds digital technology

We exploit **explicitly** the functionalities of the technology **for mathematics teaching & learning**

- its dynamic & visual nature …plus multi-media, connectivity ….
- its potential to
  - **present & link different representations dynamically**
  - provide feedback designed so students **learn** from the results of their actions
  - leave a trace of **how solution is constructed**, not just the answer
  - provide tools so students can **share** and discuss

Theoretical framework of Constructionism

Design research that embeds digital technology

Again dramatic success in design experiments
But not just the technology of course…….
and problems of scale

Some examples

Designing software for mathematical engagement through modelling, 17th ICMI study book Hoyles & Lagrange (2009)

Theoretical framework of Constructionism

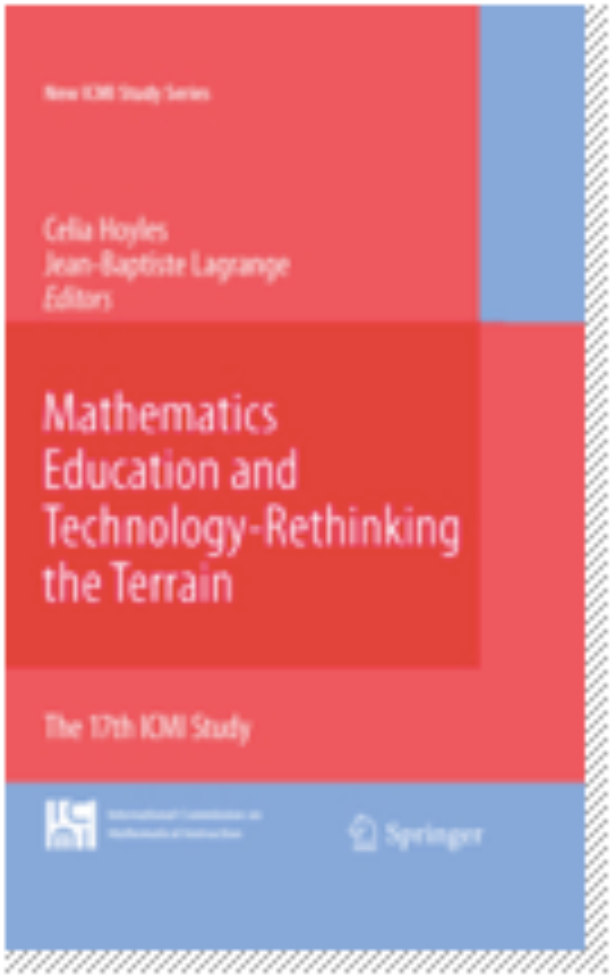
ICMI Study 1: the influence of computers & informatics on mathematics & its teaching 1985

Churchhouse, R. F., Cornu, B., Howson, A. G. Kahane, J.-P., van Lint. J. H., Pluvinage, F., Ralston, A. & Yamaguti, M. (Editorial Board). (1986). *The influence of computers and informatics on mathematics and its teaching.* Cambridge: Cambridge University Press, ICMI Study series.

reprinted 1992

The 17th ICMI Study Technology revisited

Hoyles. C & Lagrange J-B (eds) (2009) *Mathematics Education and Technology- Rethinking the terrain*



Five perspectives

- theory: (wealth of perspectives)
- the role of the teacher
- curricula framing
- geographical diversity
- design

‘new’ issues

Many new issues compared to first ICMI study

- equity
- diversity
- Papert’s 10% - new types of mathematical knowledge and practice
- ……..
- connectivity

And now…?

Mobile technology

applets & **tablets**

and…

Design research that embeds digital technology

top down or bottom up?

Need balance of

- teacher autonomy & supportive CPD
- pragmatic tool use & epistemic tool use
- ….and top down support aligned with bottom up growth

Need to research the mechanism of scaling up

Starting points for successful scaling of design research?

1. enhance teacher capacity for professional learning in mathematics
2. make mathematics more visible: opening up the ‘black box’
3. build teacher capacity ‘bottom up’ through communities of teachers

1. Enhance teacher capacity for professional learning in mathematics

The National Centre for Excellence in the Teaching of Mathematics

Set up in 2006 I have been Director since 2007

Vision to develop a sustainable national infrastructure for subject-specific professional development of teachers of mathematics

Aims:

to meet the professional aspirations of all teachers of mathematics

to realise the potential of learners

NCETM: blended activities

face-to-face events & network meetings

interactions with the NCETM portal
www.ncetm.org.uk

news, resources, tools & group discussions

rsonal Learning Space

OYLES

My Details

My Communities

My Files & Folders

My Favourites & Notes

My Self-evaluation

My Online CPD

My Learning Journal

My Career Portfolio

Sharing & Contacts

The NCETM 'essentials' collection: Guiding you to t right solution

The NCETM online resources number many thousands of pages, and it can sometimes be a little daunting to find exactly what you want. Our guidance pa contain links to relevant resources from across the NCETM, and include links discussion forums, offering the opportunity to examine and record your own pr and thoughts.

Featured Projects

Mathematics resources for Teachers in Training

Resources, guidance and reflective activities for ITE students and tutors, aiming to support all aspects of the course that relate to mathematics.

Teaching Assistants and Other Adults in the Mathematics Classroom

If you work with groups of children in the classroom and are not the classroom teacher, this microsite aims to help support workers develop the wide variety of professional skills needed.

