Disciplinary Inclusivity in Educational Research Design: Permeability and Affordances in STEM Education

Keynote address presented to the conference: STEM Education and Our Planet: Making Connections Across Contexts.
University of British Columbia, Vancouver, Canada, July 12, 2014.

David Clarke
International Centre for Classroom Research
University of Melbourne, Australia

Part One:

What is it that brings us together?

What is it that brings us together?

Who should identify themselves as a “member of the STEM community” and with what are they affiliating?

Look around you.

What is it that brings us together?

Who should identify themselves as a “member of the STEM community” and with what are they affiliating?

Look around you. The Enlightened or the Embittered?

What is it that brings us together?

Who should identify themselves as a “member of the STEM community” and with what are they affiliating?

Look around you. The Enlightened or the Embittered?

What is it that unites us?

Shared vision or shared concern?

I would like to suggest that the acronym STEM primarily signifies a community of shared concern.

What is it that STEM explains?

If STEM is to be useful as a construct, it should do useful explanatory work.

There should be some aspect of our world that becomes more understandable because of the acronym “STEM” – I am not talking about the separate disciplines signified by the acronym, I am talking about the acronym itself and what we think it stands for.

Research has demonstrated the capacity of STEM to distinguish between groups of students. But the implications of these distinctions are not clear.

STEM graduation rates

Country	% STEM graduates in 2006
Australia	29
USA	32
Canada	33
European Union	34
Singapore	51
China	53
Japan	63

(National Science Board, 2010a).

STEM graduation rates

Country	% STEM graduates in 2006
Australia	29
USA	32
Canada	33
European Union	34
Singapore	51
China	53
Japan	63

(National Science Board, 2010a).

Is there an optimal proportion? Is bigger always better?

STEM graduation rates

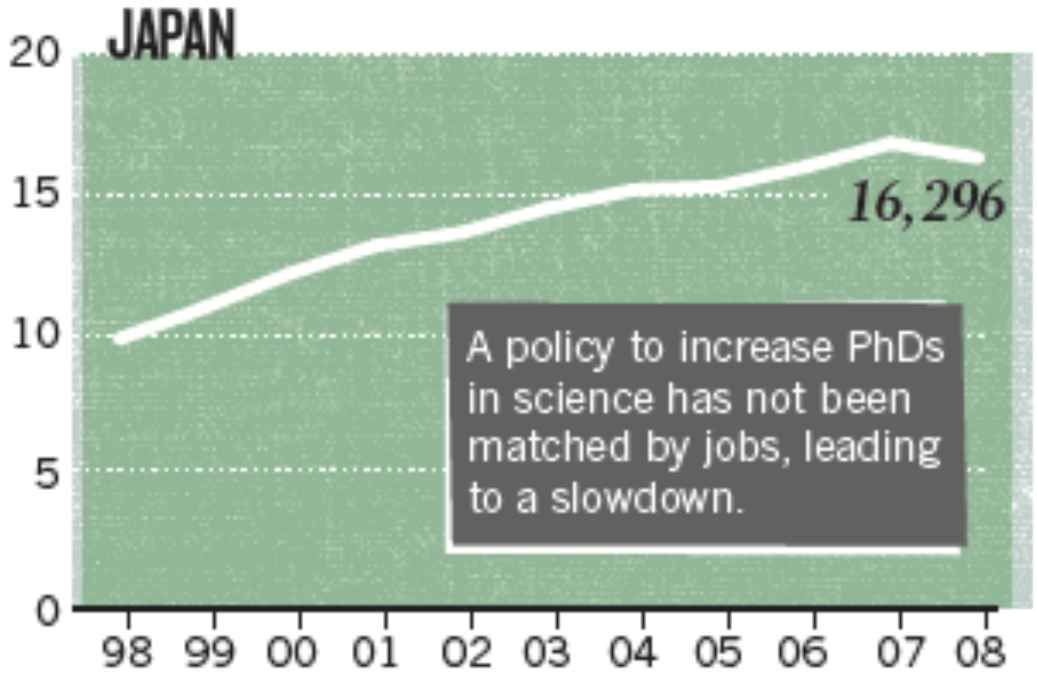
Country	% STEM graduates in 2006
Australia	29
USA	32
Canada	33
European Union	34
Singapore	51
China	53
Japan	63

(National Science Board, 2010a).

Is there an optimal proportion? Is bigger always better?

Increasing STEM Participation

To what end?



"Of all the countries in which to graduate with a Science PhD, Japan is arguably one of the worst" (Cyranoski, Gilbert, Ledford, Nayar & Yahia, *Nature*, 2011, p. 276). Japanese government policy in the 1990s aimed to triple the number of postdocs as a means to boost Japan's science capacity. The strategy succeeded but did not give sufficient thought to employment prospects.

STEM graduation rates

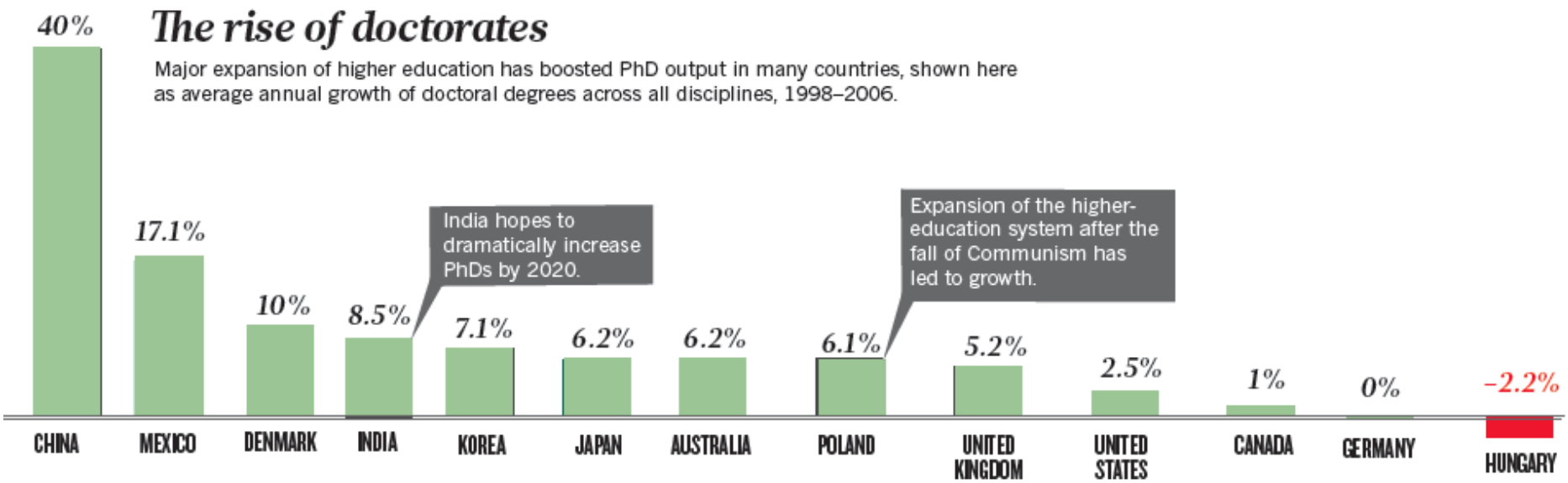
Country	% STEM graduates in 2006
Australia	29
USA	32
Canada	33
European Union	34
Singapore	51
China	53
Japan	63

(National Science Board, 2010a).

Is there an optimal proportion? Is bigger always better?

Increasing STEM Participation

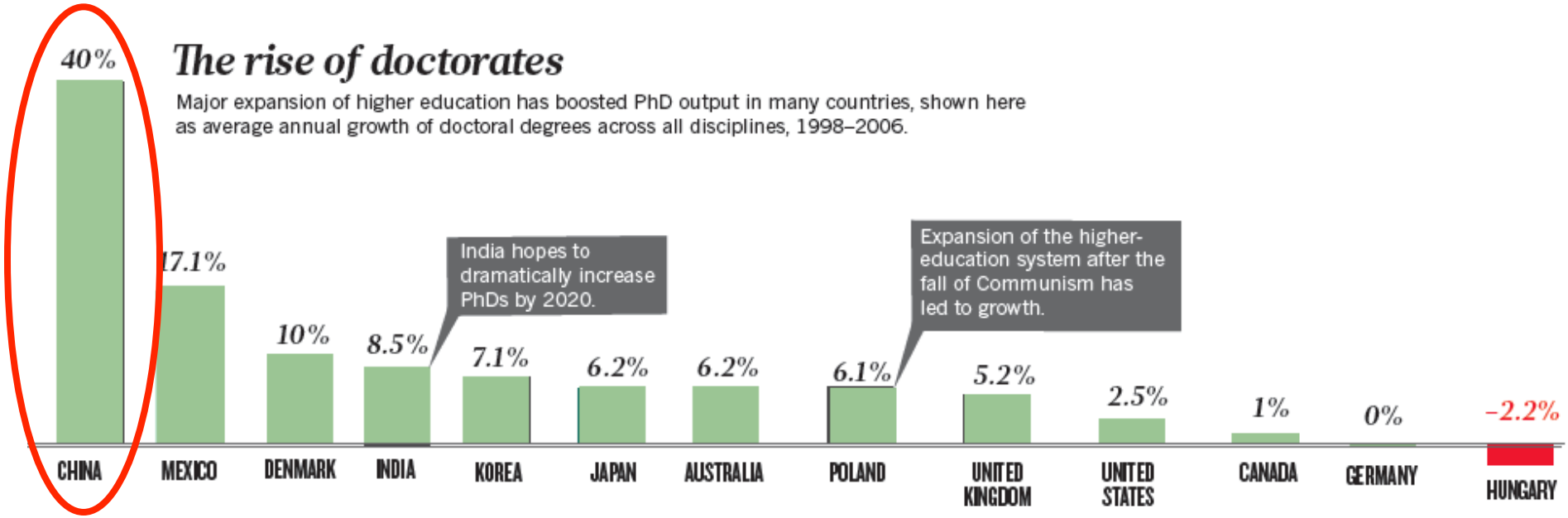
Quantity vs Quality: A very old question



"By some counts, China has overtaken the United States to become the world's biggest producer of PhDs . . . The main problem is the low quality of many graduates" (Cyranoski, Gilbert, Ledford, Nayar & Yahia, *Nature*, 2011, p. 277).

Increasing STEM Participation

Quantity vs Quality: A very old question



"By some counts, China has overtaken the United States to become the world's biggest producer of PhDs . . . The main problem is the low quality of many graduates" (Cyranoski, Gilbert, Ledford, Nayar & Yahia, *Nature*, 2011, p. 277).

This problem is not restricted to Chinese STEM graduates, but it makes the point that participation is not enough – we need to consider the quality of the educational program and of its graduates.

STEM graduation rates

Country	% STEM graduates in 2006
Australia	29
USA	32
Canada	33
European Union	34
Singapore	51
China	53
Japan	63

(National Science Board, 2010a).

Is there an optimal proportion? Is bigger always better?

Increasing STEM Participation
Strategic, systemic and well-resourced

"The picture is much rosier in Singapore. Here, the past few years have seen major investment and expansion in the university system and in science and technology infrastructure" (Cyranoski, Gilbert, Ledford, Nayar & Yahia, *Nature*, 2011, p. 277).

"In 2002 . . . Singapore undertook a review of junior college/upper secondary education. The aim was . . . to move the system towards more problem-based pedagogy, with an emphasis on teacher co-curricular planning, student interdisciplinary study, and the making of textual/multimodal artifacts with community and intellectual application" (Luke, Freebody, Shun, & Gopinathan, 2005, p. 10).

Increasing STEM Participation

The arguments that are voiced in favour of student participation in STEM-related subjects tend to take this form:

“STEM skills and knowledge will be essential to meeting the challenges of the new century, through scientific advances, technological innovation, and mathematics as a tool underpinning these” (Tytler et al., 2008).

PISA data: Student attitudes

Australian students'

•perception of the **value of science,**

•their **interest in learning science** and

•**enjoyment of science**

were all below the international mean.

Only three of 57 countries had a lower **interest in learning science** than Australia (PISA, 2006).

Australian males reported higher levels of interest and enjoyment in mathematics than females (PISA 2003).

PISA data: Student attitudes

Australian students'

•perception of the **value of science,**

•their **interest in learning science** and

•**enjoyment of science**

were all below the international mean.

Only three of 57 countries had a lower **interest in learning science** than Australia (PISA, 2006).

Australian males reported higher levels of interest and enjoyment in mathematics than females (PISA 2003).

Increasing STEM Participation
Winning their hearts AND their minds

"For mathematics, the development of problem solving capabilities, and for science, engagement with investigative processes, are significant curriculum innovations that are capable of engaging students, with appropriate pedagogical support" (Tytler et al., 2008, p. viii).

"A key to student engagement lies not so much in the nature of the subject content, but rather with pedagogy" (Tytler et al., 2008, p. viii).

PISA data: Student attitudes

Australian students'

•perception of the **value of science,**

•their **interest in learning science** and

•**enjoyment of science**

were all below the international mean.

Only three of 57 countries had a lower **interest in learning science** than Australia (PISA, 2006).

Australian males reported higher levels of interest and enjoyment in mathematics than females (PISA 2003).

PISA data: Student attitudes

Australian students'

•perception of the **value of science,**

•their **interest in learning science** and

•**enjoyment of science**

were all below the international mean.

Only three of 57 countries had a lower **interest in learning science** than Australia (PISA, 2006).

Australian males reported higher levels of interest and enjoyment in mathematics than females (PISA 2003).

So – what can we learn from gender differences?

Science subject participation in Western Australia

Subject	1986			2012		
	Number	Per cent of Year 12 cohort	Per cent female	Number	Per cent of Year 12 cohort	Per cent female
Biology	3 366	30	53	1 715	8	65
Human Biology	5 045	45	74	4 290	19	68
Chemistry	3 233	29	37	4 809	21	46
Physics	3 129	28	29	3 585	16	30
Geology/EES	120	1	8	285	1	45
Other Science	1163	7	39	165	0.7	49
TOTAL	16 056	1.42 subjs / stu		14 849	0.66 subjs / stu	

(from Hackling, 2014)

Science subject participation in Western Australia

Subject	1986			2012		
	Number	Per cent of Year 12 cohort	Per cent female	Number	Per cent of Year 12 cohort	Per cent female
Biology	3 366	30	53	1 715	8	65
Human Biology	5 045	45	74	4 290	19	68
Chemistry	3 233	29	37	4 809	21	46
Physics	3 129	28	29	3 585	16	30
Geology/EES	120	1	8	285	1	45
Other Science	1163	7	39	165	0.7	49
TOTAL	16 056	1.42 subjs / stu		14 849	0.66 subjs / stu	

(from Hackling, 2014)

Science subject participation in Western Australia

Subject	1986			2012		
	Number	Per cent of Year 12 cohort	Per cent female	Number	Per cent of Year 12 cohort	Per cent female
Biology	3 366	30	53	1 715	8	65
Human Biology	5 045	45	74	4 290	19	68
Chemistry	3 233	29	37	4 809	21	46
Physics	3 129	28	29	3 585	16	30
Geology/EES	120	1	8	285	1	45
Other Science	1163	7	39	165	0.7	49
TOTAL	16 056	1.42 subjs / stu		14 849	0.66 subjs / stu	

(from Hackling, 2014)

Science subject participation in Western Australia

Subject	1986			2012		
	Number	Per cent of Year 12 cohort	Per cent female	Number	Per cent of Year 12 cohort	Per cent female
Biology	3 366	30	53	1 715	8	65
Human Biology	5 045	45	74	4 290	19	68
Chemistry	3 233	29	37	4 809	21	46
Physics	3 129	28	29	3 585	16	30
Geology/EES	120	1	8	285	1	45
Other Science	1163	7	39	165	0.7	49
TOTAL	16 056	1.42 subjs / stu		14 849	0.66 subjs / stu	

(from Hackling, 2014)

Science subject participation in Western Australia

Subject	1986			2012		
	Number	Per cent of Year 12 cohort	Per cent female	Number	Per cent of Year 12 cohort	Per cent female
Biology	3 366	30	53	1 715	8	65
Human Biology	5 045	45	74	4 290	19	68
Chemistry	3 233	29	37	4 809	21	46
Physics	3 129	28	29	3 585	16	30
Geology/EES	120	1	8	285	1	45
Other Science	1163	7	39	165	0.7	49
TOTAL	16 056	1.42 subjs / stu		14 849	0.66 subjs / stu	

