What works in science lessons – and why

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Componential approaches to learning

- Improved understanding over past 20 years of component skills involved in learning to read/do arithmetic, based on analysis of cognitive/other predictors of individual variation in key aspects of performance
- Improving levels of teacher understanding of learning processes/remediation techniques on back of this work
- Little comparable work on science learning, despite importance attached to this
- To move forward, need to

  a) specify potential focal areas of skill

  b) assess impact of possible influences – especially neurocognitive – on these

Learning science – problem and solution?

- Recognised during 1980s that children start school with many naive and mistaken ideas about causal events, and these are resistant to instruction (e.g., Driver et al., 1983; Vosniadou, 1994)
- Work by McCloskey (1983) showed many of these persist into adulthood, even among physics undergraduates
- Range of work on collaborative learning has established that discussion around *predict-test-explain* tasks produces robust improvements in understanding (Blatchford et al., 2006; Schachar & Fischer, 2004; Tolmie et al., 2010)
- But, no consensus on why: Piagetian theory (conflict/re-equilibration), Vygotskian theory (co-construction), representational redescription (explication/coordination)…
- Consistent indications of importance of explanations, but does manipulation of outcomes contribute too? And why does problem of resistant naïve ideas arise?

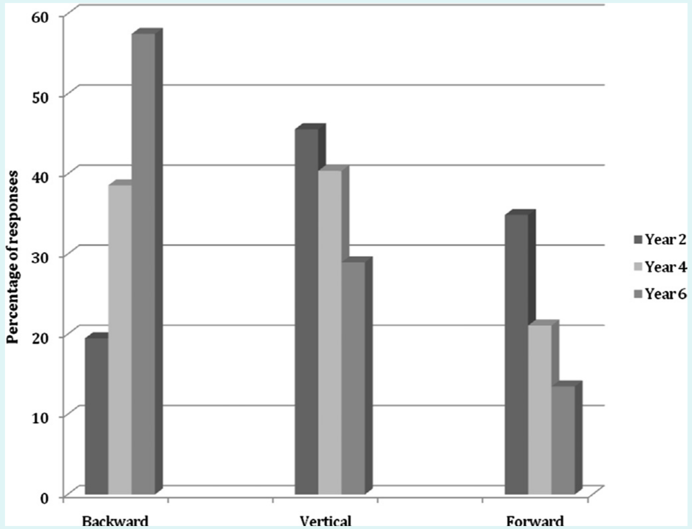
Separate types of science knowledge?

- Recent research indicates some form of disjunction exists between preverbal/tacit and explicit/manipulable knowledge of cause-effect relations
- Sobel et al. (2004), Schulz et al. (2007), accurate *retrospective* awareness of causal association from patterns of covariation across ambiguous trials (e.g. ‘blicket detector’ paradigm) from 24 months, apparently based on statistical sensitivity

- Hast (2011), 4 to 11 year olds asked to compare motion of balls of different weight down incline, either by predicting speed and justifying answer or by judging whether motion looked right or not in genuine/modified videos - tacit responses were typically accurate, but explicit were not

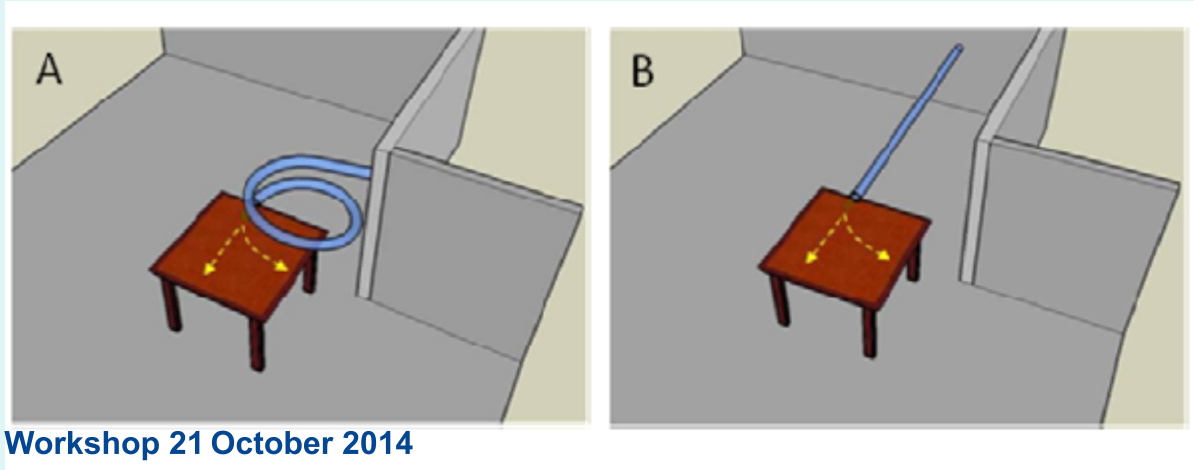
Separate types of science knowledge?