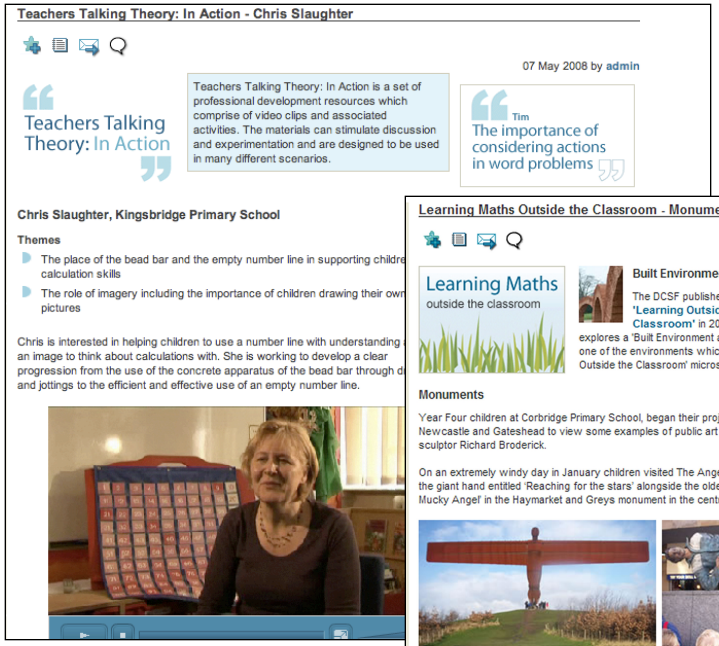
Online Magazines

- Early Years
- Primary
- Secondary
- FE

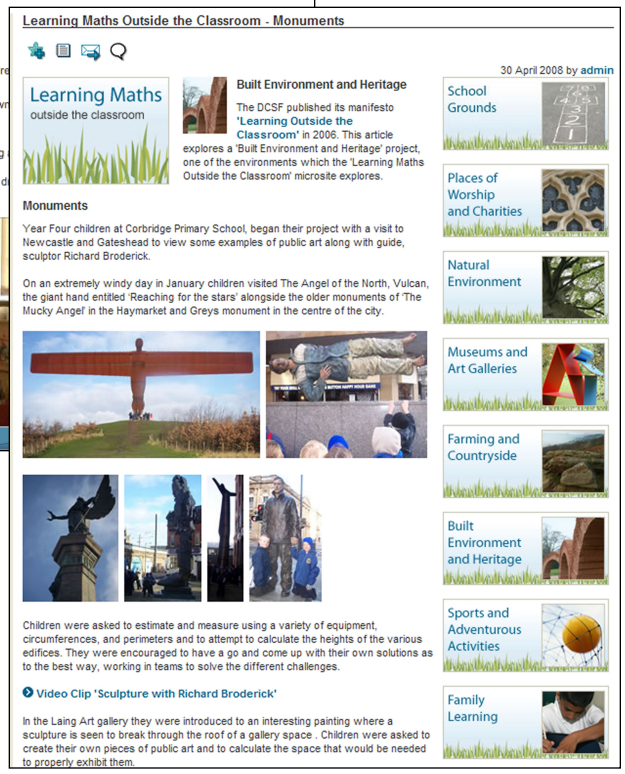
Online Learning

Online CPD Modules: guide activities to dev your thinking an reflection.

NCETM portal micro-sites



Teachers Talking Theory in Action



Learning Outside the Classroom

Maths of Wimbledon

NCETM Reports

- Reseaching Effective CPD in Mathematics Education (RECME)
  www.ncetm.org.uk/recme-report

- Mathematics Matters
  The NCETM publishes Mathematics Matters Final Report – NCETM

What makes a Good Resource

What makes a good classroom resource?: Changes in my classroom

Classroom resources alone cannot guarantee effective learning and teaching. But they do have the potential to trigger new approaches and behaviours – i.e. changes in our classroom. In this way good resources can provide a great source of professional development.

The activities have been written and devised by real teachers determin
teaching mathematical ideas and topics.

Quicklinks

- What Makes A Good Resource
- Early Years Sector
- Primary Sector
- Secondary Sector
- Further Education Sector
- Special Educational Needs Sector
- Using the Materials

Sections on

What I did

Reflection

Comments

www.ncetm.org.uk/goodresource

Collaborative Teacher Projects www.ncetm.org.uk/ctp

- Funding of up to £5000 for projects in schools for teachers to work collaboratively with the support of an improvement agent
- **Why?**

Why Collaborative Teacher Projects? www.ncetm.org.uk/ctp

giving status to teachers' work

"NCETM funding was hugely valuable but the really big thing was that it meant we had a name for the project, we had status within the schools and we had a reason for meetings…and that was really good and really big and really important"

building a community

"*I was surprised at how it welded my staff together doing this type of learning in this particular way, how it helped develop the ethos of the school, it sounds very dramatic but it did … really thinking together and sharing thoughts and ideas and reflecting together really helped to bind my staff together as a very strong team*"

taking risks

"*People actually taking things they were not sure about, trying them in their class and coming back the next time saying that they couldn't believe how much the children were talking about mathematics…and there was a lot of enthusiasm for getting children talking about mathematics … all of us got quite excited …"*

Statistics

National Centre for Excellence in the Teaching of Mathematics

Over 100,000 registered users……..

End of March 2013




we encourage collaborative projects that involved the use of digital technologies

But this is not sufficient for scaling ☹





2. Make mathematics more visible:
opening up the ‘black box’

EPSRC
Pioneering research and skills

Institute of mathematics & its applications

Research Case Studies of impact of contemporary research in mathematics on society

Mobile Phones: improving signal transmission

Climate Change

Human Genome

Advancing the Digital Arts

MATHEMATICS MATTERS

http://www.ima.org.uk/i_love_maths/mathematics_matters.cfm),

2. Make mathematics more visible:
opening up the 'black box'

Getting mathematicians to provide a glimpse of the underlying mathematics

Hoyles., ,C. Noss, R. Kent, P. Bakke,r A. *Mathematics in the Workplace: Issues and Challenges* in Eds Alain Damlamian, Jose Francisco Rodrigues , Rudolf Straesser (eds.): *Educational Interfaces between Mathematics and Industry - A joint ICMI/ICIAM study*. Springer (Heidelberg 2013.)

3. build teacher capacity ‘bottom up’ through communities of teachers

around **specific** aspects of core knowledge

- with **different** levels of support & engagement
- **spiral & iterative** with teachers (& schools) taking control at different levels
- CPD by ‘experts”…who can balance the support of **instrumentation** with a focus on epistemic tool use ----

Example 1

an intelligent exploratory learning environment for supporting the construction of mathematical generalisations & their expression as rules

What is the problem?

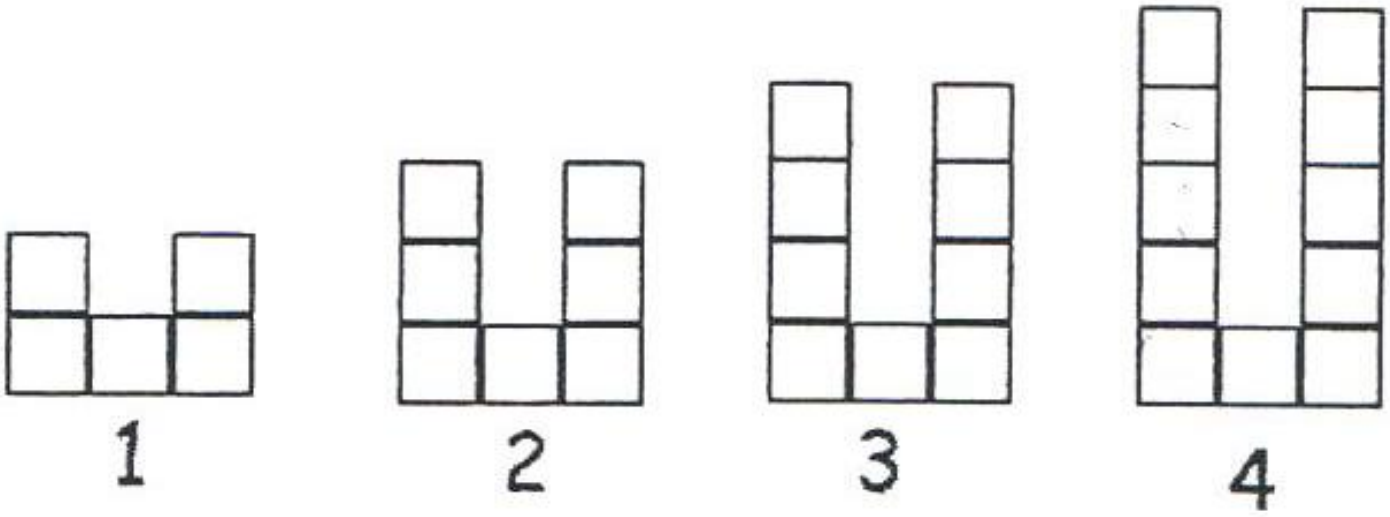
expressing generality is a well-known challenging topic…