(from Hackling, 2014)

Gender effect: Mathematics participation in Western Australia

Year	Maths Stage 2		Maths Stage 3		Specialist Maths Stage 3	
	# candidates	% male	# candidates	% male	# candidates	% male
2010	5094	43.1	3570	60.6	1611	73.0
2011	3564	41.3	3488	59.2	1396	69.6
2012	4079	43.5	3749	58.9	1490	71.1

(from Hackling, 2014)

Gender effect: Mathematics participation in Western Australia

Year	Maths Stage 2		Maths Stage 3		Specialist Maths Stage 3	
	# candidates	% male	# candidates	% male	# candidates	% male
2010	5094	43.1	3570	60.6	1611	73.0
2011	3564	41.3	3488	59.2	1396	69.6
2012	4079	43.5	3749	58.9	1490	71.1

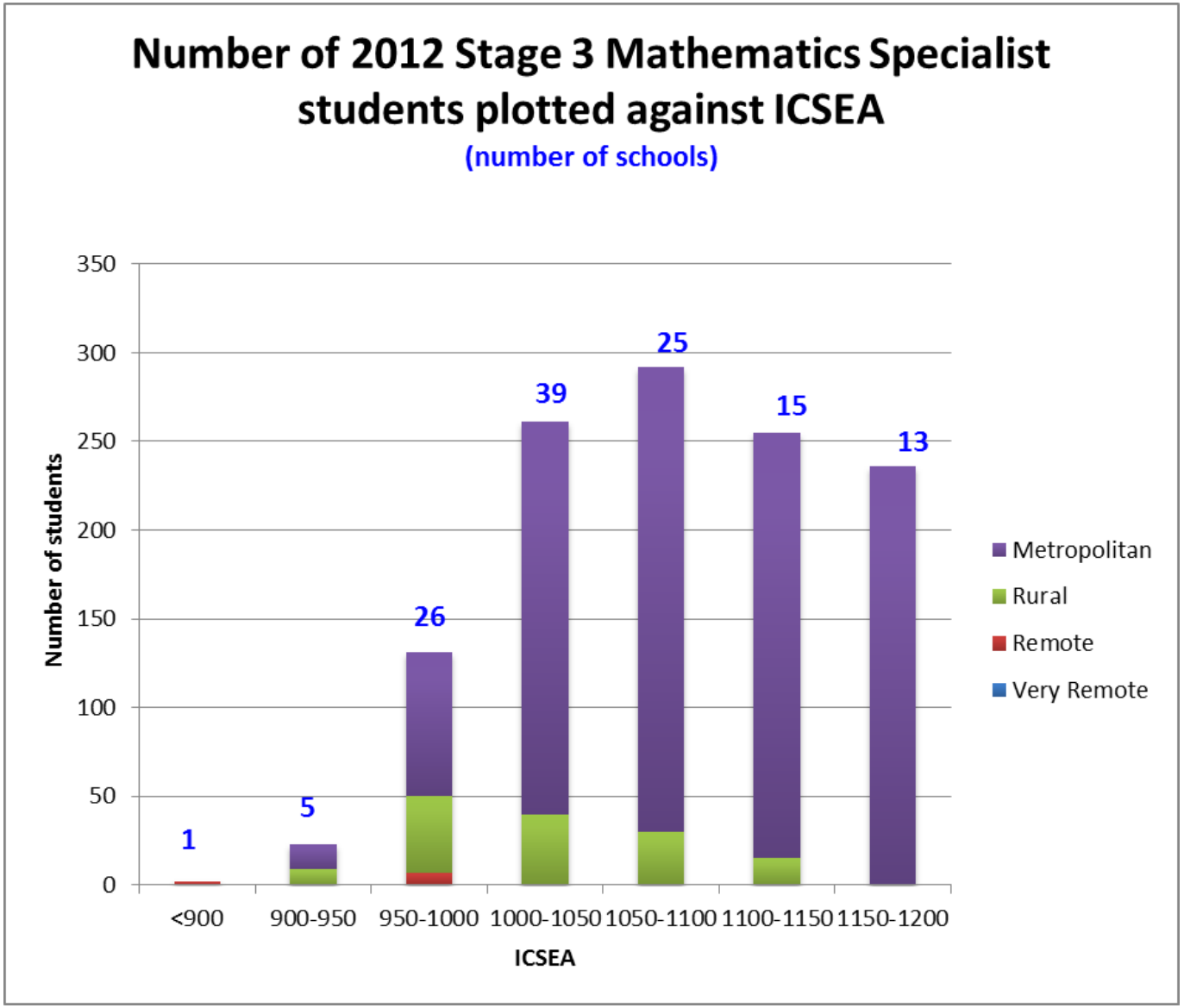
(from Hackling, 2014)

Increasing STEM Participation
Winning their hearts AND their minds

"Low enrolments in mathematics and the physical sciences by girls at the tertiary level compared to their participation in tertiary education overall reflects the clinical rather than human nature of the way many of these STEM subjects are presented" (Tytler et al., 2008, p. ix).

"The finding that pedagogy is the critical element in enlisting student engagement with mathematics or science aligns with well-established findings that the quality of classroom teaching is the most significant factor in student learning and engagement" (Tytler et al., 2008, p. viii).

SES effect: Participation in Higher Mathematics



(from Hackling, 2014)

Impact of social disadvantage

Scientific literacy ranks and mean scores from PISA 2012

China	1	580		
			Aust HSEQ	567
Hong Kong	2	554		
Liechtenstein	11	525		
			Aust Non-Indig	524
Australia	16	521		
OECD	26	501		
			Aust LSEQ	479
Iceland	40	478		
Thailand	49	444		
			Aust Indig	440
Mexico	56	415		

Impact of social disadvantage

Scientific literacy ranks and mean scores from PISA 2012

China	1	580		
			Aust HSEQ	567
Hong Kong	2	554		
Liechtenstein	11	525		
			Aust Non-Indig	524
Australia	16	521		
OECD	26	501		
			Aust LSEQ	479
Iceland	40	478		
Thailand	49	444		
			Aust Indig	440
Mexico	56	415		

Berliner (2001) reported similar partitioning of US TIMSS results.

Differentiated Delivery: Social Reproduction
(Ong & Clarke, 2014)

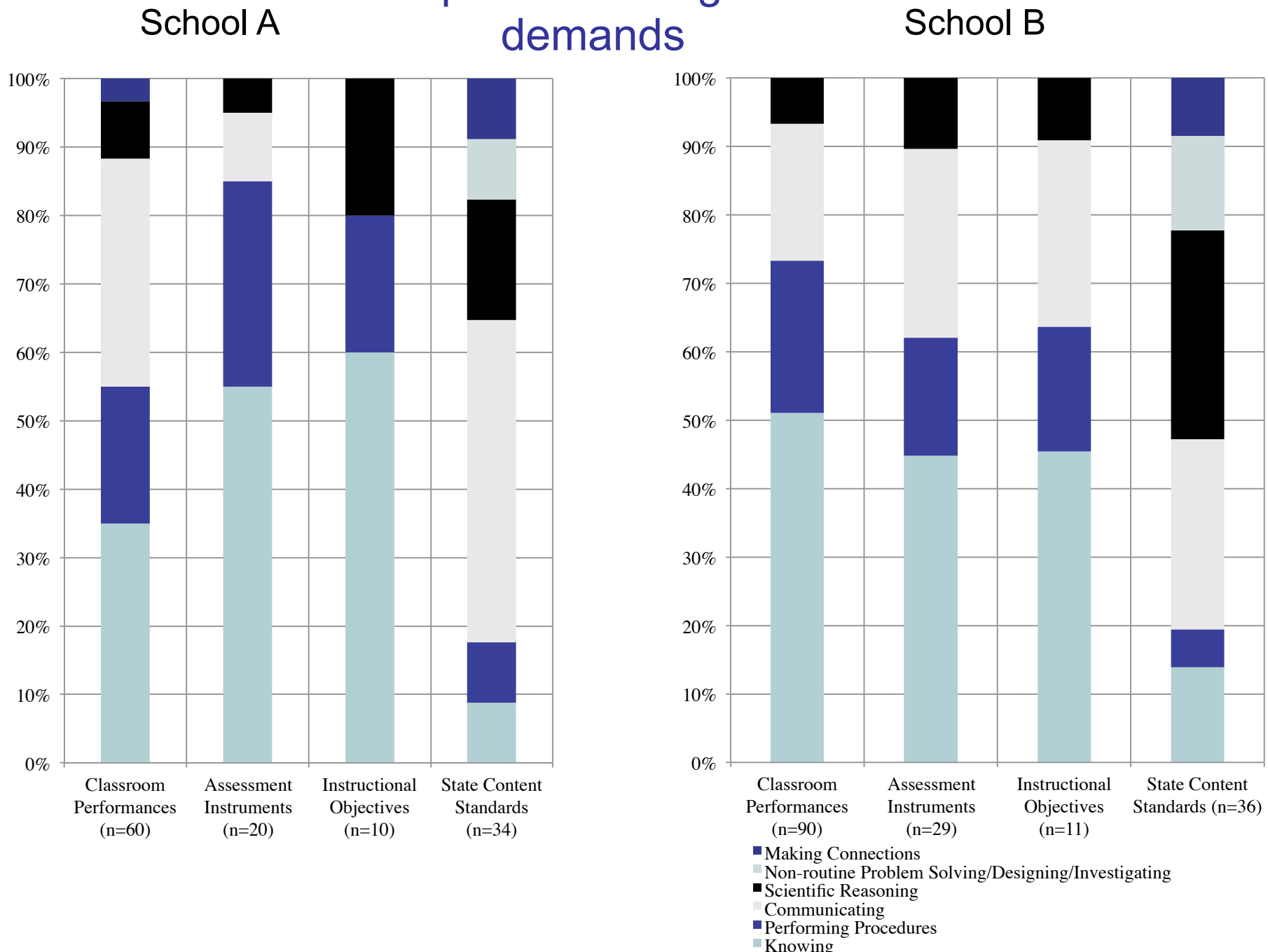
- The Alignment Project is a current large-scale research project that investigates both curricular alignment and the interpretive process whereby curricular aspirations are performatively realized in mathematics and science classrooms in Melbourne, Beijing, Helsinki and Tel Aviv.
- One analysis (undertaken by Ong) contrasts curricular implementation in two 9th grade science classrooms in the context of a statewide, standards-based science curriculum in Victoria, Australia.

Project Aims

i) To determine the correspondence between the cognitive demands prioritized by the teachers in their science classroom instruction and assessment compared with those represented in curricular standards at a school and state level

ii) To investigate the rationale behind curricular decisions made by teachers in their efforts to deliver a curriculum to meet the reform goals (school or state standards)

Comparison of cognitive demands



1. Differences between curricular views

School A	School B
• Students viewed as high academic achievers but need enhancement in literacy development • Students need thinking and inquiry-oriented skills as well as communication skills	• Students viewed as ‘less open to learning’ and they need encouragement to participate and engage • Students need development of work habits to be responsible learners

2. Differences between instructional activities

School A	School B
• **Quizzes and peer assessment** • **Literacy tasks** e.g. annotated reading, creative writing • **Inquiry-oriented and reflection tasks** e.g. peer inquiry, concept map	• **Computer-based activities** e.g. applets, textbook website • **Science practicals** e.g. guided experiments • **Note: Class management** due to students' resistance/ disruption

3. Differences between classroom talk

Figure 1: Talk patterns coded in a School A lesson with mainly whole class teaching (some individual seatwork)

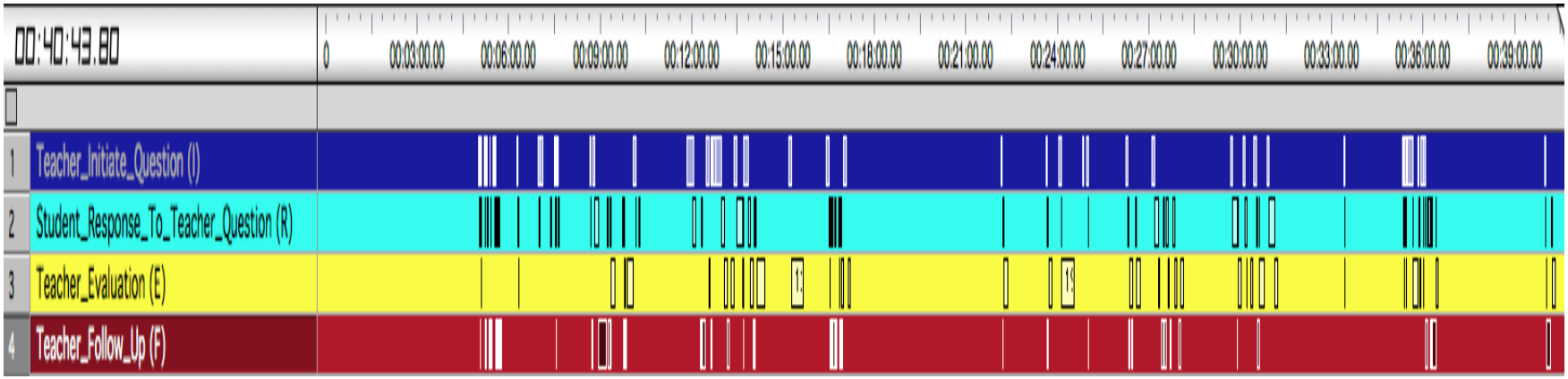
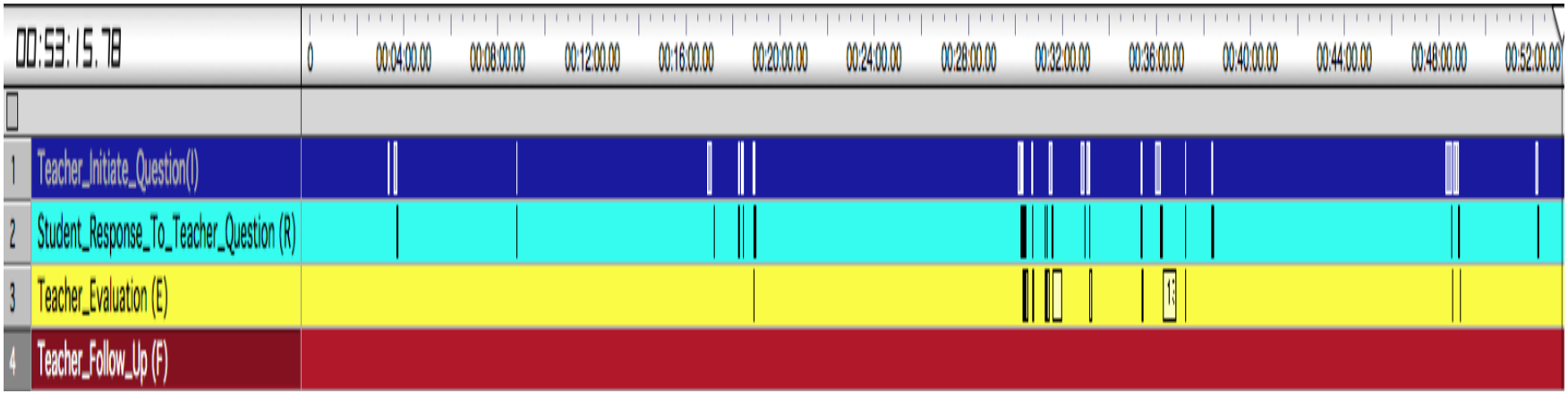


Figure 2: Talk patterns coded in a School B lesson with mainly whole class teaching (some individual seatwork)



Teacher expectations: Interview Data

Key quotes – School A teacher

•"We think our **students are capable of doing year nine topics at year seven** and they do exceptionally well"

•Peer marking to let students "take the role of a teacher" and "start **being analytical or critical…about assessments that they do**…and **they can have success if they can put themselves in the shoes of the examine**r…"

•Creative writing because students can "**express their ideas**" in "**non-rigid contexts**" because "science has a very rigid way of thinking . . . some students are not familiar or comfortable… in a test environment"

Key quotes – School B teacher

•"kids bring prior experiences with science and **a lot of them… don't like science or [are] not good at science** and so, trying to get past their mental barriers… where they're going to be **open to learning is one of the biggest challenges**…"

•"making sure that **the program is varied**… [and] it's not all just copying out from the board" and "to make [learning] accessible and as interesting as possible"

•"**doing whatever DVDs [videoclips], whatever other… practical activities to get the students to engage with the topic**"

Key points

1. Our findings bear striking resemblance to Anyon's (1980) findings regarding social reproduction.
2. The differentiated curricula reflect each school's commitment to addressing perceived student needs of their community (as evident from the emphasis on literacy needs and learning engagement) – the intentions are good!
3. The quality of classroom talk suggested strongly differentiated enacted curricula between the two schools. As Luke proposed, the classroom discourse via IRF exchange patterns can reflect and maintain inequalities in contemporary classrooms.