- Howe et al. (2012), 6 to 10 year olds, recognition vs prediction of trajectory followed by falling object, prediction responses characterised by increasing tendency to portray backwards motion – but backwards selected in only 22% of recognition responses, no change with age



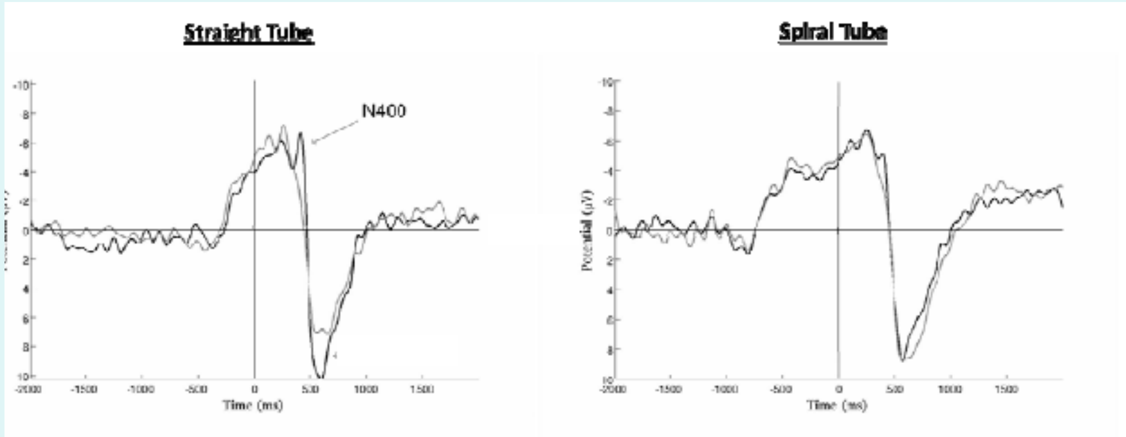
Separate types of science knowledge?

- *Adult* judgements of outcome probabilities also appear to be based on statistical sensitivity, but deliberate reasoning is poor (e.g. Tenenbaum et al., 2006)
- Kallai & Reiner (2010), ERP study with adults using McCloskey trajectory tasks, in which animations displayed of object exiting a) straight vs circular tube with b) linear vs curved motion



Separate types of knowledge?

- Behavioural judgements (key press) of whether displayed motion correct or not showed effect of tube, in line with McCloskey
- But, ERP data showed activation peak at N400 (~ semantic violations) for curved motion from *both* tube types, suggesting accurate implicit expectation



Social influences on causal knowledge

- Disjunction may be because explicit understanding often derives from *social* experiences, conversations/narratives within those contexts, **not** from observation (cf. Harris & Koenig, 2006, on impact of testimony; Howe, 1998, on conversational mapping)
- Encoding in language may happen without this, but conversation seems to have particular power
- Implies children may acquire *two* forms of science knowledge:
  - bottom-up, descriptive knowledge derived from observation
  - top-down, explanatory knowledge based on dominant conversational 'figures'
- If this account is correct, then would expect to find dissociation between quality of explanations and quality of descriptions where relevant everyday language more common

The state change study

- Our recent work has tested this in relation to children's understanding of physical state change, since marked difference in frequency of direct encounter/reference: *melting* > *freezing* > *evaporation* = *condensation*
- Sample: 95 children in three age groups (5 to 6, 7 to 8 and 9 to 10 year olds) from range of backgrounds, with language abilities straddling normal range
- Children interviewed individually in school over two sessions a week apart
- First session focused on range of general cognitive measures: BPVS, digit span, block span, backward digit span, Stroop (chimeric animals), Wisconsin, CEFT
- In second session, watched 30-second video clips of instances of state change (two clips for each type of change, contrasting in how evident effect was, order systematically varied)
- Asked 'what do you think is happening there?', responses transcribed and coded

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Results

Variable	Effect size (partial eta squared)	Means (SDs)				Notes
		Melt	Fr'ze	Evap	Con	
Description	State change .49 Year .32	2.83_a (.47)	2.55_b (.70)	1.96_c (.75)	1.64_d (.56)	Correlation with explanation smaller for melting, freezing (.28/.27) than for evaporation (.53) Negative correlation with Stroop errors for melting, freezing
Explanation	State .22 Year .16 State x Year .05	0.60_a (.71)	0.34_b (.46)	0.36_b (.56)	0.03_c (.14)	Interaction due to sharper growth for evaporation, no growth for condensation Correlation with process for all
Process terms	State .21	0.48_a (.66)	0.51_a (.60)	0.65_a (.63)	0.08_b (.24)	Negative correlation with block span for melting, freezing

Results

- For description melting>freezing>evaporation>condensation
- Differences less sharp across explanation/process indices, evaporation responses show different developmental trajectory, with sharper increase from lower base
- Explanation plays a stronger role in growth of description for evaporation than for melting and freezing
- For descriptions, melting/freezing and evaporation/condensation form separately related pairs, consistent with differences in origin
- Melting/freezing quality of description is negatively related to Stroop errors, suggesting semantic inhibitory control plays specific role for these
- Explanations are linked to use of process terms, unsurprisingly, but latter has negative relationship to block span for melting and freezing only, suggesting stronger visuospatial ability is disadvantageous here

Conclusions

- Differences in performance consistent with impact of frequency of both direct encounter and conversational reference
- Pattern not quite full dissociation between quality of explanations and descriptions, but data consistent with 'received' language dominating explanations where this is available
- Role of inhibitory control may suggest received forms have to be suppressed to some extent for observations to be more accurately described
- Where received language is less available, explanations appear to be generated in bottom-up fashion and feed into descriptions more directly
- Note implications for origin of 'misconceptions' in dialogue
- Observational abilities may often remain inaccessible in educational terms until properly integrated with explanations

Implications

- Suggests focus should be on observational and dialogue-based core skills during primary years
- Mapping into language may then provide basis for manipulation of information (cf. scientific thinking) and argumentation
- Account has clear pedagogical implications, in line with componential work on reading and arithmetic
- Teachers have important strategic role to play in organizing effective observational activities, and providing language to capture ideas about mechanisms/processes at right moment – which is why collaborative learning tasks are effective