- students might identify patterns but are not necessarily able to articulate the generality

- algebra is often viewed as an endpoint & disconnected from other means of expressing generality

UK Curriculum for grade 4/5

7 Draw the next 2 diagrams in this sequence:



a) Write down the number of squares in each term:

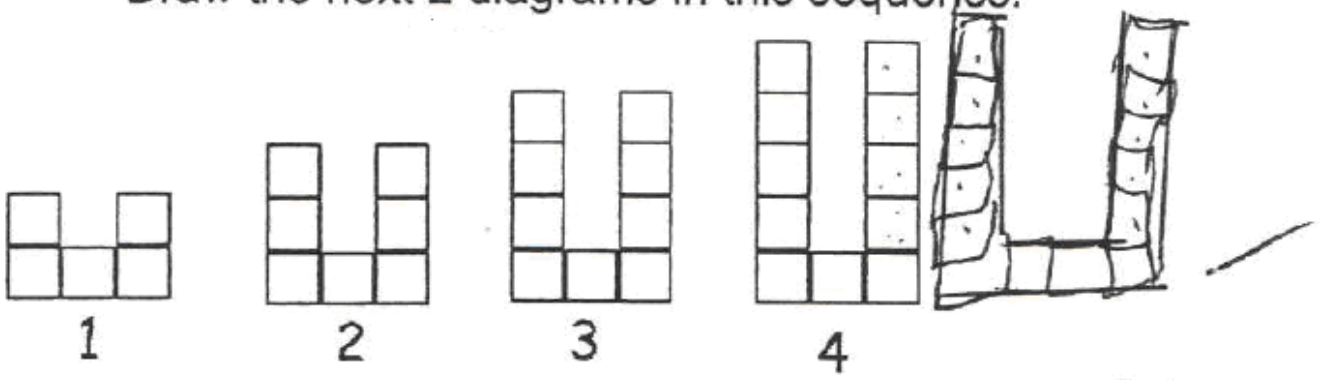
b) How many squares are needed for the 10^{th} term?

c) How many squares are needed for the 50^{th} term?

Show your working out.

A well –known problem

7 Draw the next 2 diagrams in this sequence:



a) Write down the number of squares in each term 5, 7, 9, 11 ✓

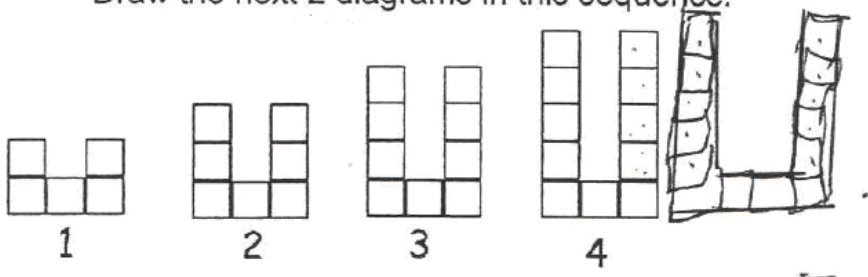
b) How many squares are needed for the 10th term? 50 ×

c) How many squares are needed for the 50th term? 250 ×

Show your working out.

an epistemological obstacle

7 Draw the next 2 diagrams in this sequence:



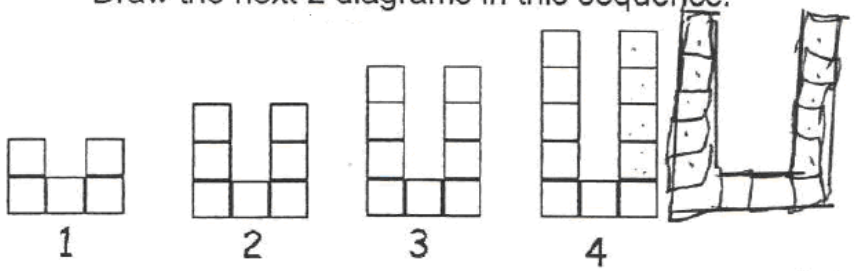
a) Write down the number of squares in each term 5, 7, 9, 11 ✓
b) How many squares are needed for the 10th term? 50 ×
c) How many squares are needed for the 50th term? 250 ×
Show your working out.

˙our´ epistemology

- the special case is a way of thinking about the general case
  - How many here? How many there? How many *in general?* Count and at same time recognise structure of the pattern, **apply the pattern** to any 'given number'.

an epistemological obstacle

7 Draw the next 2 diagrams in this sequence:



a) Write down the number of squares in each term. 5, 7, 9, 11 ✓
b) How many squares are needed for the 10th term? 50 ×
c) How many squares are needed for the 50th term? 250 ×
Show your working out.

students´ epistemology

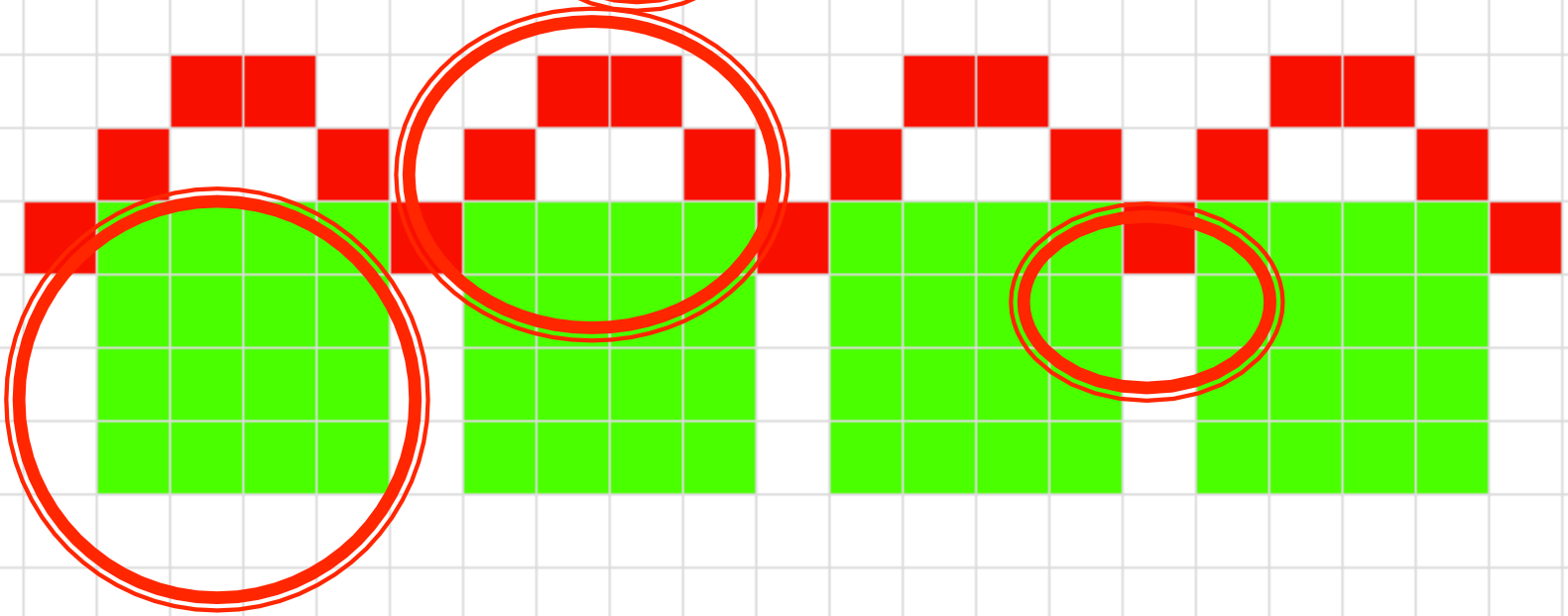
- the answer is the number of tiles – i'll count them then spot **any** pattern