What is it that brings us together?

The demographics of educational participation are widely recognised. Demographically differentiated participation in STEM reflects more general social reproductive mechanisms operating in society, rather than indicating a problem idiosyncratic to the STEM area.

If we are promoting a STEM agenda, then we must be prepared to justify our advocacy. Of course, it is possible to reconstruct STEM as the solution, rather than the problem: STEM-led educational reform. That is, not educational reform as a mechanism for increasing STEM participation, but, instead, STEM participation as leveraging educational reform.

If the acronym STEM signifies a community of shared concern. Can it also come to represent a shared vision?

Part Two:

What is it that STEM brings together?

Part Two:

What is it that STEM brings together?

[my wife says that people only have an attention span of ten minutes, so you have probably all tuned-out by now]

What is it that STEM brings together?

We are so accustomed to the subject grouping for which STEM is the acronym, that it is difficult to recognise that STEM could be the name for a fairly monumental category error.

What is it that **S**cience

Technology

Engineering, and

Mathematics

have in common?

One reasonable answer is “not much”!

What is it that STEM brings together?

Alternative acronyms reveal their particular agenda:

Science

Technology

Engineering

Arts

Mathematics

seems just a euphemism for the integrated curriculum.

Certainly not an argument for prioritizing STEM.

What is it that STEM brings together?

One approach is to consider the nature of the truth claims characteristic of each discipline and the authorities to which such truth claims might appeal:

Science – empirical consistency

Technology – tool utility

Engineering – built viability

Mathematics – logical coherence

This approach seems much more interesting, but also demonstrates just how fundamental are the differences between STEM disciplines.

Also – STEM clearly does not exhaust all possible types of truth claim.

What is it that STEM brings together?

How many types of truth claim are there – and what are the authorities to which they appeal?

Mathematics – logic

Art/s - aesthetics

Science – empiricism

Technology - utility

Engineering – viability

Religion – revelation

You – intuition

Such diversity suggests complementarity rather than integration.

What is it that STEM brings together?

How many types of truth claim are there – and what are the authorities to which they appeal?

Mathematics – logic

Art/s - aesthetics

Science – empiricism

Technology - utility

Engineering – viability

Religion – revelation

You – intuition

Such diversity suggests complementarity rather than integration.

But this relegates STEM to just a sub-set of MASTERY.

The dangers of categorization

Science – empiricism

History – precedence

Art/s – aesthetics

Mathematics – logic

Religion – revelation

Engineering – viability

Anthropology - custom

Law - justice

Immanence – inherent/embodied

Technology - utility

You – intuition

The dangers of categorization

Science – empiricism

History – precedence

Art/s – aesthetics

Mathematics – logic

Religion – revelation

Engineering – viability

Anthropology - custom

Law - justice

Immanence – embodied

Technology - utility

You – intuition

Each set of categories constructs a different "SHAM REALITY" - omitting as much as it includes and offering an inevitably partial vision.

The dangers of categorization

Science – empiricism

History – precedence

Art/s – aesthetics

Mathematics – logic

STEM?

Religion – revelation

Engineering – viability

Anthropology - custom

Law - justice

Immanence - inherent

Technology - utility

You – intuition/wisdom of practice

What is it that STEM brings together?

Around WHAT does STEM cohere?

S
T
COHERE
M

What is it that STEM brings together?

Around WHAT does STEM cohere?

S

T

COHERE

M

What is it that STEM brings together?

Around WHAT does STEM cohere?

S
T
COHERE
META-CURRICULUM
P
R
EVIDENCE
S
DISCOURSE
N
T

What is it that STEM brings together?

Around WHAT does STEM cohere?

S
T
COHERE
M
ETA-CURRICULUM
P
R
EVIDENCE
S
DISCOURSE
N
TRANSCENDENT

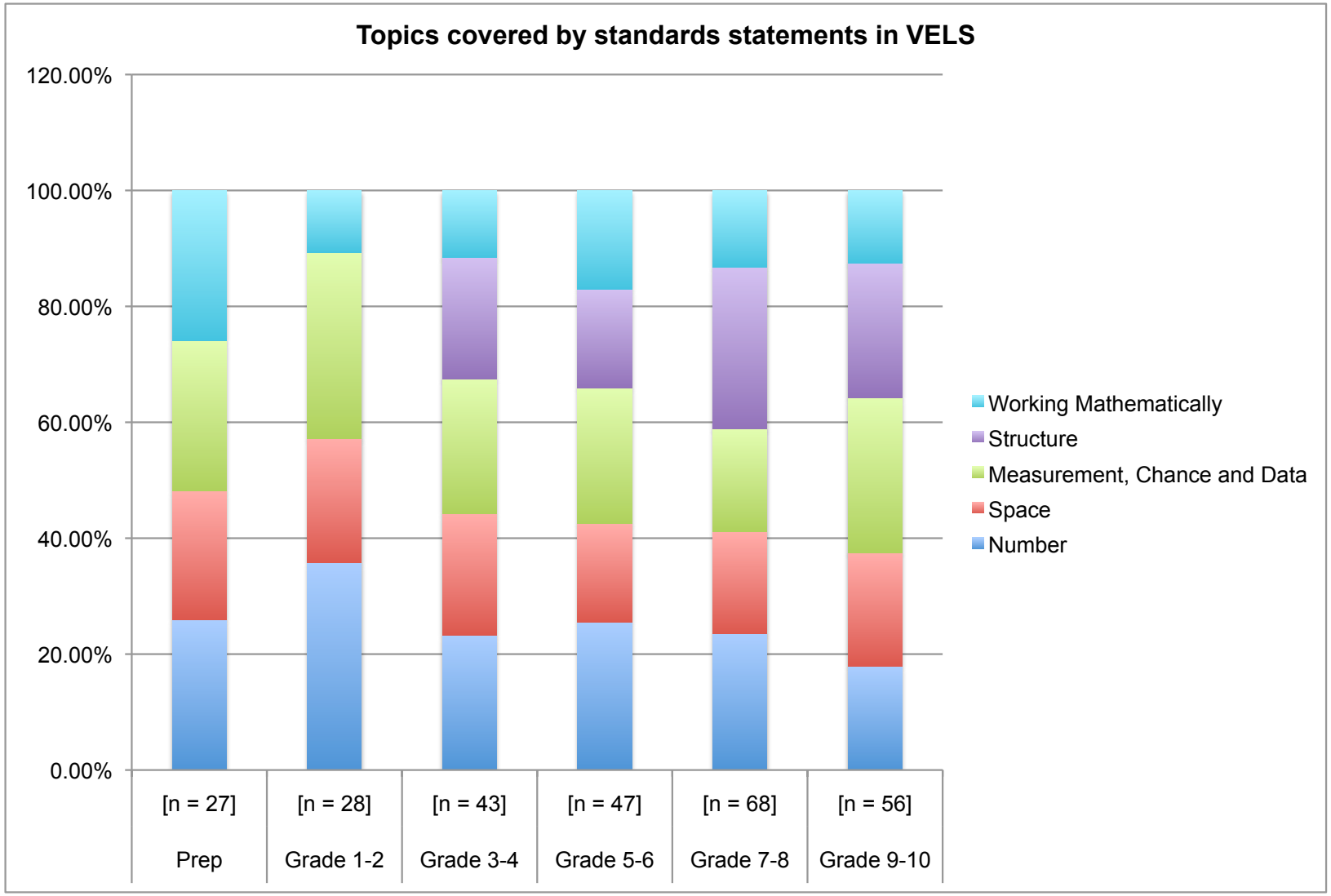
What is it that STEM brings together?

Around WHAT does STEM cohere?

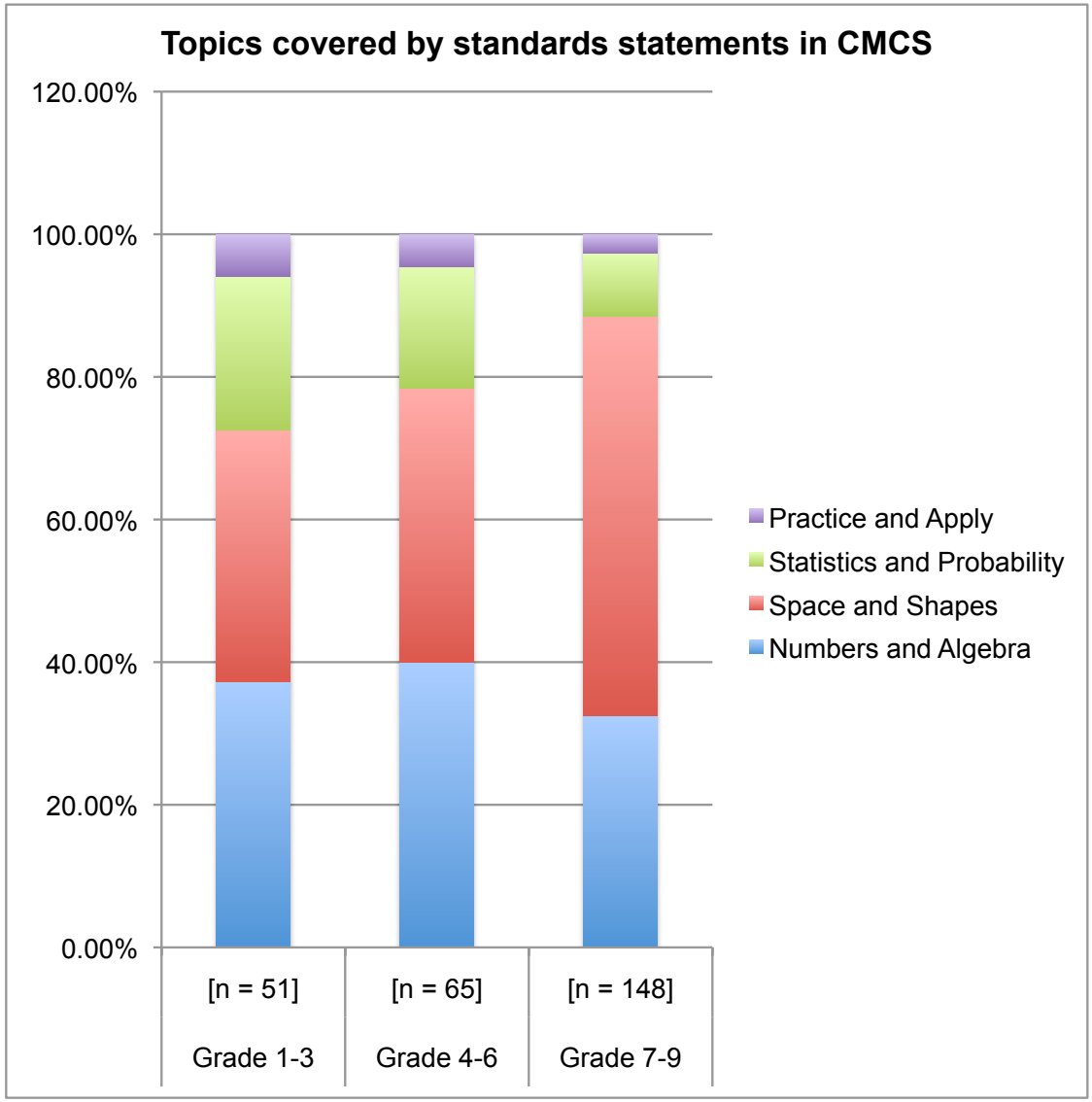
S
T
COHERE
M
ETA-CURRICULUM
P
R
EVIDENCE
S
DISCOURSE
N
TRANSCENDENT

Comparing Curricula: Problematizing Disciplinary Integrity

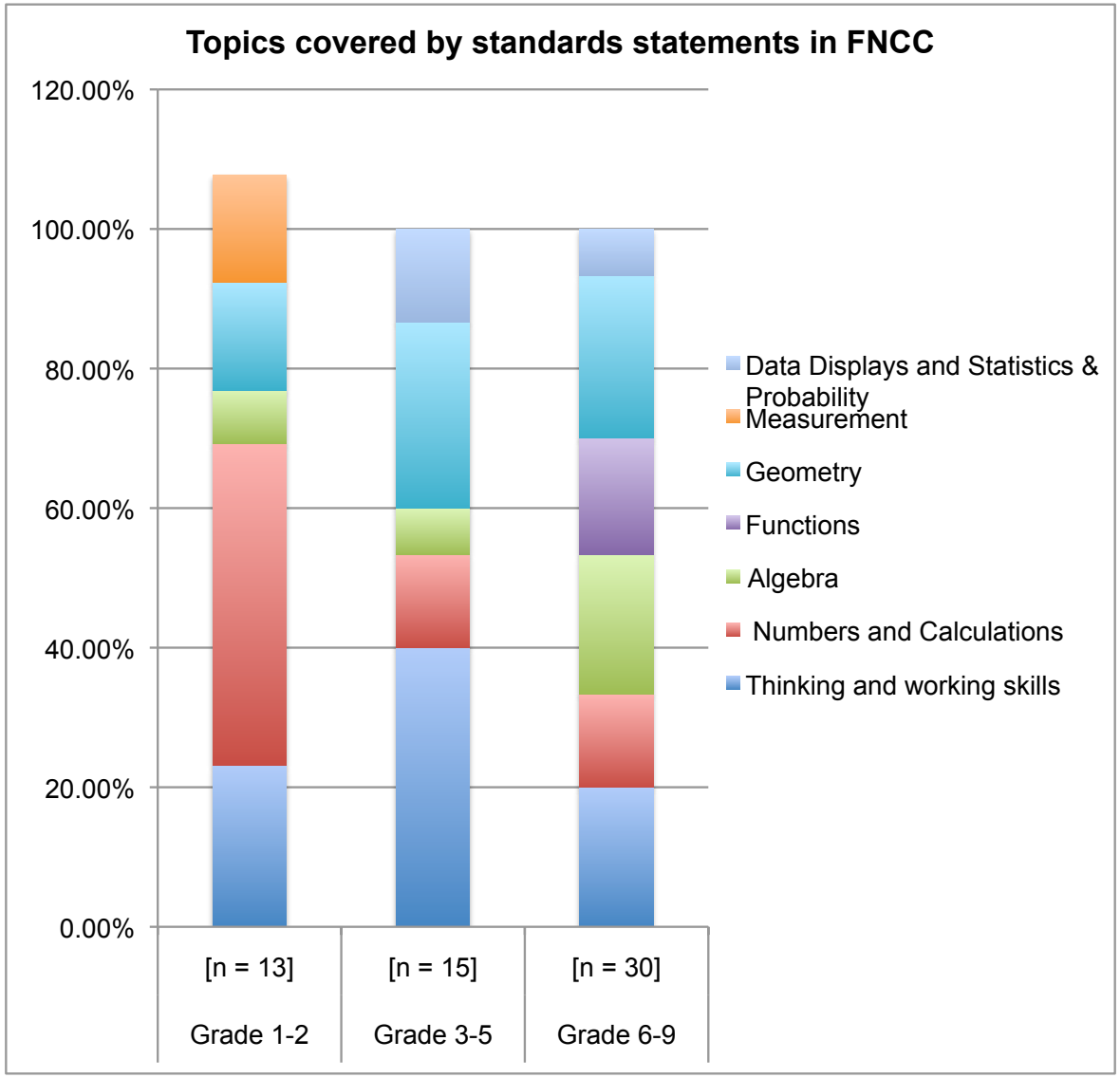
The Mathematics Content of the Victorian Curriculum



The Mathematics Content of the Chinese Curriculum



The Content and Organisation of the Finnish Curriculum



Comparing Curricula

Each country uses different terms to categorise and structure the curriculum.