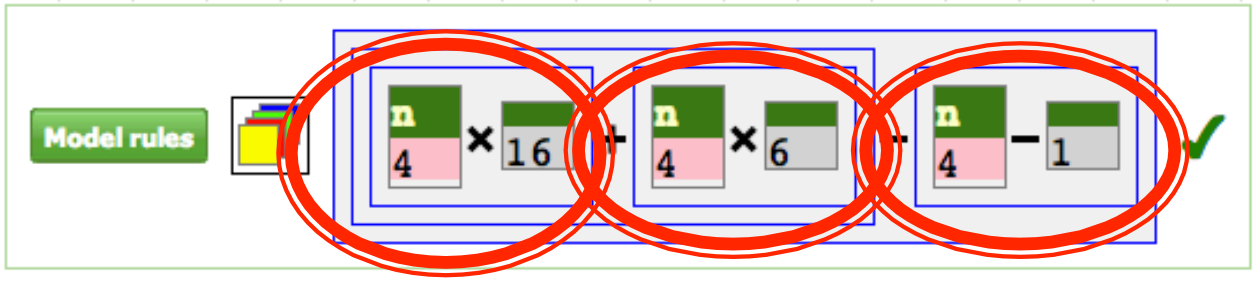
- what is this other thing i'm supposed to do and why am I supposed to be doing it?

Migen: Design decisions in response to the epistemological challenges

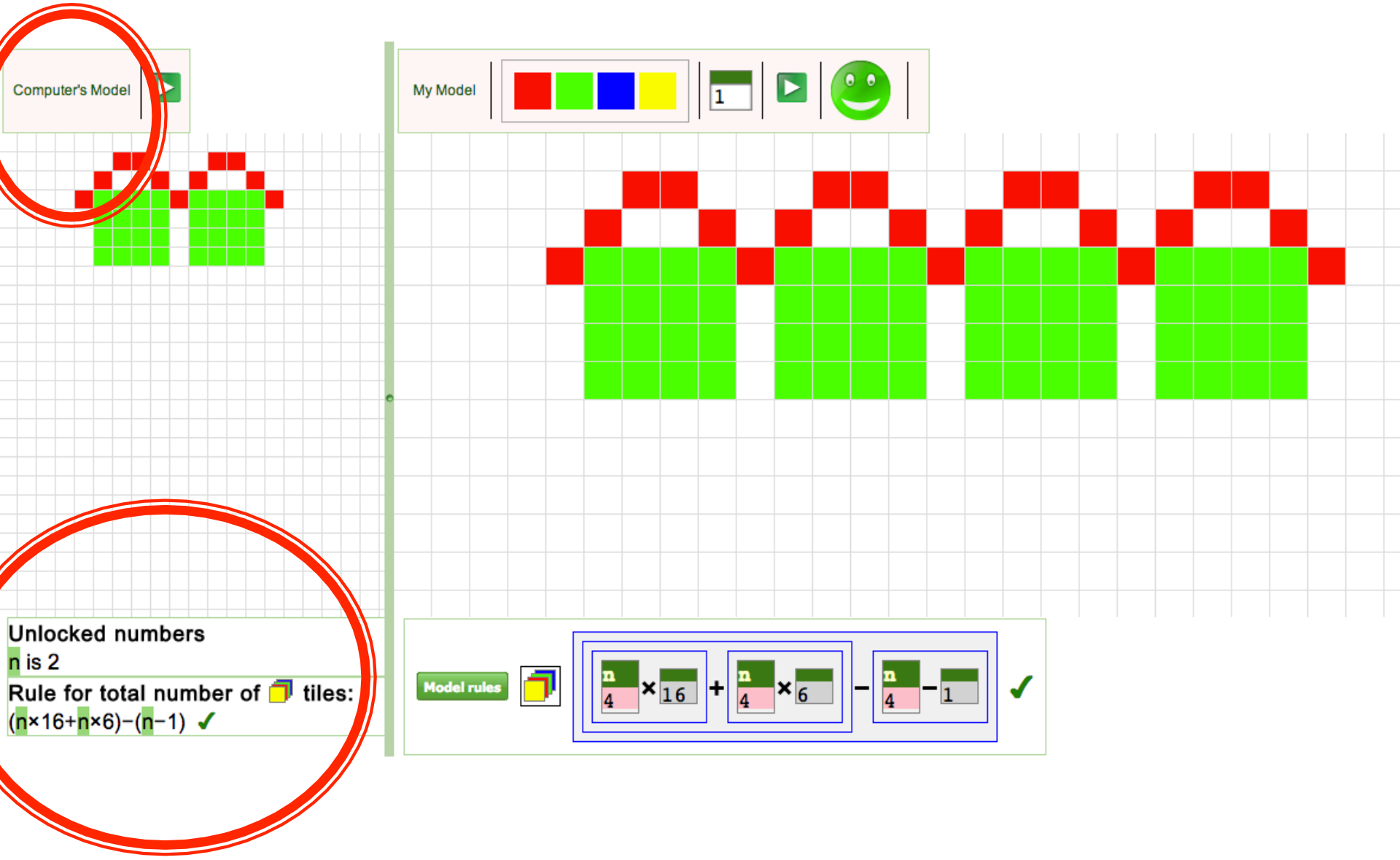
- dynamically presented tasks
- 'unlocked numbers' as a model for for constants and variables …as bridge to algebra
- synchronous view of the general case alongside any actions on special cases……. theory building….
- some intelligent support & teacher tools