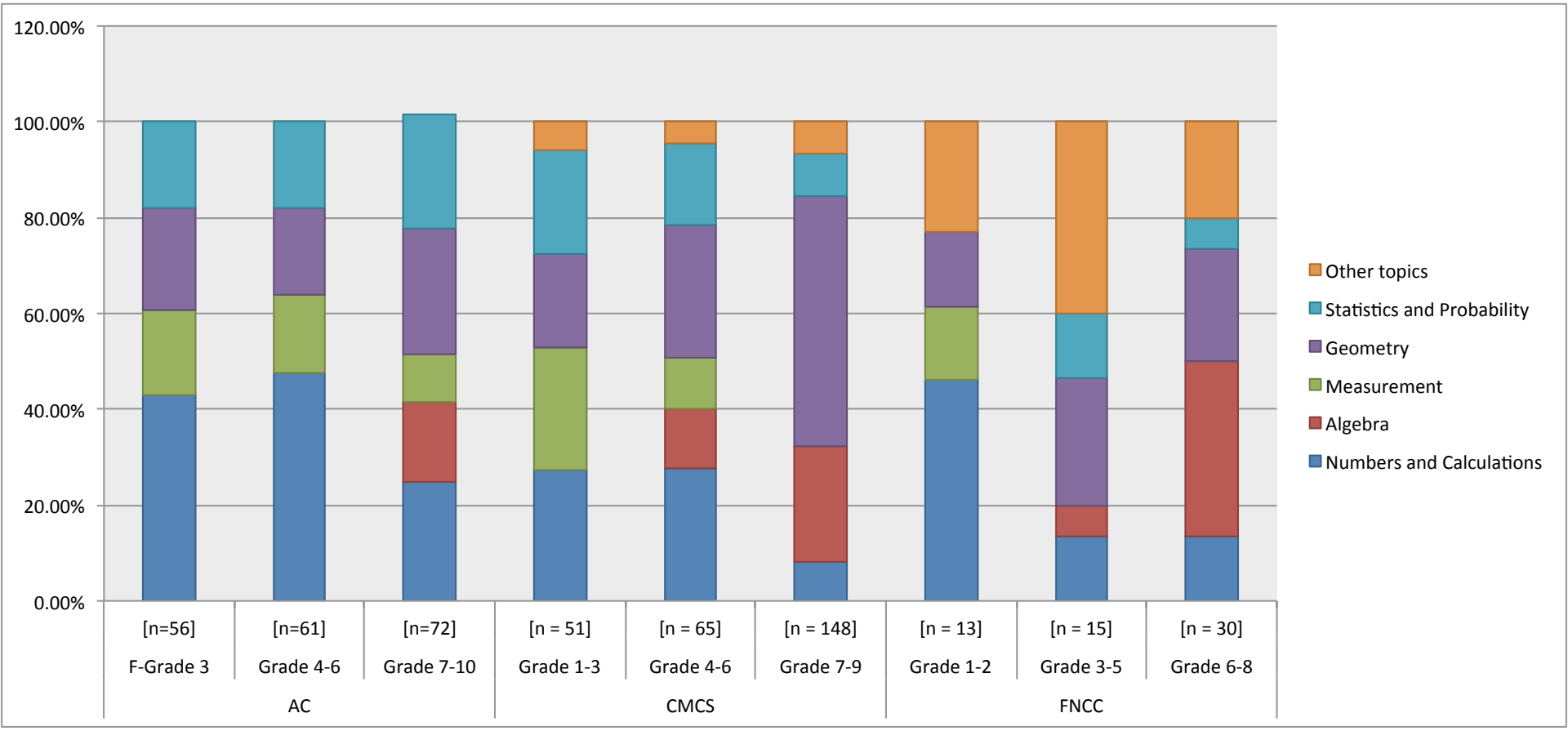
In order to compare curricula, we must apply the same categorisation system.

Curriculum Comparison: Content [Externally imposed framework]

Content:

1. **Numbers and Calculations**
2. **Measurement**
3. **Algebra**
4. **Geometry**
5. **Statistics and Probability**
6. **Other topics**

Topics covered by Standards Statements across three Curricula



The content and organisation of the three curricula are very different, suggesting that the school subject “mathematics” is an artefact generated distinctively by each school system.

Curriculum Comparison: Performance Expectations

Topic:

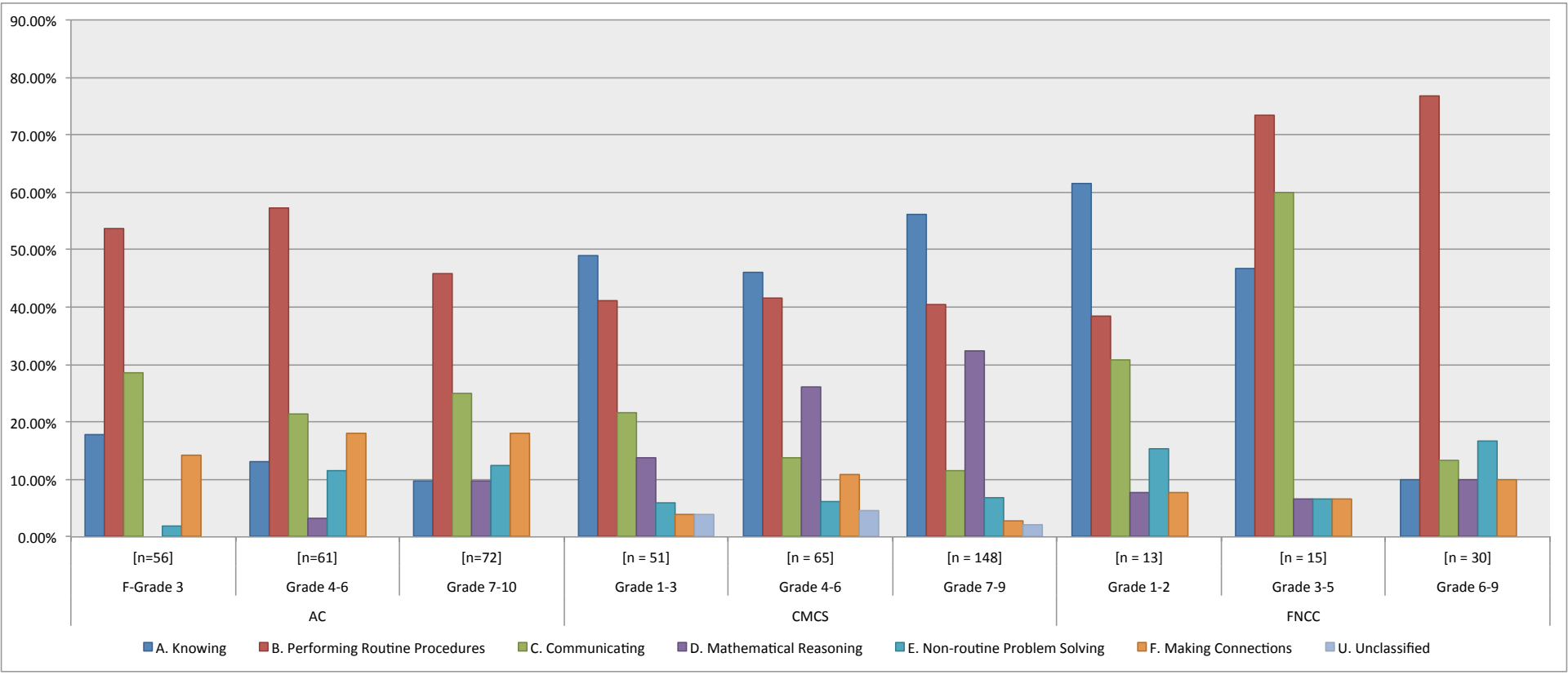
1. **Numbers and Calculations**
2. **Measurement**
3. **Algebra**
4. **Geometry**
5. **Statistics and Probability**
6. **Other topics**

Performance Expectations:

A. **Knowing**
B. **Performing Routine Procedures**
C. **Communicating**
D. **Mathematical Reasoning**
E. **Non-routine Problem Solving**
F. **Making Connections**
U. **Unclassified**

Adapted from the work of Andrew Porter and his colleagues

Performance Expectations across three curricula: Australia, China and Finland



Not only are the distinctions between content categories malleable – the types of mathematical performances are differently emphasized within different curricula.

Presumptions about the integrity and stability of school subjects are in error.

Disciplinary Inclusivity and Pedagogical Content Knowledge (PCK): An important tension

My premise: Entrenched Differentiation

The disciplines encompassed by STEM are currently distinguished by associated bodies of practice, particularly in the practice of research.

Analogous distinctions apply in STEM Education, extending to the signature pedagogies that characterise each discipline. Research within STEM Education is similarly differentiated with respect to methods, theories, and questions investigated.

Current curricular design reflects restrictive conceptions of field-specificity and the unique integrity of bodies of knowledge encrypted as school subjects.

International enthusiasm for Pedagogical Content Knowledge (PCK) as the key to effective teaching amplifies the insistence on finely focused domain-specific expertise and exacerbates the siloing of disciplines within the context of instruction.

Well-intentioned Misrepresentation

The prioritisation of teacher Pedagogical Content Knowledge is plausible and understandable, but it may be unrealistic for most practical purposes.

There are two presumptions of stability that underlie the advocacy of PCK as the most productive focus for our teacher education programs:

(i) Discipline integrity and stability

(ii) Student typification and consistency

Neither of these are defensible given current research evidence.

HOWEVER, I am not advocating the discarding of PCK - it may be salvageable in a reconstructed and less prescriptive form – but consideration of STEM offers an entry point to interrogate its efficacy as a focus of teacher education.

Well-intentioned Misrepresentation

The prioritisation of teacher Pedagogical Content Knowledge is plausible and understandable, but it may be unrealistic in any practical context.

There are two presumptions of stability that underlie the advocacy of PCK as the most productive focus for our teacher education programs:

(i) Discipline integrity and stability (FIXED SUBJECT MATTER)

(ii) Student typification and consistency (PREDICTABLE STUDENTS)

Neither of these are defensible given current research evidence and each will be addressed in the remainder of this presentation.

HOWEVER, I am not advocating the discarding of PCK - it may be salvageable in a reconstructed form – but consideration of STEM offers an entry point to interrogate its efficacy as a focus of teacher education.

My hypothesis: Enhanced Educational Opportunities through Permeability and Affordances

Attention must be paid to the affordances of affiliation and research undertaken to explore the legitimacy of STEM disciplines as communities of practice offering **enhanced educational opportunities through their interconnection**.

The approach pursued in the remainder of this presentation is to examine those constructs to which the boundary walls of the STEM disciplines seem most permeable. Employing necessarily inclusive research designs, one consequence could be the reconceptualization of the organising principles of the curriculum.

As noted: Any enthusiasm for an assumed connectedness among the STEM school subjects is in tension with the equally fervent enthusiasm for PCK (Pedagogical Content Knowledge), which requires teachers to have fine-grained content-specific knowledge that underlies the teacher's representational choices when crafting an instructional program.

My hypothesis: Enhanced Educational Opportunities through Permeability and Affordances

Attention must be paid to the affordances of affiliation and research undertaken to explore the legitimacy of STEM disciplines as communities of practice offering **enhanced educational opportunities through their interconnection**.

The approach pursued in the remainder of this presentation is to examine those constructs to which the boundary walls of the STEM disciplines seem most permeable. Employing necessarily inclusive research designs, one consequence could be the reconceptualization of the organising principles of the curriculum.

As noted: Any enthusiasm for an assumed connectedness among the STEM school subjects is in tension with the equally fervent enthusiasm for PCK (Pedagogical Content Knowledge), which requires teachers to have fine-grained content-specific knowledge that underlies the teacher's representational choices when crafting an instructional program.

Reconceptualizing STEM
[Desperately seeking synergy]

"Synergy"

- the interaction or cooperation of two or more organizations, substances, or other agents to produce a combined effect greater than the sum of their separate effects.

IS THIS WHAT STEM MIGHT OFFER US?

HOW?

Reconceptualizing “Out of Field” as Horizontal Expertise in Boundary Crossing

“Out of Field” Teaching

- teachers teaching subjects for which they have little education or training (Ingersoll, 2002).

“Boundary Crossing”

- boundary crossing entails entering into unfamiliar domains (Suchman, 1994).

“Horizontal Expertise”

- horizontal expertise where practitioners must move across boundaries to seek and give help (Engeström, Engeström, & Kärkkäinen, 1995)

STEM and the needs of industry

"In an environment requiring constant innovation, it is, however, the very (high level) generic skills that industry are now seeking for the changed business landscape."

"STEM education does instill technical and thinking skills . . . Industry and academia diverge at the fulcrum of the application of skills necessary for commercial awareness, high-level professionalism, leveraging knowledge for competitive advantage, leadership and initiative."

Industry is after "inter-professional collaboration where professionals and non-professionals with diverse skills and knowledge work to facilitate positive outcomes for a client."

"Industry representatives believe that it is easier to up-skill someone technically than it is to teach the necessary interpersonal and intrapersonal skills for workplace practice and career success" (Collet & Hine, 2013).

Polycontextuality and Boundary Crossing: THE central STEM activity

Activity Systems

“An activity system is a complex and relatively enduring “community of practice” that often takes the shape of an institution” (Engeström, Engeström, & Kärkkäinen, 1995, p. 320).

The contemporary workplace has become “flatter in structure, more collaborative and service-focused” (Collet & Hine, 2013, p. 2).

“Boundary crossing will be the basic mode of operation in flat, team- and network-based organizations” (Engeström, Engeström, & Kärkkäinen, 1995, p. 321).

Activity Systems and Boundary Objects: Connecting the STEM disciplines

Consider the activity systems characteristic of two particular disciplines, say Science and Mathematics (or, if we want to sharpen our focus: Physics and Geometry). Activities (and activity systems) are distinguished by their objects.

What are boundary objects of these two activity systems?

Explanation and Proof, respectively, might be two contenders.

Would an individual encountering (participating in) both activity systems experience these boundary objects as harmonious or in tension?

This is the pointy end of any public pretence that STEM characterizes a consortium of related practices.

Activity Systems and Boundary Objects: Connecting the STEM disciplines

Both Explanation and Proof call upon conceptions of Evidence.

"Evidence" is a Boundary Object that mediates between STEM cells.

Are there boundary objects common to the STEM disciplines and what affordances would such commonality of object provide for "the STEM community"?

What if such objects became the structural elements of a new curriculum?

Expert Teachers as Habitual Boundary Crossers

"Experts operate in and move between multiple parallel activity contexts. These multiple contexts demand and afford different, complementary but also conflicting cognitive tools, rules and patterns of social interaction. The criteria of expert knowledge and skill are different in the various contexts." (Engeström, Engeström, & Kärkkäinen, 1995, p. 319).

The "traditional notion of expertise assumes that (a) expertise is manifested in well defined tasks that can be fully analysed into their components by virtue of being repeated often enough, and (b) that tasks in which expertise is manifested are stable and relatively unchanging. The exclusively vertical conception of expertise is based on these assumptions" (Engeström, Engeström, & Kärkkäinen, 1995, p. 331).

Alternatively, we can postulate, "horizontal expertise where practitioners must move across boundaries to seek and give help, to find information and tools wherever they happen to be available" (Engeström, Engeström, & Kärkkäinen, 1995, p. 332).

Re-conceptualising Teacher Expertise

"An activity-theoretical framework, focussing on the objects and mediating artifacts of actual recorded processes of collaborative work and problem solving, may indeed be useful in the articulation of the horizontal dimension of expertise" (Engeström, Engeström, & Kärkkäinen, 1995, p. 333).

"Boundary crossing entails stepping into unfamiliar domains" (Engeström, Engeström, & Kärkkäinen, 1995, p. 333).

The STEM disciplines provide the sites for the development of horizontal expertise through the expectation that expert teachers are also expert boundary crossers. But what do these boundary crossers carry with them? What are the boundary objects of the STEM disciplines and what are the implications for curricula and teacher expertise?

Part Three:

What is it that brings STEM together?

Explain the World
or
Explain yourself!

EXPLAIN YOURSELF

In 2011, during a plenary address at the ESERA conference, Isabelle Stengers suggested that scientists were too seldom asked to explain themselves. At the time, I suggested that acceptance of such an obligation could provide the basis for a reconception of the nature of the science curriculum and the function of science education.

This suggestion was not terribly well received.

HOWEVER . . .

If we take this obligation seriously, and extend its scope to include the consortium of STEM disciplines, the implications are quite confronting.

Pick the STEM discipline with which you feel greatest sympathy – how might a practitioner of that discipline respond to the directive, “Explain yourself!”

Most importantly, for this presentation, which elements of such explanations would be similar and which would be different?