Building a model & rule for the number of tiles in our microworld eXpresser

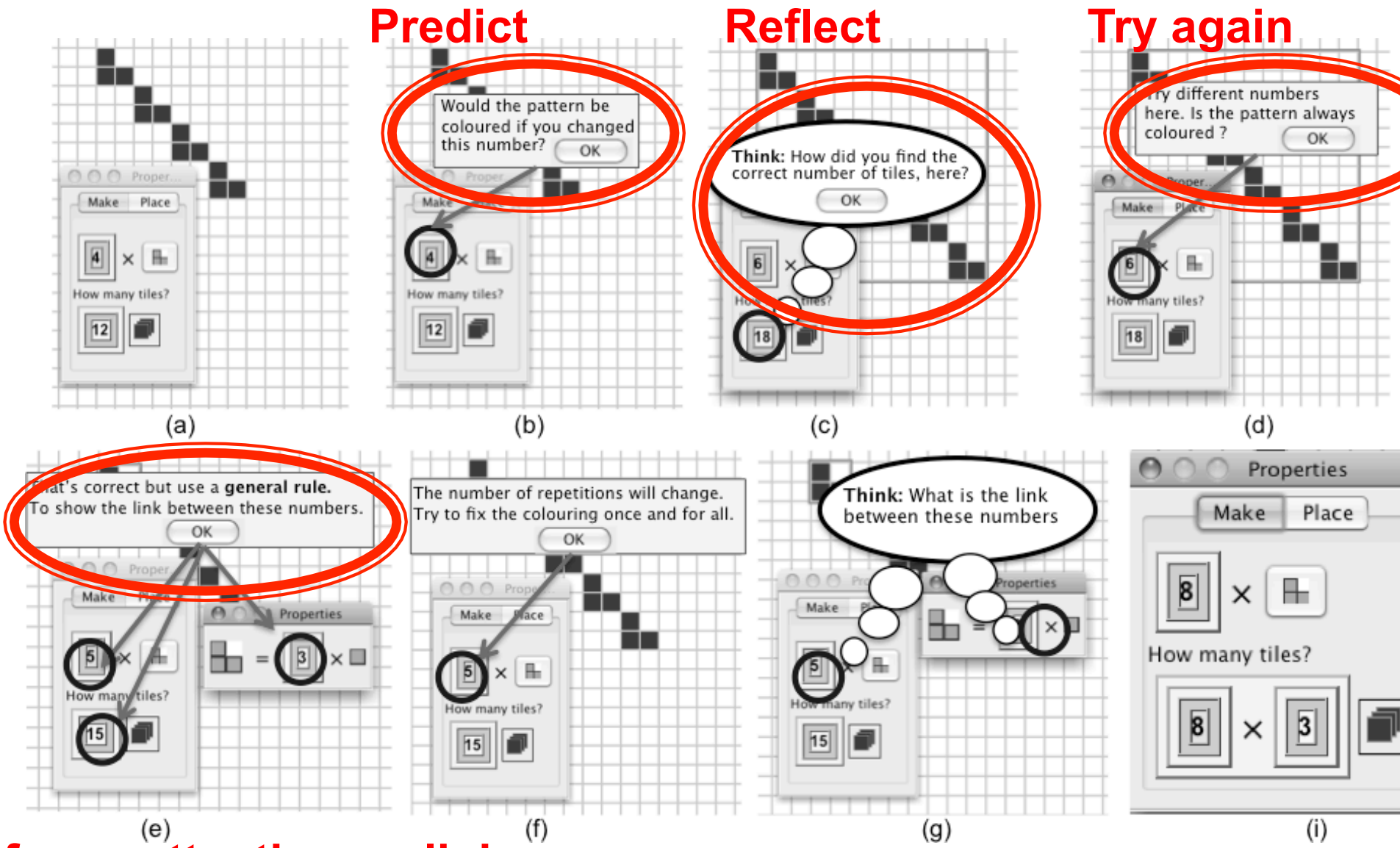




‘looking at’ the general



Sequence of prompts from intelligent support



Next design challenge….

- mapping new learning trajectories
- designing collaborative bridging tasks

And to scale …

Massive ‘new’ interest.. Why ?.....

Everybody needs to program: re-mixing

theguardian | The Observer

Why all our kids should be taught how to code

There is a growing consensus that the way children in schools are being taught information technology is in need of a radical overhaul. Here John Naughton explains the problem and offers a manifesto for revolutionary action

John Naughton
The Observer, Saturday 31 March 2012 20.15 BST

Jump to comments (288)

And – inevitably -- -

calls for **programming to be part of mathematics** ☺

3. **Example 2: a design experiment 'with an eye to scaling'**

Cornerstone Maths

An approach to technology-enhanced curriculum innovation at scale

Celia Hoyles & Richard Noss LKL

Jeremy Roschelle & SRI international

SRI International®

李嘉誠基金會 LI KA SHING FOUNDATION
Education · Healthcare · Culture · Community

IOE LONDON
Leading education and social research
Institute of Education
University of London

londonknowledgelab
exploring the future of learning with digital technologies

Four Elements of Cornerstone Maths

'Big research-based mathematical ideas': explicit & evidence-based reasons for using ICT for mathematics learning: multiple & dynamic representations

Teacher professional development
+ Teacher community

Replacement curriculum units
Package of teacher & student Activities (aligned to National Curriculum), trialled

Scaling

Why replacement unit strategy ?

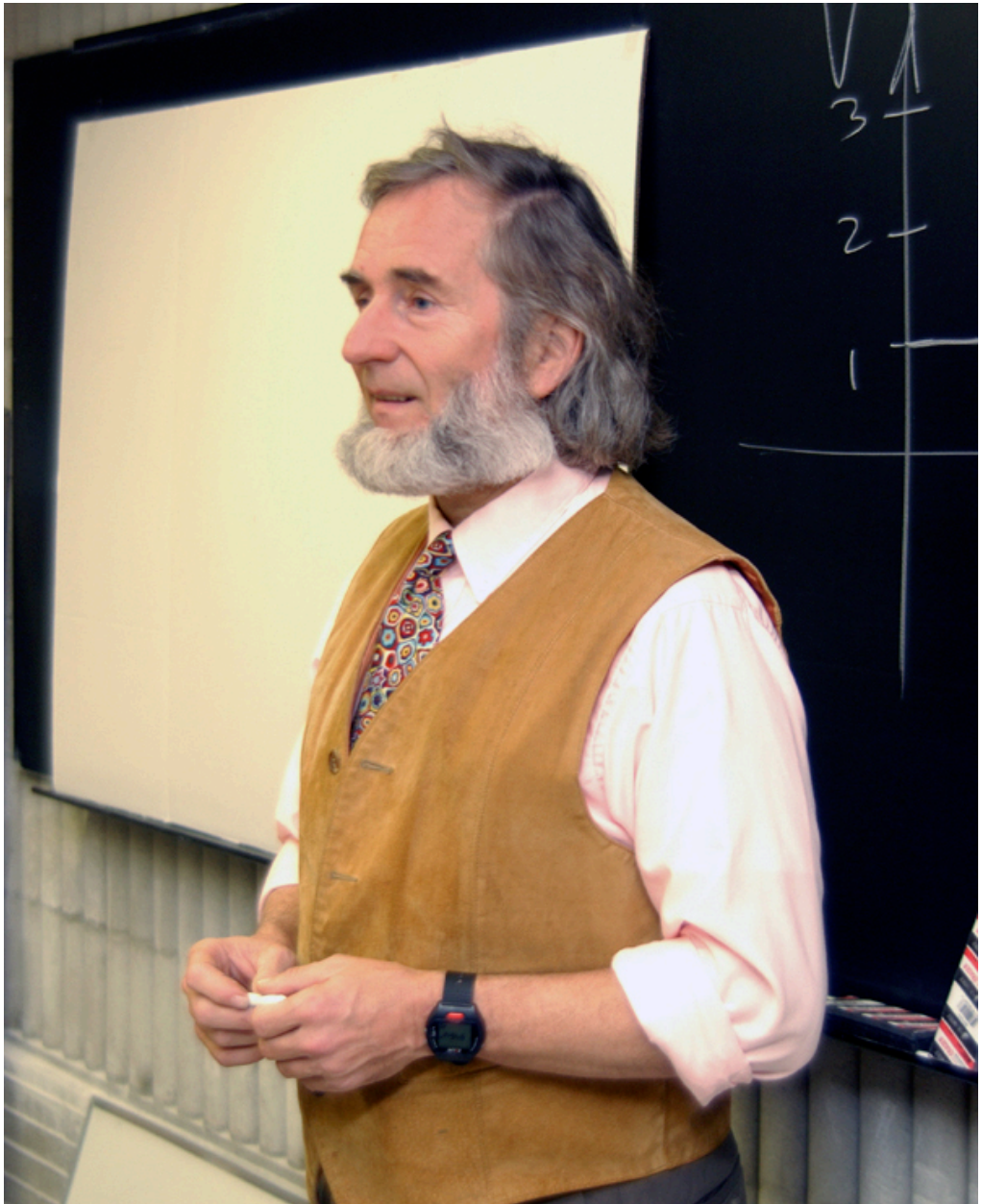
- one unit is large enough to observe the hoped for classroom change and meaningful learning, but small enough that teachers & schools will take risk of experiment
- unit explicitly connects the innovation (and researchers' interests) to teachers' priorities for curriculum coverage and improving student outcomes on hard-to-teach topics. (Roschelle et al, 2010)