EXPLAIN YOURSELF!

From the 50s into the 60s, there was an expectation that science would explain the world to us. Even mathematics has been presented as “the language in which the universe has been written” (Disney-style voiceover please).

If our new expectation of science, scientists and science education is that they should explain themselves, that is, explain what they do and why they do it, rather than what they know, then we relocate the emphasis of both the subject and the educative process onto an assimilation into practice rather than an accumulation of knowledge.

If the same expectation is placed upon all those who would align themselves with the STEM community, then the implications for STEM education are quite interesting.

EXPLAIN YOURSELF!

Happily, we find endorsement for this emphasis on practice in the recent position paper “Science, Technology, Engineering and Mathematics in the National Interest: A Strategic Approach” emanating from the Office of the Chief Scientist (Professor Ian Chubb) in Australia.

“In order to reverse the declining trends in STEM participation:

Curricula . . . should reflect the transient and evolving character of the factual knowledge of STEM and provide a strong focus on the practice of STEM” (Office of the Chief Scientist, 2013, p. 13).

What activities (possibilities) are afforded if we construct STEM Education around practices rather than knowledge categories?

What different constructs are foregrounded by this reconception?

Discourse, Artefacts, Reasoning & Evidence

What we need to identify are terms that demonstrably do explanatory work in more than one domain within the confederated states of STEM.

How permeable are the disciplinary boundaries? And to which constructs are they permeable? Here are four contenders:

Discourse – reasonable speech

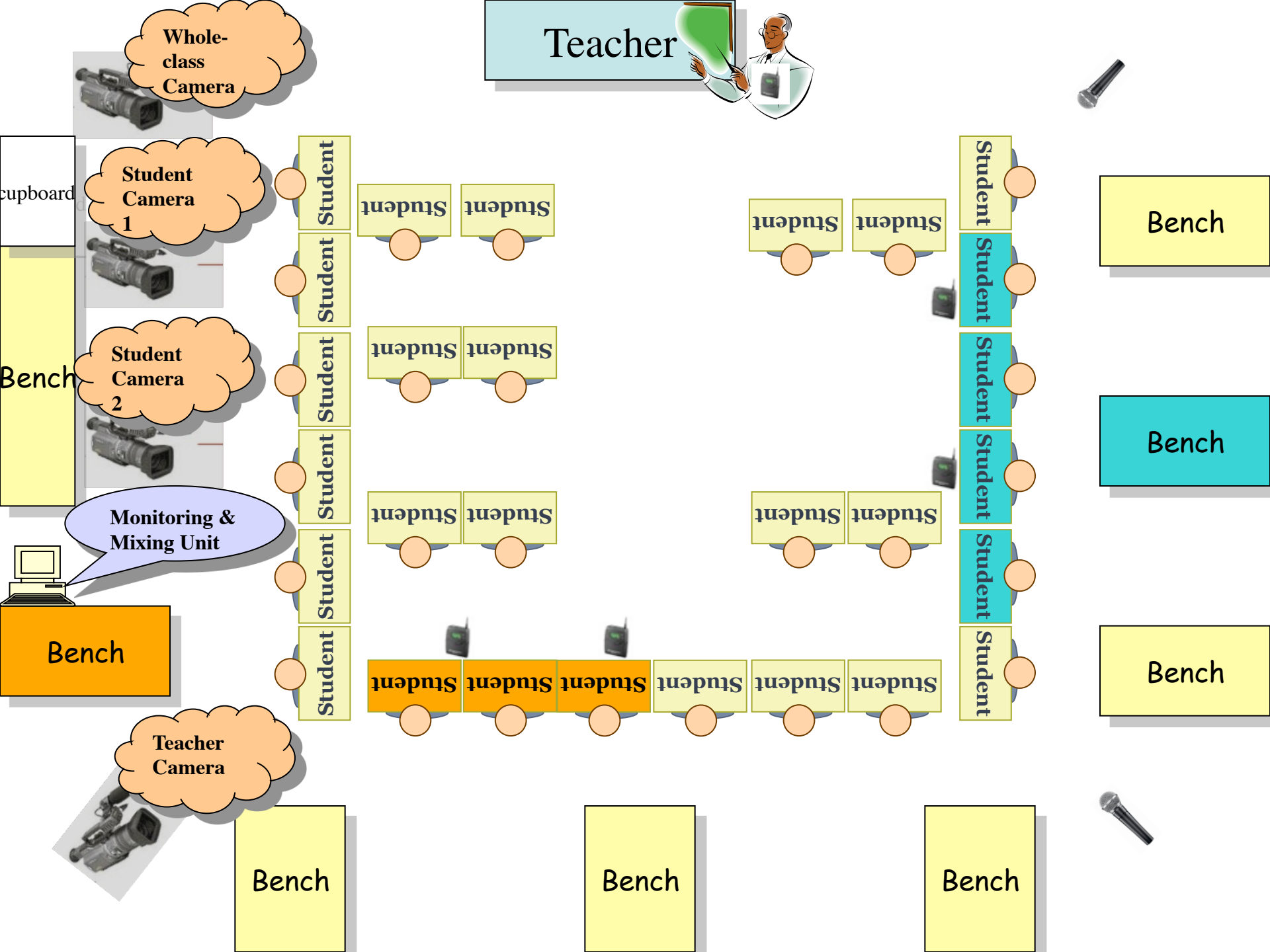
Artefacts – constructed objects

Reasoning – purposeful thought

Evidence – objects of justification

How are these constructs transformed in their passage between STEM cells? Do we find conservation of form accompanied by transformation of function?

Discourse


Teacher
Whole-class Camera
cupboard
Student Camera 1
Student Camera 2
Bench
Monitoring & Mixing Unit
Bench
Teacher Camera
Student
Bench
Bench
Bench
Bench
Bench
Bench

Studiocode

A1-L04M.mov

AU1-L04_pub, 442 MB, 320 x 240

Find text

<AND> <NOT> Clear

diameter

generate results
case sensitive
whole word
underline
bold
auto clear
Rows before 0
Rows after 0

Transcription

print column row bold italic color size movie populate play stop
lines 2
loop 5 secs

Column 1	Column 2	Column 3
00:08:35:07 00:08:44:18 00:00:09:11 AU1-L04_pub	Sarah	"Um, [...] diameter [...] a straight line [...] straight through the middle [...]"
00:08:56:20 00:08:58:08 00:00:01:88 AU1-L04_pub	T	to identify the diameter?
00:08:59:22 00:09:10:25 00:00:11:03 AU1-L04_pub	T	"[to all] Is there an, a relationship that connects the diameter and the radius?"
00:09:18:19 00:09:20:19 00:00:02:00	Amit	[...] the diameter and the radius [...]

AU1-L04_pub

merge rows
Make movie
append slow
text tracks
Find
Database
Matrix
Note
New row

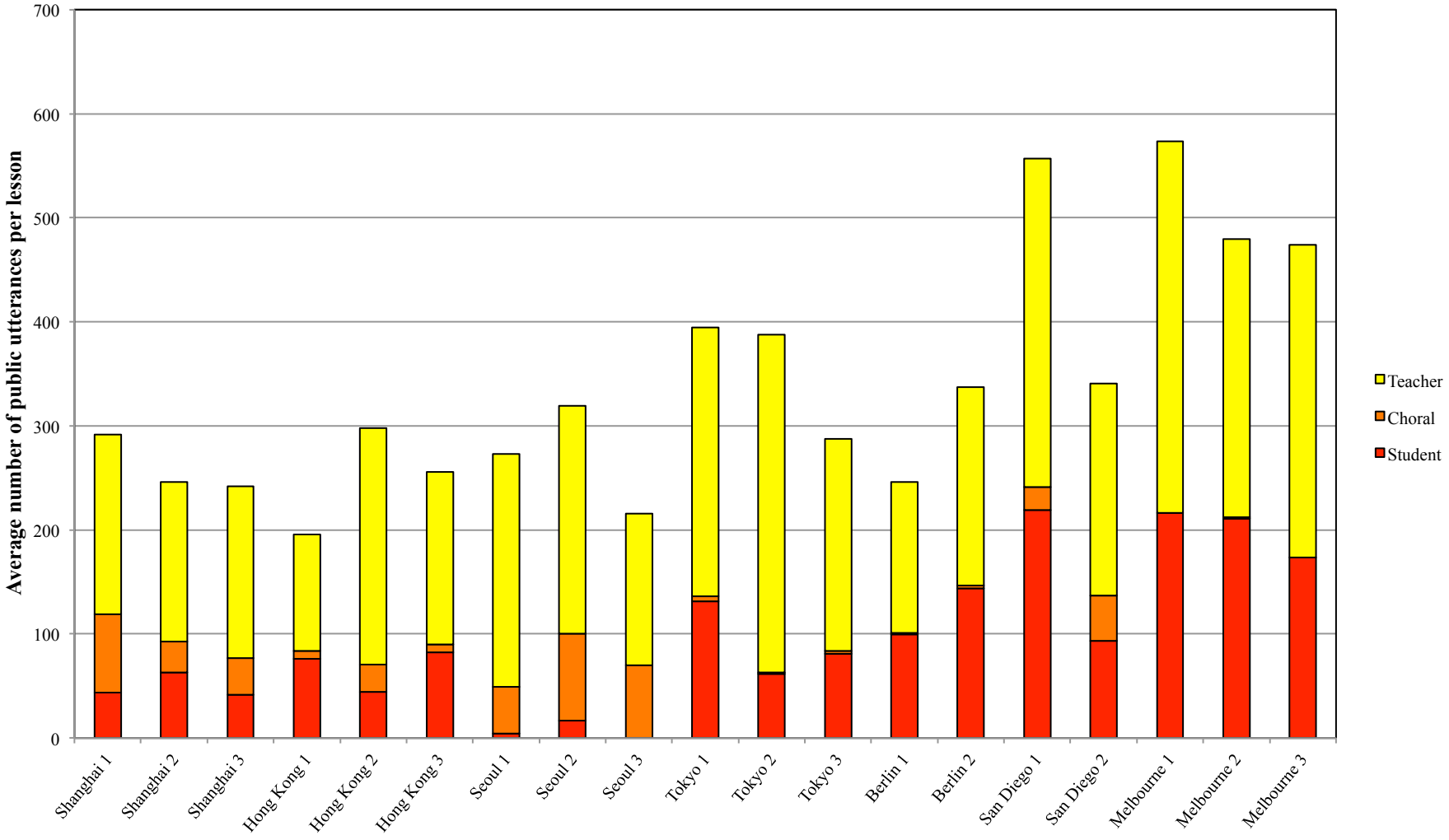
00:46:44.52

0 00:04:00.00 00:08:00.00 00:12:00.00 00:16:00.00 00:20:00.00 00:24:00.00 00:28:00.00 00:32:00.00 00:36:00.00 00:40:00.00 00:44:00.00

1. T circle
2. Josh circle
3. Amit circle
4. Ben circumference
5. T circumference
6. Amit circumference
7. Sam circumference
8. Mich circumference
9. Euan circumference
10. Sarah diameter
11. T diameter
12. Amit diameter
13. Step diameter
14. Josh diameter
15. Sam diameter
16. Mich diameter
17. Euan diameter
18. Ben perimeter
19. T perimeter
20. Josh perimeter
21. Levi radius

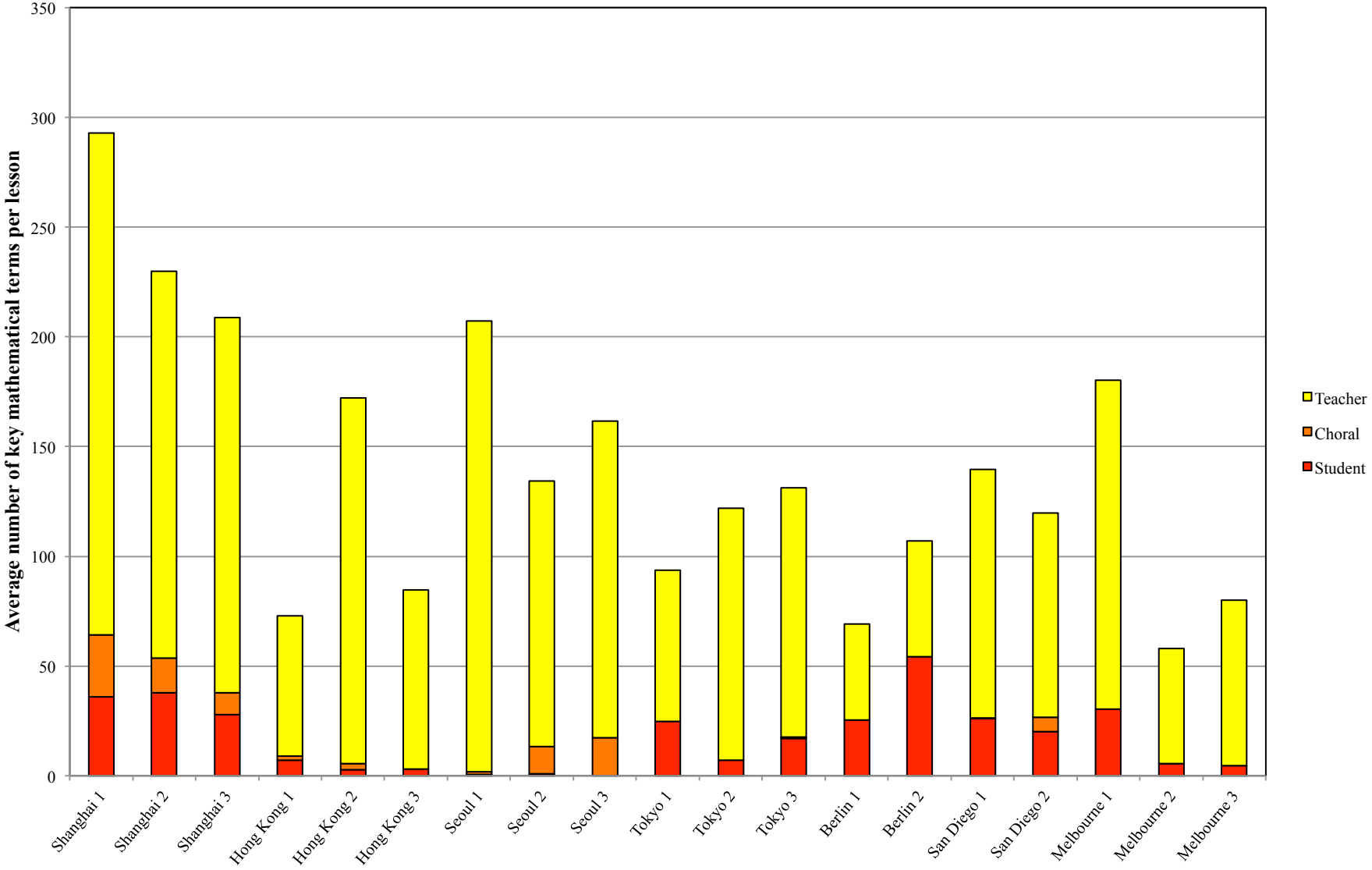
zoom in zoom out

Who is Speaking in Mathematics Classrooms?