Unit 1
Designing Mobile Games

A module on linear functions

Derived from ground breaking work of Simcalc Kaput et al

Democratizing Access to Advanced Mathematics



Jim Kaput
"SimCalc"

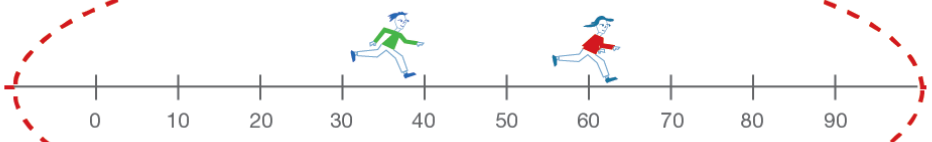
Unit 1 Linear Functions

Narrative

Red Reynaldo started off ahead, but was running slowly. Green Geneva started off behind, but ran faster and was ahead by the end.

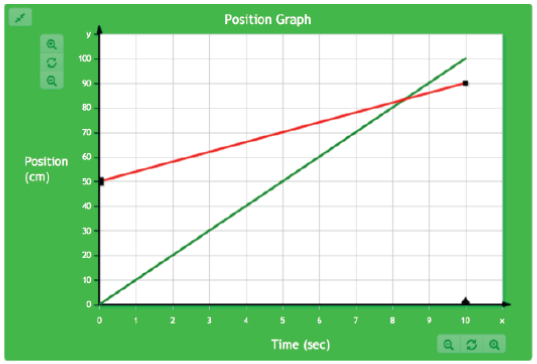
Algebraic Expression

$y = 4x + 50$
$y = 10x$



Motion Phenomena

Graph



Table

Time (sec)	Reynaldo	Geneva
00.00	50.00	0.00
01.00	54.00	10.00
02.00	58.00	20.00
03.00	62.00	30.00
04.00	66.00	40.00
05.00	70.00	50.00
06.00	74.00	60.00
07.00	78.00	70.00
08.00	82.00	80.00
09.00	86.00	90.00
10.00	90.00	100.00
Time (sec)	Reynaldo	Geneva
05.00	70.00	50.00

Big ‘mathematical’ ideas

- **Coordinating** algebraic, graphical, and tabular representations
- y= mx+c as a model of constant velocity motion – the **meaning of m and c in the motion context**
- **Velocity** as speed with direction
- **Average velocity**

Pilot: Design experiment over 18 months with
9 schools, 19 teachers
very **diverse** sample in terms of

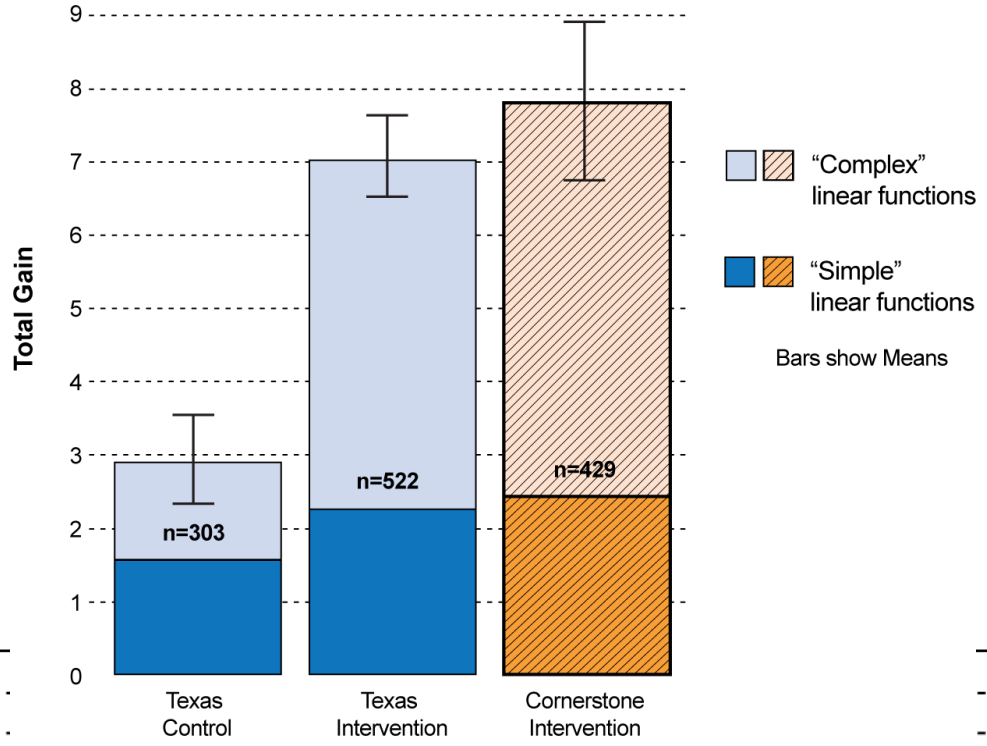
- school contexts
- prior student achievement
- teacher experience

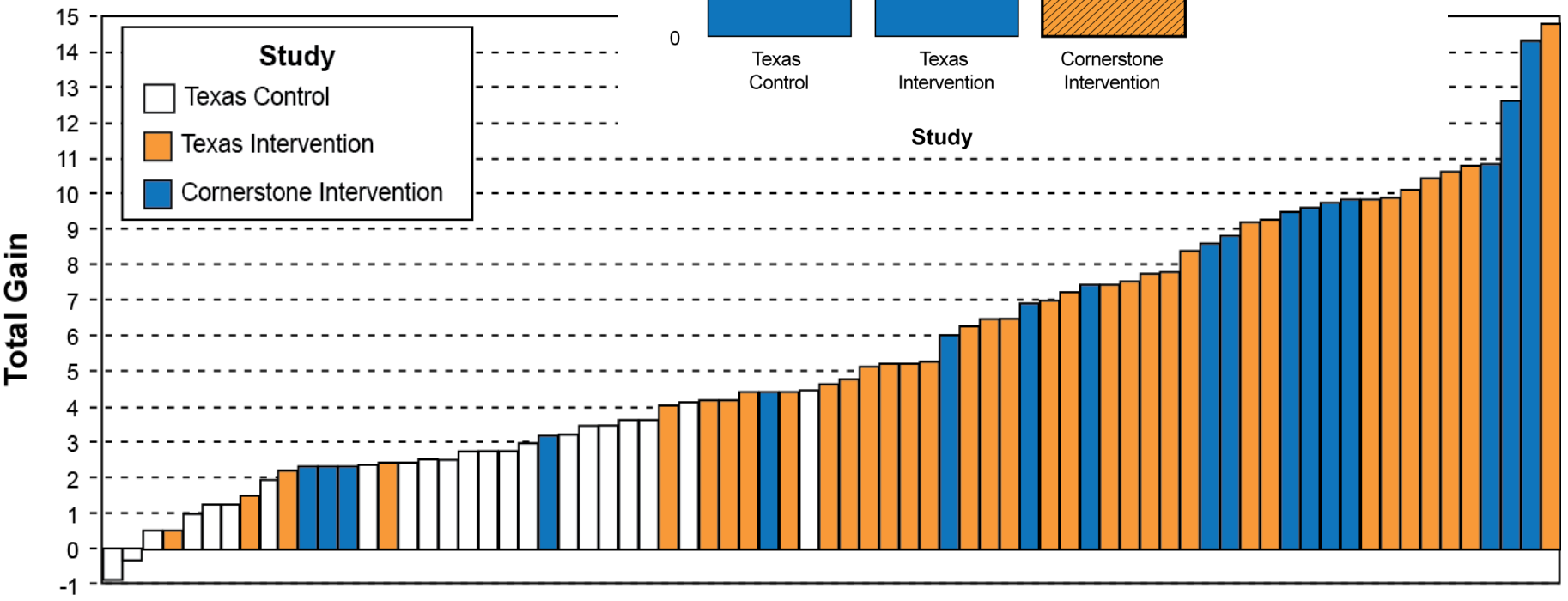
Massive success as evident in robust evaluation

- pre- and post- tests of student responses to core mathematical items
- teacher, student interviews & classroom observation
- external evaluation

we believe this is sufficiently robust to scale but…we shall see ..we are scaling to 100 schools from Jan 2013 ….

Quantitative results





Unit 1: Results from pilot (pre and post test)

Learning gains were as good as those observed in previous Texas study

Gains predominantly in “complex” conceptions (light blue)

(TEST SCORES:

mean pre = 10.7

mean post= 18.5,

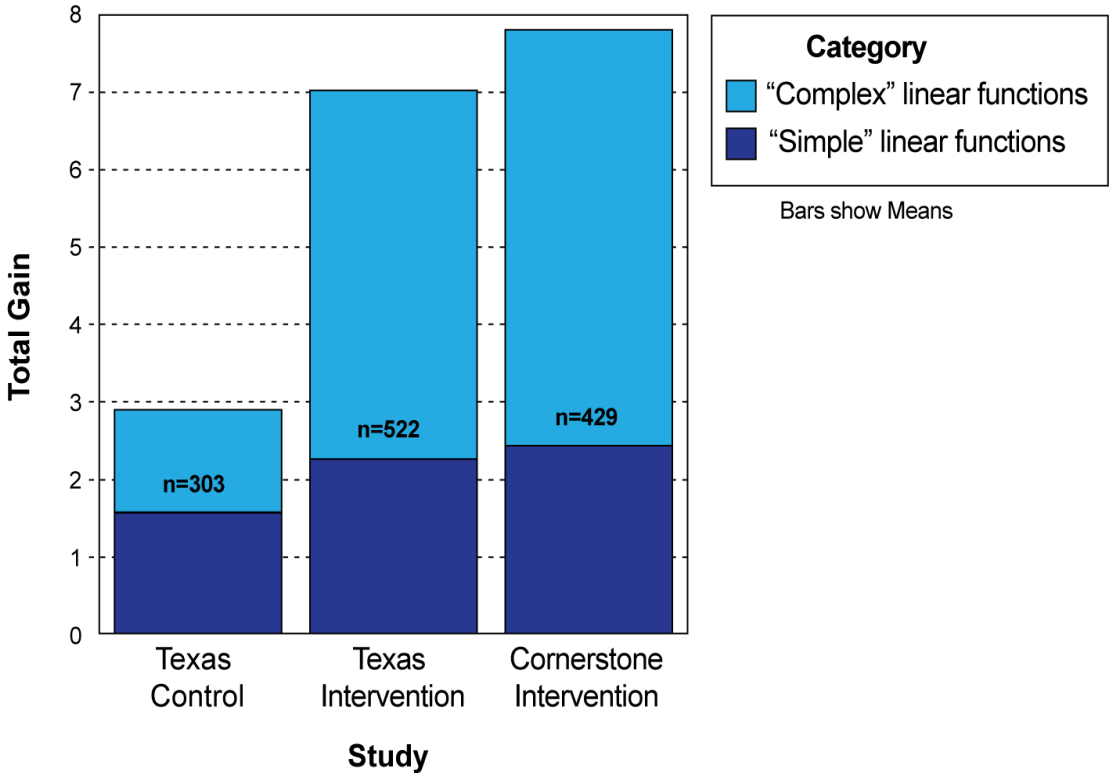
Maximum of 32)

STUDENTS (N=429)

(Y7) 179 (42%)

(Y8) 227 (53%)

(Y9) 23 (5%)



Our plans for scaling

http://tinyurl.com/csmaths

1. move to web based offer (including on Ipads) that embeds
   - software
   - curriculum materials
   - formative assessment
2. growing a team of expert CPD providers
3. building teacher capacity & leadership in regional hubs
4. moving from central to hub-based offer of professional support
   - face to face
   - through web-based in collaborative **online** teacher communities

Cornerstone units

- linear functions (Unit 1)
- geometric similarity (Unit 2): building on research with dynamic geometry
- algebraic generalisations (Unit 3): building on specifically on MiGen research
- ratio and proportion (Unit 4)

Final remarks

1. Be clear (again) that hardware alone doesn't work

"XXXXX to buy $50 million of tablets"

2. If we have an effect, what is it an effect of?
   - An *integration* of dynamic representations, curriculum workbooks & teacher professional development

3. What it is an effect on?
   - In Unit 1 Conceptual understanding of rate, expressed through multiple representations; weaker effects on more numeric proportionality problems

4. Always more challenges
   - New National Curriculum in England
   - move away from paper-based materials?
   - New platforms

Broader Closing Remarks

It took a long time –15 years - and large multidisciplinary teams

Many experiments at scale may be failing not because the technology is bad, but because of poor integrations:

- Leaving it to teachers to connect with curriculum
- Not providing focused PD with expert PD team
- Measuring the wrong outcomes
- More????