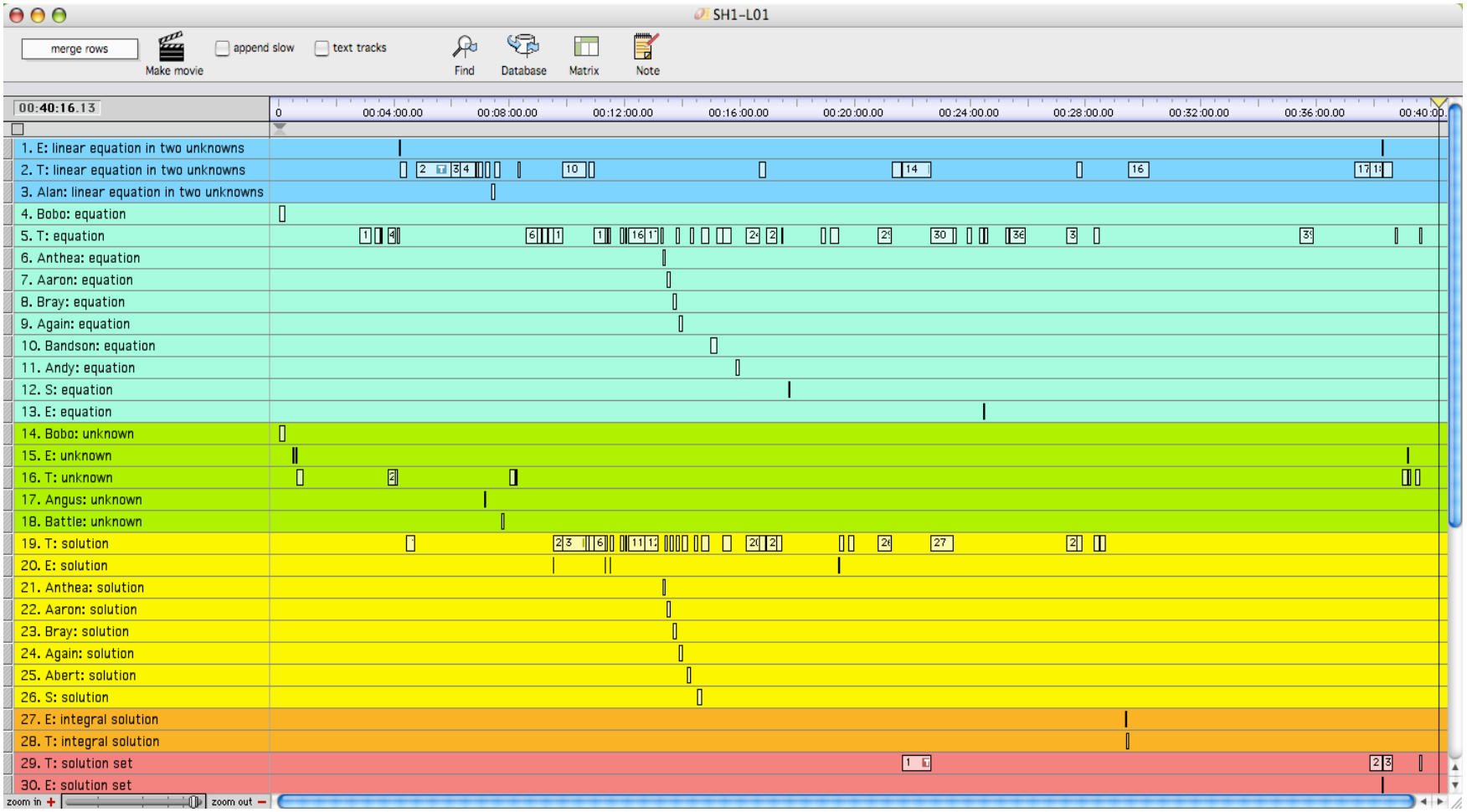
*Each bar represents an average over five lessons

Who is speaking mathematics?

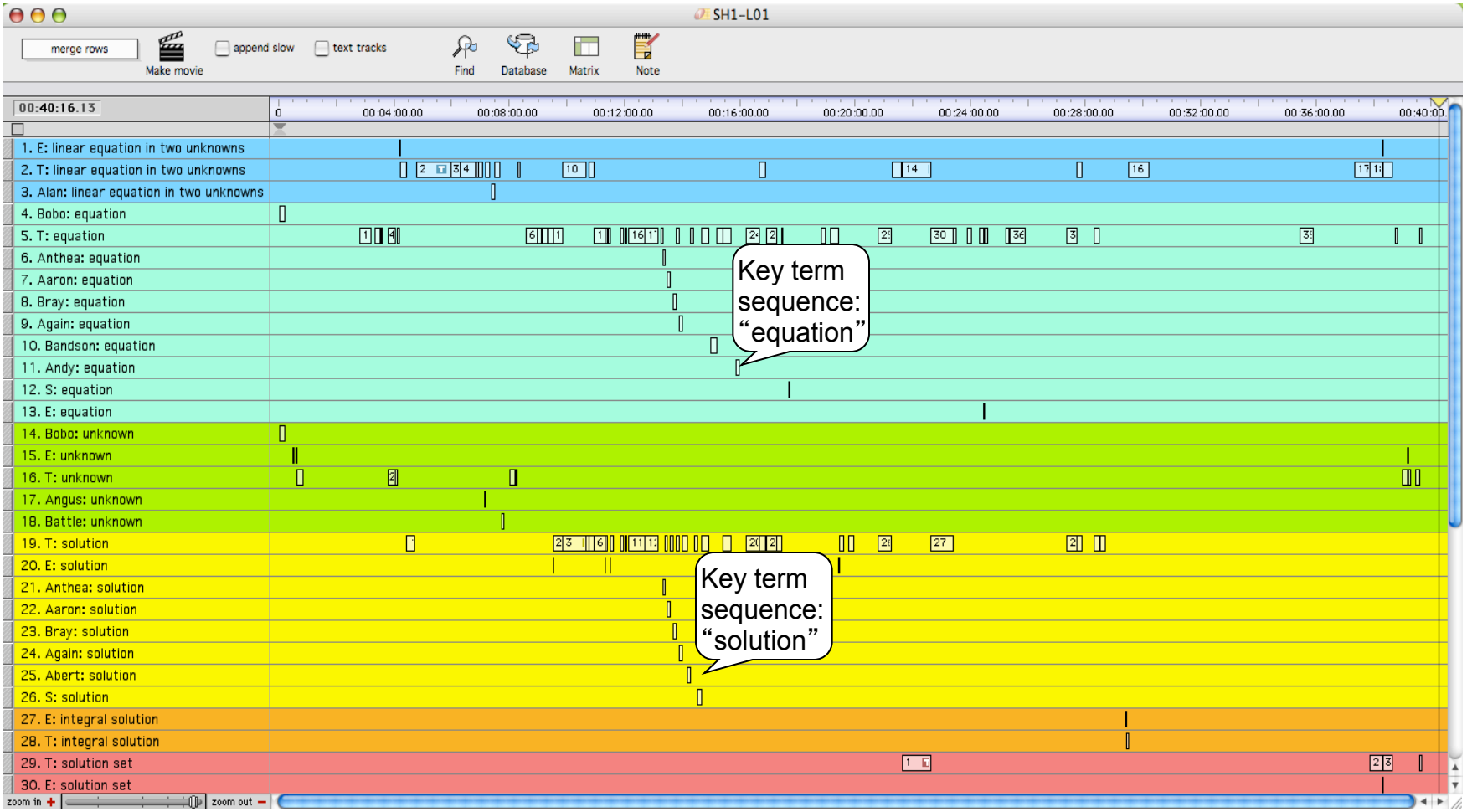


*Each bar represents an average over five lessons

Discourse Patterns: SH1-L01



Discourse Patterns: SH1-L01

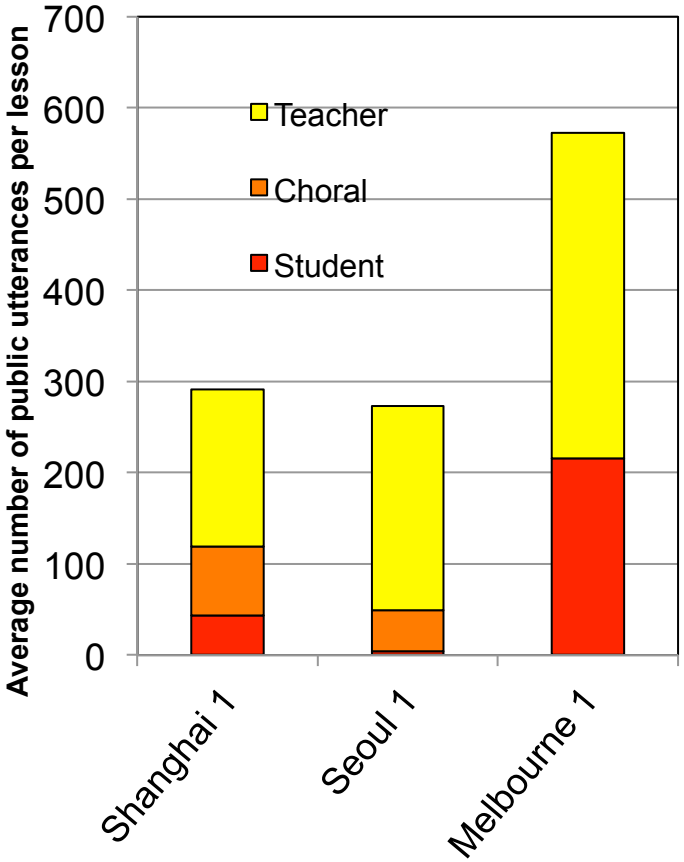


Examining discourse patterns

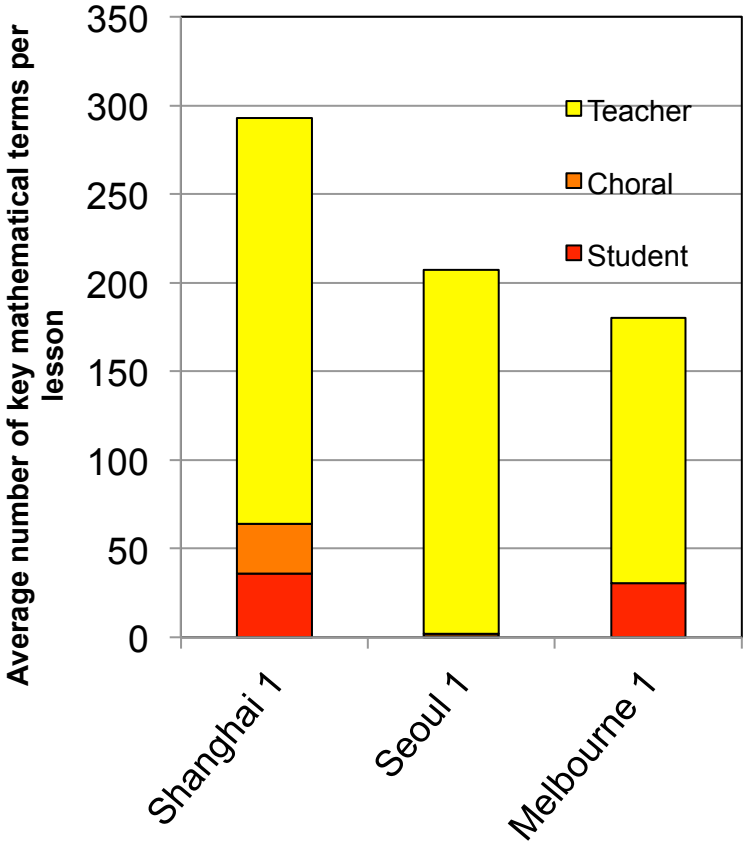
The highly visual nature of the timeline display can reveal temporal patterns in the coded terms. In the case of Shanghai Teacher One, the solicited articulation of the key term (e.g. “solution”) by a sequence of students, seems to be a distinctive characteristic of that teacher’s practice. Once identified, such distinctive patterns can be examined in more detail. Consider specifically the transcript of a two-minute interaction (min: sec) focusing on the term “solution.”

12:42 (m:s)	T:	So let's read ... ah, let's read question one, question one. It says... in the following pairs of number value, each of them can be matched with a pair of x and y. So, let's read this. It is asking, which of them are the **solutions** of the equation two x plus y equals three? Which are the **solutions** of the equation three x plus four y equals two? Come on, have a try.
13:10	T:	So, let's take a look. How about the first one? Oh, ok, you.
13:14	Anthea:	x is equal to zero, y is equal to three. It is.
13:17	T:	It's an equation. That means, x is equal to zero, y is equal to three. It is... ?
13:21	Anthea:	It is a **solution** of the equation two x plus y equals three..
13:24	T:	A **solution**. Okay, sit down please. How about you, Aaron?
13:28	Aaron:	x equals zero and y equals one over two is a **solution** of the equation three x plus four y equals two..

A tale of three maths classrooms: Public Talk



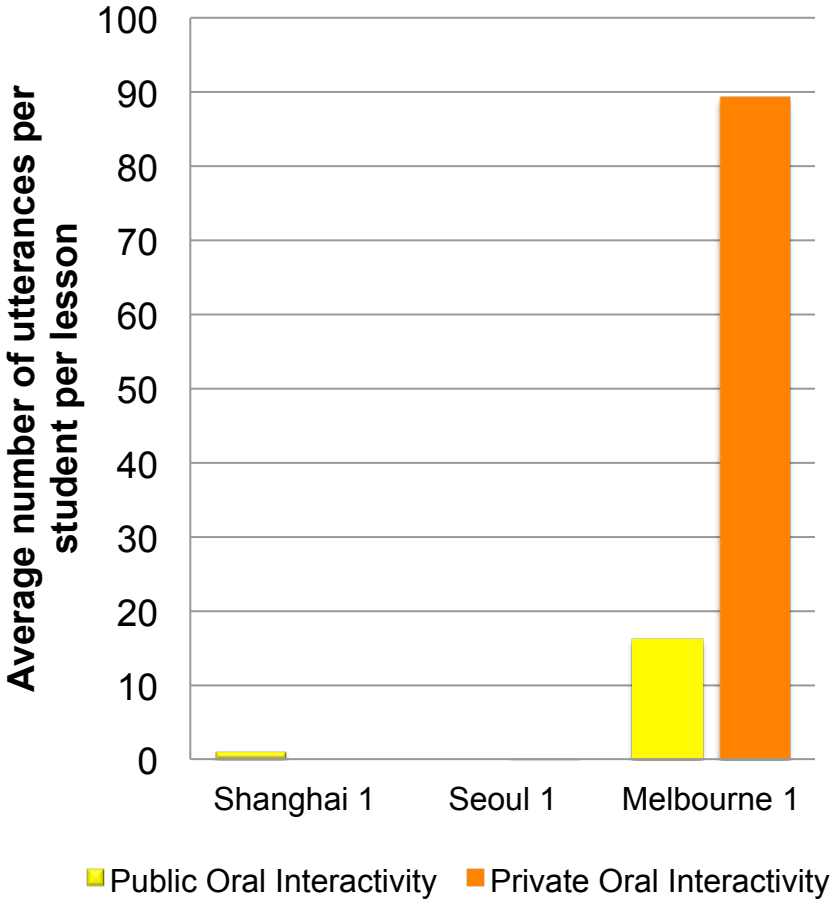
Public Utterances

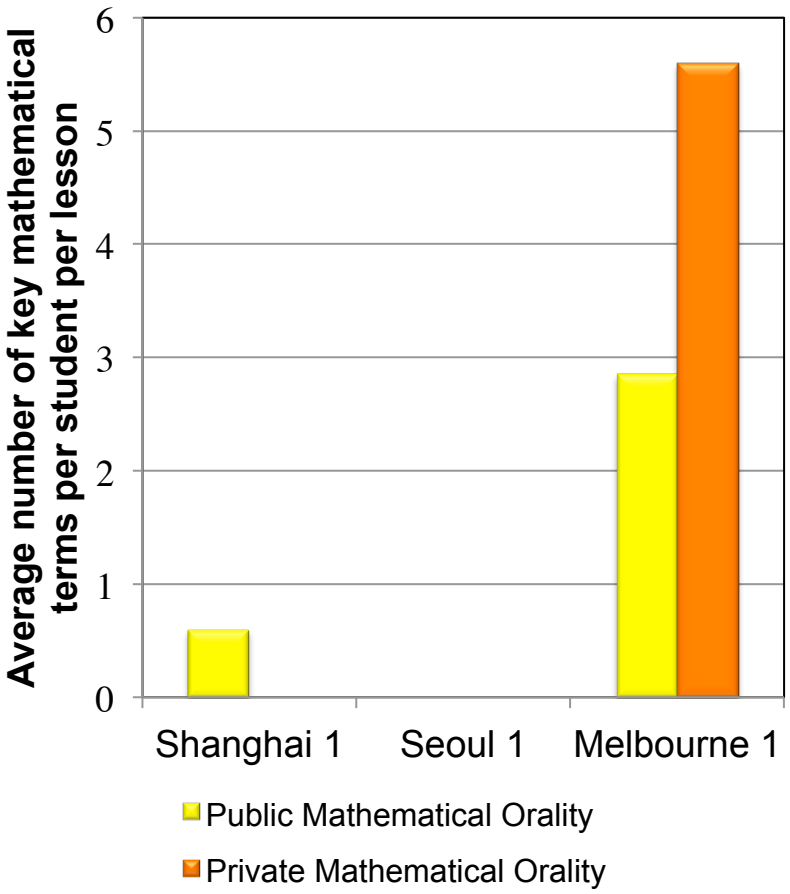


Key Mathematical Terms

*Each bar represents an average over five lessons (ie ten students)

Three classrooms – the student experience: Public vs Private Talk





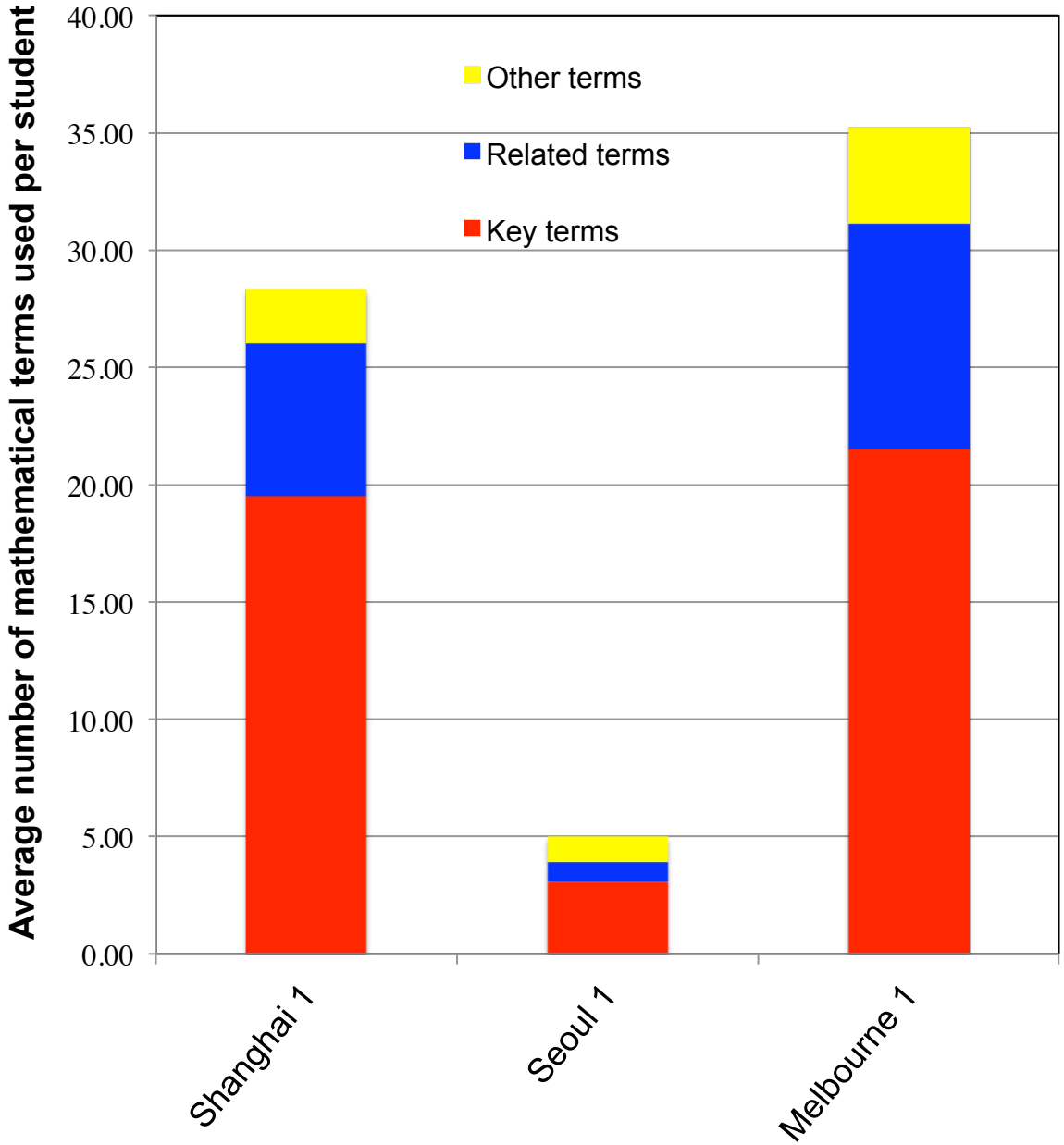
Public and Private Utterances

Key Mathematical Terms

n(SH1=50; SE1=36; ME1=25)

*Each bar represents an average over five lessons (ie ten students)

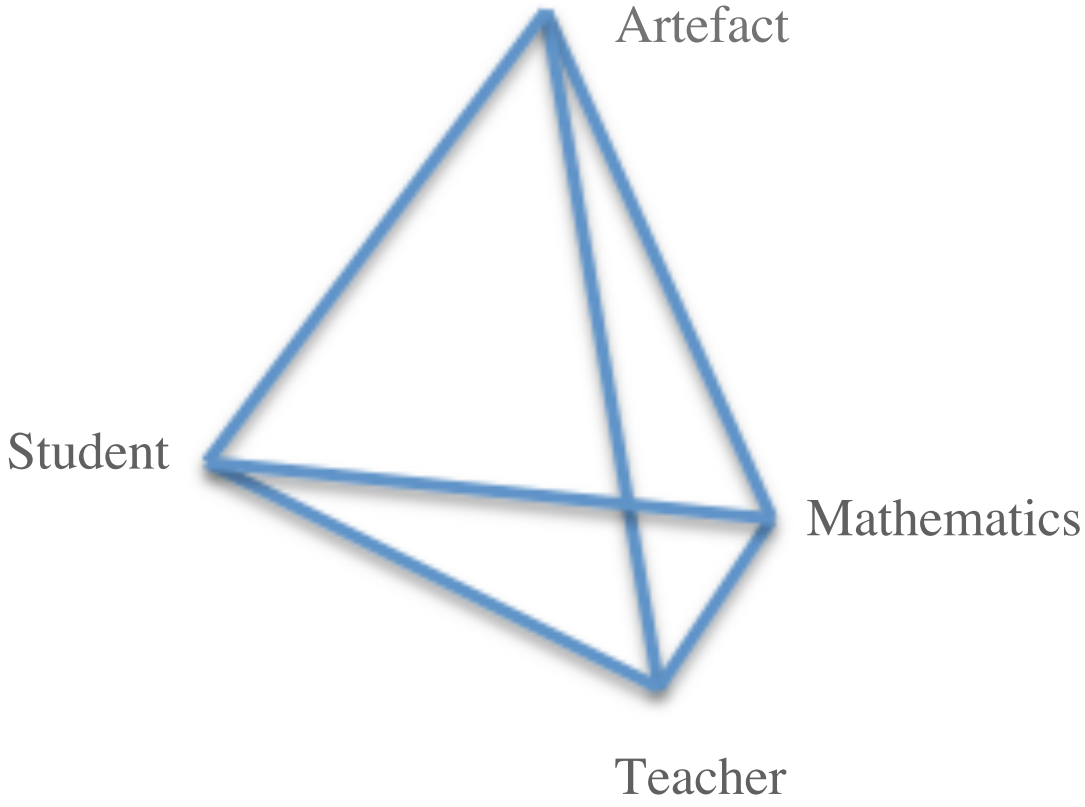
Frequency of Student use of Mathematical Terms in Post-lesson Interviews



*Each bar represents an average over ten students

Artefacts

The Socio-Didactical Tetrahedron

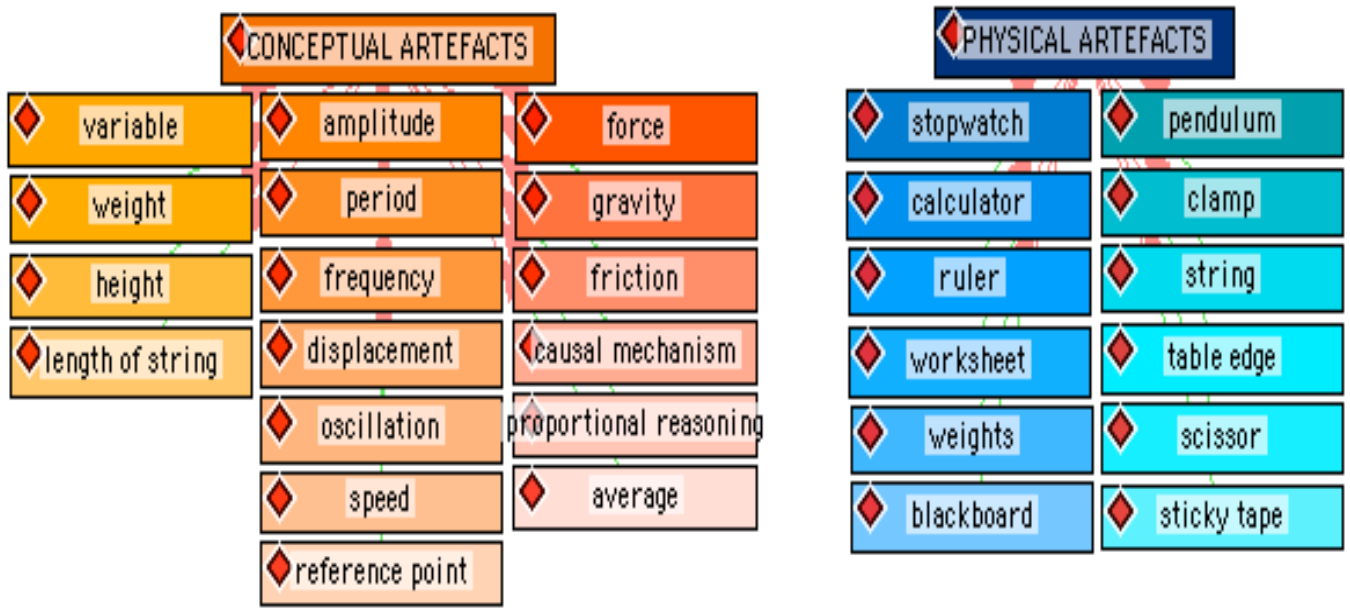


The Socio-Didactical Tetrahedron (Rezat & Strässer, 2012)

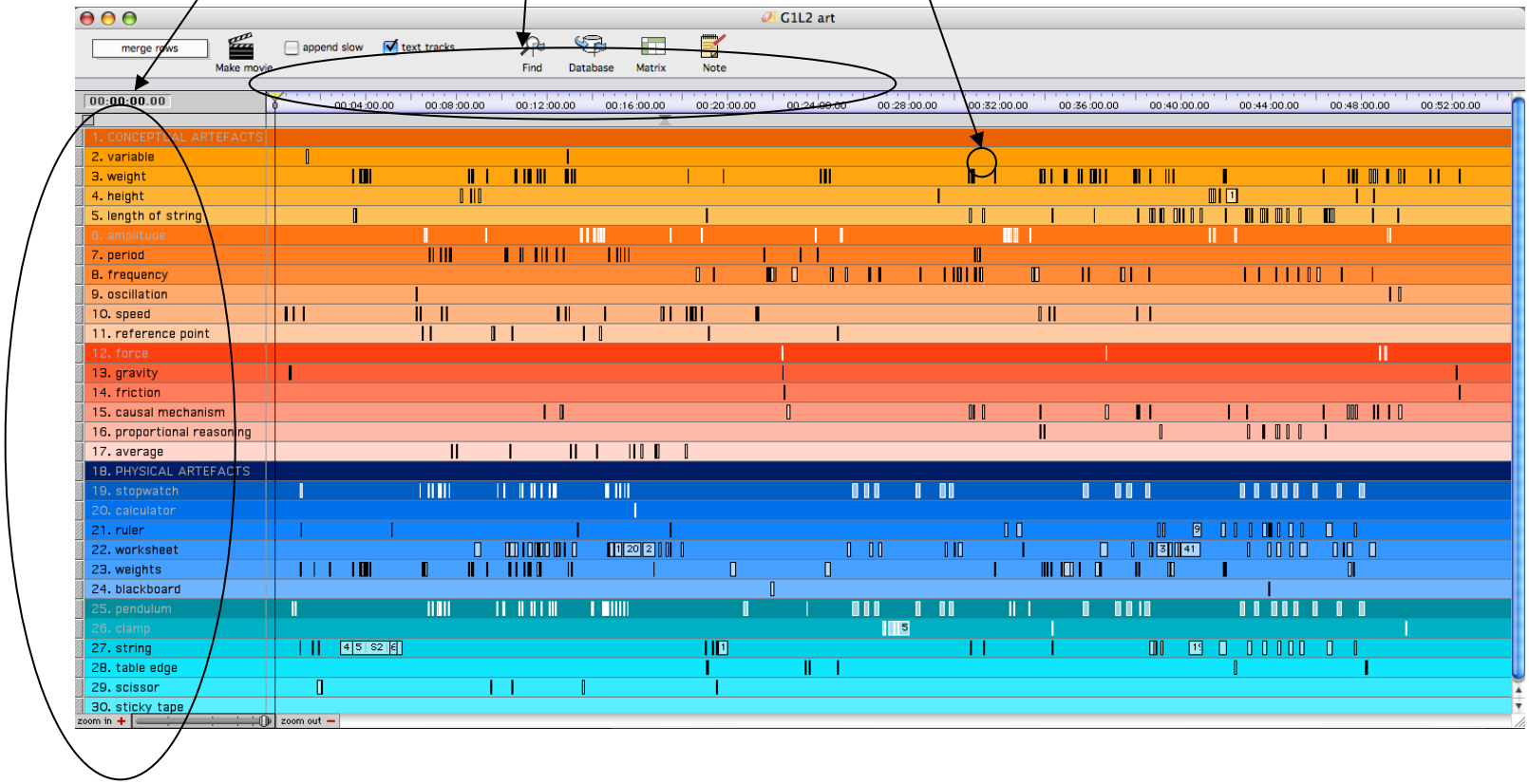
Distributed Cognition: Artefact Categories