But it is worth it……..

One teacher 18months after pilot:

“ There was a distinct demarcation in my year 8 class between half students who did Cornerstone last year and half who didn’t. I can categorically say that Cornerstone pupils’ retention a year on is significantly better than pupils who had done similar things out of a textbook.”

Reflection from an experienced CPD provider:

“ important point is that the teachers are fairly every day teachers …it is being part of the research and development project that has developed them into teachers who could present clear reflections about their participation and what they and the pupils gained. **Wonderful”.**

Danke für Ihre Aufmerksamkeit

Some References

Churchhouse, R. F., Cornu, B., Howson, A. G. Kahane, J.-P., van Lint. J. H., Pluvinage, F., Ralston, A. & Yamaguti, M. (Editorial Board). (1986). *The influence of computers and informatics on mathematics and its teaching.* Cambridge: Cambridge University Press, ICMI Study series.

Coburn, C. E. (2003). Rethinking scale: Moving beyond numbers to deep and lasting change. Educational Researcher 32 (6), 3-12.

Confrey, J, Hoyles, C., Jones, D, Kahn, K, Maloney, A, Nguyen, K.H., Noss R. & Pratt, D (2009) Designing software for mathematical engagement through modelling in Hoyles. C & Lagrange J-B (eds) (2009) *Mathematics Education and Technology- Rethinking the terrain* Springer pp19-46

DiSessa, A. (2000). Changing Minds: Computers, Learning, and Literacy. Cambridge, MA: The MIT Press.

diSessa, A.A. & Cobb, P. Ontological Innovation and the Role of Theory in Design Experiments, *Journal of the Learning Sciences* 13(1), 77–103 Copyright © 2004, Lawrence Erlbaum Associates, Inc.

Hoyles, C. (2008) Working in Partnership: Continuing Professional Development for Teachers of Mathematics and the role of the National Centre for Excellence in the Teaching of Mathematics (NCETM), *MSOR Connections* Vol 8 No 2 May – July, pp 8-10

Some References (ctd)

Hoyles, C. (2001), 'From describing to designing mathematical activity: the next step in developing a social approach to research in mathematics education'. *Educational Studies in Mathematics,* 46, 1-3, 273-286.

Hoyles, C. (2010) Creating an Inclusive Culture in Mathematics through subject-specific teacher professional development: a case study from England The Journal of Mathematics and Culture Feb, Vol 5, no 1, pp 43-61

Hoyles, C. & Ferrini-Mundy, J.(2012 in press) Policy Implications of Developing Mathematics Education Research (in press, 2012) in Clements, M. A. (Ken) Bishop, A, Keitel, C. Kilpatrick, J, & Leung, F (Eds) *Third International Handbook of Mathematics Education*, Springer

Hoyles, C. Noss, R., Kent,P. & Bakker, A. (2010) *Improving Mathematics at Work: The need for techno-mathematical literacies* Routledge

Hoyles. C & Lagrange J-B (eds) (2009) *Mathematics Education and Technology- Rethinking the terrain* Springer

Kaput, J., & Schorr, R. (2008). Changing representational infrastructures changes most everything: The case of SimCalc, Algebra, and Calculus. In K. Heid & G.W. Blume (Eds.), Research on the impact of technology on the teaching and learning of mathematics: Volume 2, (pp. 211-253). Information Age Publishing.

Some References (ctd)

Kaput, J., Noss, R., & Hoyles, C. (2002). Developing New Notations for a Learnable Mathematics in the Computational Era. In L. D. English (Ed.), Handbook of International Research in Mathematics Education (pp.51-75). Lawrence Erlbaum.

Mathematics Matters case studies: Institute of Mathematics and its Applications http://www.ima.org.uk/i_love_maths/mathematics_matters.cfm)

Mavrikis, M., Noss, R., Hoyles, C. & Geraniou E. (2011) Sowing the seeds of algebraic generalization: designing epistemic affordances for an intelligent microworld*. Journal of Computer Assisted Learning (special issue)*

Noss, R. & Hoyles, C. (2013, submitted) Constructionism & Microworlds in E. Duval, R. Sutherland, M. Sharples (eds.), The Technology-Enhanced Learning Reader, Springer, 2013

Noss, R. and Hoyles , C. (1996). Windows on Mathematical Meanings: Learning Cultures and Computers. Kluwer Academic.

Noss, R., Hoyles, C., Mavrikis, M., Geraniou, E., Gutierrez-Santos, S. & Pearce, D. (2009, issue 4). Broadening the sense of 'dynamic': a microworld to support students' mathematical generalisation. In Hegedus, S. & Moreno-Armelia, L. (eds) Transforming Mathematics Education through the use of Dynamic Mathematics Technologies, Special Issue*, Zentralblatt für Didaktik der Mathematik (ZDM).* The International Journal on Mathematics Education pp 493- 503

Some References (ctd)

Papert, S. (1996). An exploration in the space of mathematics educations. International Journal of Computers for Mathematical Learning 1 (1), 95-123.

Roschelle, J., D. Tatar, and J. Kaput (2008). Getting to scale with innovations that deeply restructure how students come to know mathematics. In A. E. Kelly, R. Lesh, and J. Y. Baek (Eds.), Handbook of design research methods in education, pp. 369-395. New York: Routledge.

Roschelle, J., N. Shechtman, D. Tatar, S. Hegedus, B. Hopkins, S. Empson, J. Knudsen, and L. Gallagher (2010). Integration of technology, curriculum, and professional development for advancing middle school mathematics. American Educational Research Journal 47 (4), 833-878.

Zehetmeier, S. and K. Krainer (2011). Ways of promoting the sustainability of mathematics teachers' professional development. ZDM 43 (6), 875-887.

.

- Coburn, C. E. (2003). Rethinking scale: Moving beyond numbers to deep and lasting change. Educational Researcher 32 (6), 3-12.

- Hoyles, C. & Ferrini-Mundy, J.(2012 in press) Policy Implications of Developing Mathematics Education Research (in press, 2012) in Clements, M. A. (Ken) Bishop, A, Keitel, C. Kilpatrick, J, & Leung, F (Eds) *Third International Handbook of Mathematics Education*, Springer

- Roschelle, J., D. Tatar, and J. Kaput (2008). Getting to scale with innovations that deeply restructure how students come to know mathematics. In A. E. Kelly, R. Lesh, and J. Y. Baek (Eds.), Handbook of design research methods in education, pp. 369-395. New York: Routledge.

- Roschelle, J., N. Shechtman, D. Tatar, S. Hegedus, B. Hopkins, S. Empson, J. Knudsen, and L. Gallagher (2010). Integration of technology, curriculum, and professional development for advancing middle school mathematics. American Educational Research Journal 47 (4), 833-878.

- Zehetmeier, S. and K. Krainer (2011). Ways of promoting the sustainability of mathematics teachers' professional development. ZDM 43 (6), 875-887.