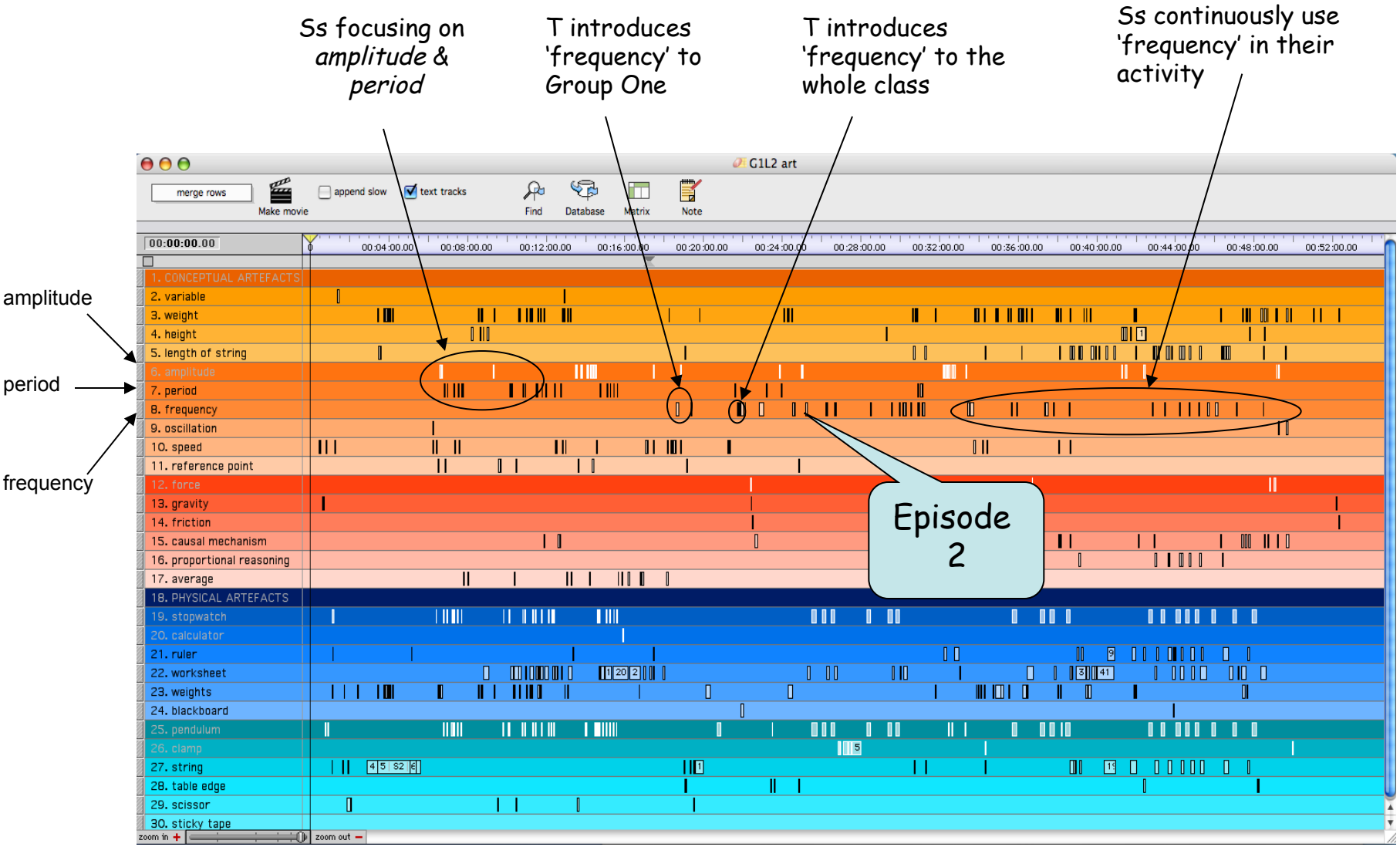
Two categories of artefacts

Artefacts involved in student activities



Artefacts Timeline Instances





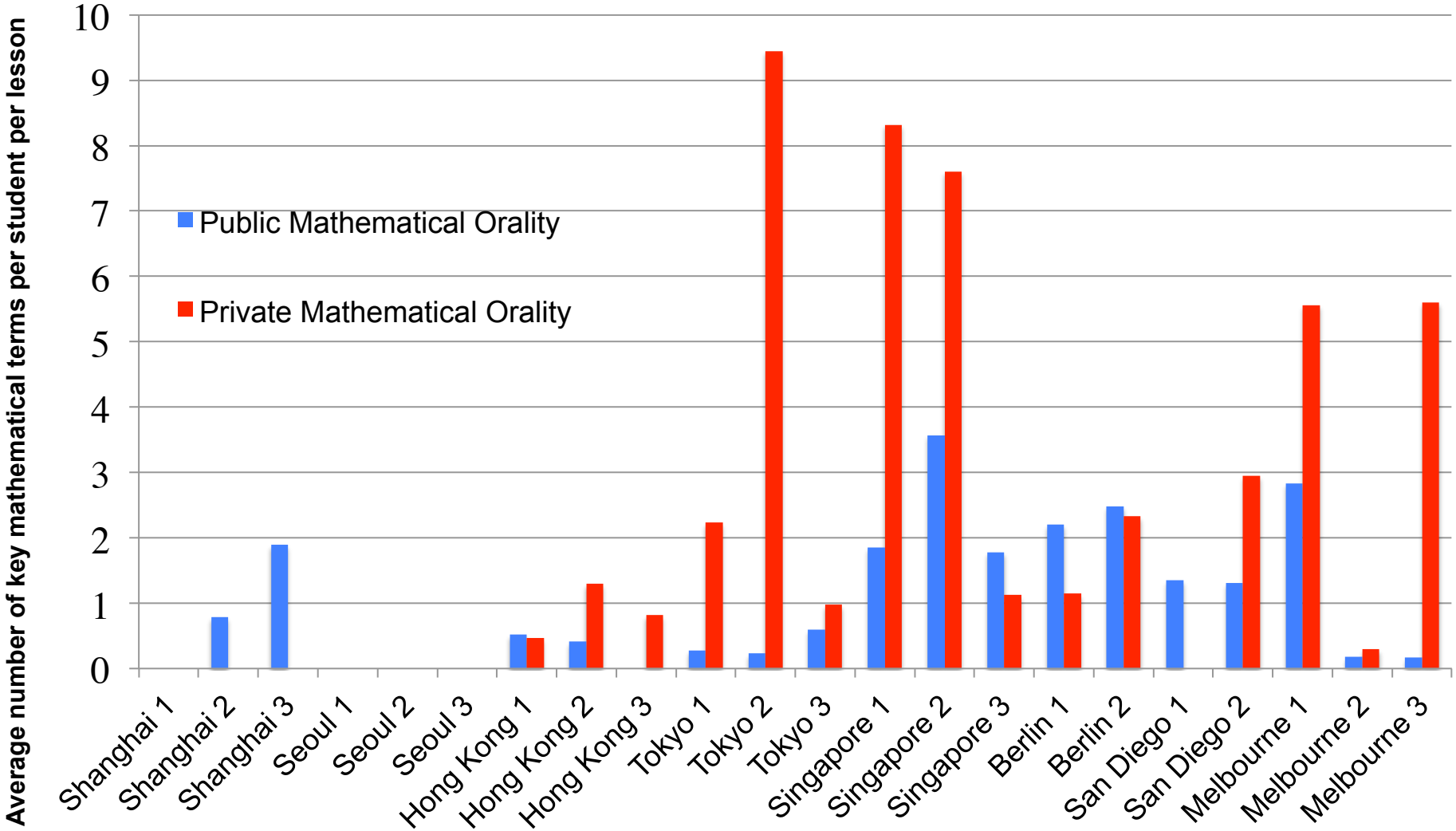
Tracing the flow of ideas - in Science

Artefacts and Relations between Artefacts

- The utilisation of an artefact may be noteworthy in itself, but documenting the chain of successive utilisation and seeking to understand the intentions and interpretations influencing each subsequent use may reveal an infrastructure of artefact utilisation that transcends the use of an individual artefact and reveals patterns of social practice (eg status differences) applicable to the utilisation of a wide range of possible classroom artefacts.

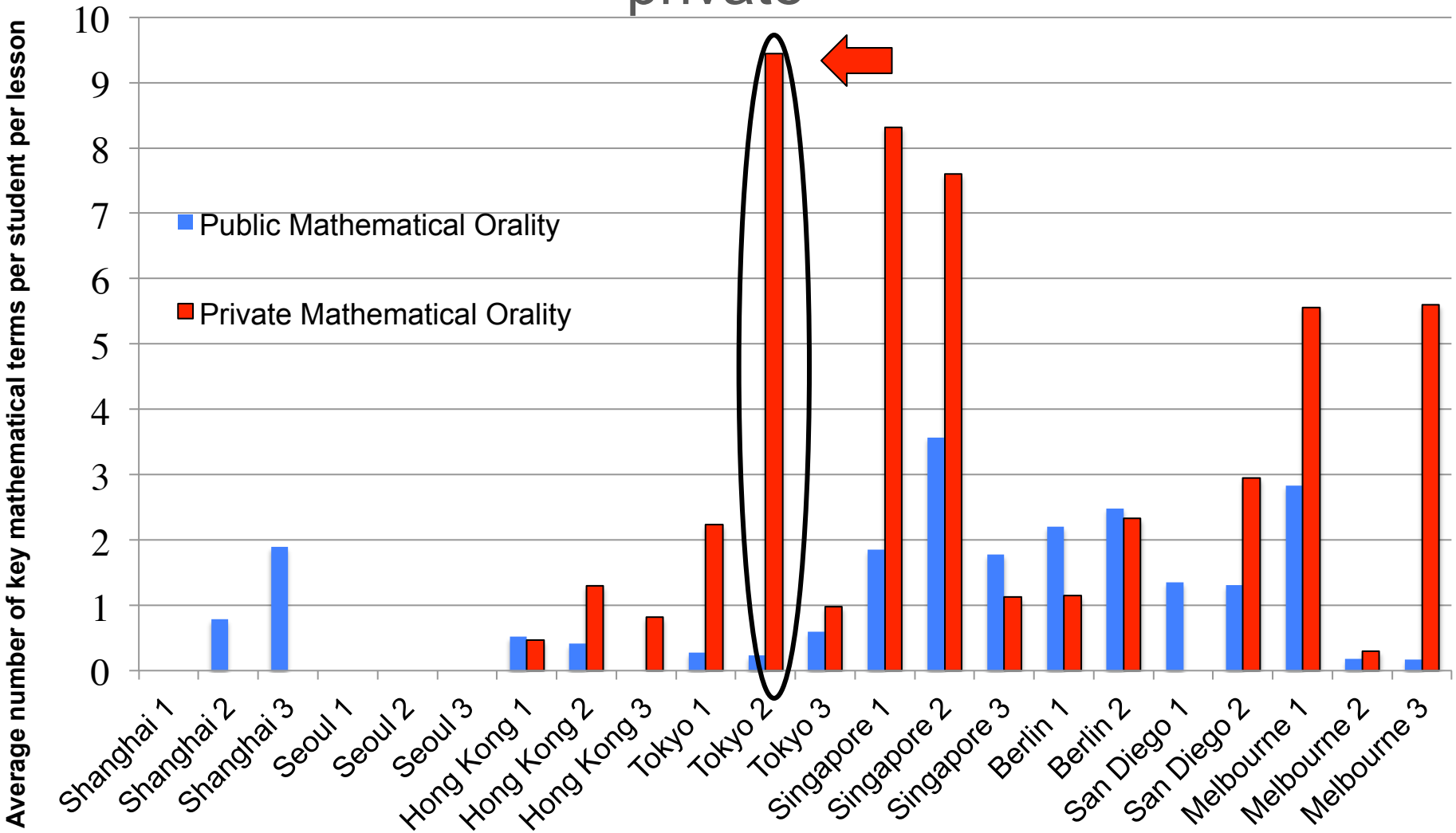
Reasoning

Individual student spoken mathematics - “public” and “private”



*Each bar represents an average over five lessons or ten students

Individual student spoken mathematics - “public” and “private”



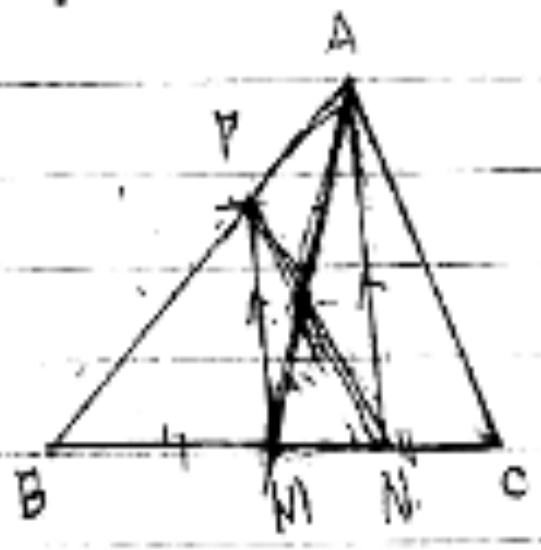
*Each bar represents an average over five lessons (ie ten students)

Sample student-student "private" interaction - Classroom transcript (Tokyo School 2 – lesson 2, 29:46:12 – 33:15:19)

- WADA Um, you drew a **middle point** [mid-point] here, right? So if you just draw a line from here, wouldn't that do?
- KAWA Can you draw a line from P?
- KAWA You're kidding. What did you say? Are you saying that you can draw a line from here?
- WADA Yes. If you draw a line from there, if goes over the **middle point** [mid-point] so there is no problem there.
- KAWA Really? Let's try then.
- KAWA What was the name of the **theorem** again?
- WADA **Middle point** [Mid-point] **connection theorem**.
- KAWA That's it! But it isn't **parallel** there. Are you going to try drawing it there?
- WADA [To Tsutahara] Doesn't this work when you draw a **parallel line** by free hand and then draw a line that goes along P?
- TSUT I don't understand what you're talking about.

Wada's work

Q 次の△ABCの点Pを通り、
面積を2等分する直線を
引け。



Sample student-student "private" interaction - Classroom transcript (Tokyo School 2 – lesson 2, 29:46:12 – 33:15:19)

- KAWA Where's the **bottom line** [base] then?
- WADA This is the **bottom line** [base], I bet. God, I don't know which one is the **bottom line** [base] now.
- KAWA This one has to be the **bottom line** [base].
- WADA This has to be the (height), this one.
  This is the **height**. I got it now!
- KAWA Is this the **height**? Is it all right if it's now **parallel**?
- WADA Well, it doesn't have to be **parallel**. No need for that.
- KAWA But then which two become equally in half?
- WADA What the hell are you saying?
- KAWA Aren't we doing the one that we have to divide in half or something like that?
- WADA Yes, that's the one we're talking about.
- KAWA I'm starting to get mixed up now.
- WADA Well, I'm starting to get a headache.

Evidence

I see, I think, I wonder

We always need to think why

The expectation of evidence

Problem: When two coins are tossed there are three possible outcomes: two heads, one head, or no heads. The probability of two heads is therefore one third.

Ss	[Discussion about sample space] from 00:33 to 01:16 (The students conclude the statement is false)
S2	**But why?**
S1	**We always need to think why!**
S3	Because there are two coins and each one has two faces . . .

How has this expectation been established?

STEM as an international priority

“Science, technology, engineering and mathematics are distinct and complementary approaches to knowledge and practice that have been proven to benefit society” (Office of the Chief Scientist (Australia), 2013, p. 24).

“Canada’s success in the 21st century will be determined by our ability to harness science, technology and innovation to drive economic prosperity and societal well-being” (Science, Technology and Innovation Council (Canada), 2013).

“A world-class STEM workforce is essential to virtually every goal we have as a nation” (Obama, 2009).

Explaining STEM

What is it that brings us together?

An affiliation of concern

What is it that STEM brings together?

Sites for the development of expertise

through habitual border crossing

What is it that brings STEM together?

Discourse

Artefacts

Reasoning

Evidence

Explaining STEM

What is it that brings us together?

An affiliation of concern

What is it that STEM brings together?

Sites for the development of expertise

through habitual border crossing

What is it that brings STEM together?

Discourse

Artefacts

Reasoning

Evidence

STEM could be the vehicle for a new approach to disciplinary inclusivity and the transformation of the organizing principles of the curriculum and of teacher expertise. Innovative research designs are needed. We have the tools.

References 1

Collet, C. & Hine, D. (2013). Preparing Graduates for Both Academia and Industry. *Australian Society for Medical Research (ASMR) Newsletter*, July, 2013., p. 2.

Cyranoski, D., Gilbert, N., Ledford, H., Nayar, A., & Yahia, M. (2011). The PhD Factory. *Nature, 472*, 276-279.

Engeström, Y., Engeström, R., & Kärkkäinen, M. (1995). Polycontextuality and Boundary Crossing in Expert Cognition: Learning and Problem Solving in Complex Work Activities. *Learning and Instruction, vol. 5*, 319-336.

Hackling, M. (2014). The Status of STEM Education in Australia: Challenges and Opportunities. Presentation to the annual conference of the Australasian Science Education Research Association, Melbourne, Australia, July 2 to 5, 2014 (see also Hackling et al. (2014) below).

Hackling, M., Murcia, K., West, J. & Anderson, K. (2014). Optimising STEM education in WA schools. Retrieved from: http://www.tiac.wa.gov.au/Publications/Current-Publications.aspx

References 2

Ingersoll, R. M. (2002). *Out-of-field teaching, educational inequity, and the organisation of schools: An exploratory analysis*. Washington, DC: Centre for the Study of Teaching and Policy.

Luke, A., Freebody, P., Shun, L. & Gopinathan, S. (2005). Towards Research-based Innovation and Reform: Singapore schooling in transition. *Asia Pacific Journal of Education, 25*(1), 5-28.

Rezat, S. & Strässer, R. (2012). From the didactical triangle to the socio-didactical tetrahedron: artifacts as fundamental constituents of the didactical situation. *ZDM – The International Journal on Mathematics Education*, *44*, 641-651.

Suchman, L. (1994). Working relations of technology production and use. *Computer Supported Cooperative Work, 2*, 21-39.

Tytler, R., Osborne, J., Williams, G., Tytler, K., & Cripps Clark, J. (2008). *Opening up pathways: Engagement in STEM across the Primary-Secondary school transition*. Canberra: Australian Department of Educational, Employment and Workplace Relations.

Acknowledgements

I would like to express my gratitude to the staff of the ICCR (Cameron, Reggie, Carmel, Li Hua, and Vivien) and to Lay Hoon, Natasha, Aloysius, whose doctoral work informed this presentation. Grateful thanks also to Linda Hobbs, Gaye Williams, Mark Hackling, Russell Tytler and Sharon La Fontaine for conversations that influenced the shape of this presentation. Thanks to the teachers and students who tolerated my filming and my questions. I would also like to express my thanks to all my colleagues in the LPS and Alignment Projects, whose insightful analyses have maintained my interest in educational research. Finally, I would like to thank the STEM conference organisers and UBC for the invitation to speak – the opportunity to give thought to these matters has been a personally enriching experience.

Thank You

For further information see:

http://www.iccr.edu.au