Methodological challenges in researching teaching and learning student capabilities

Russell Tytler, John Cripps Clark, Joseph Ferguson, Vaughan Prain

Setting the scene: competences, capabilities and issues with researching these

1. Work and life futures and STEM (Global trends, work and other futures)
2. General and domain specific competences (OECD and IBE)
3. Capabilities and proficiencies
4. Complexity of defining and measuring these:

International Bureau of Education (UNESCO)

Macro-competence 1: Lifelong learning
Knowing how to learn is a critical future competence. It affords people the regenerative capacity to reinvent themselves as knowledge becomes obsolete.

Macro-competence 2: Self-agency
Self-agency is about confidence and facility to face the known and the unknown, and to emerge accomplished and fulfilled.

Macro-competence 3: Interactively using diverse tools and resources
These tools and resources include intellectual, cultural, religious, linguistic, material, technical, fiscal, physical, and virtual resources, the interface of self and machines.

Macro-competence 4: Interacting with others
Increasing complexity demands collaboration to resolve complex problems. It is also a key competence for social interaction, social cohesion, harmony, justice.

On what basis is this set decided?

Macro-competence 5: Interacting in and with the world
Enables people to be local and global, embracing diversity as an enriching asset.

Macro-competence 6: Trans-disciplinarity
Application is at the heart of competence and it requires deep mastery of disciplines, but complexity requires a decent level of understanding of several disciplines.

Macro-competence 7: Multi-literacies
Beyond basic literacy and numeracy, this competence includes micro competences like digital, cultural, financial, health, and media literacies.

International Bureau of Education (UNESCO)

Macro-competence 1: Lifelong learning

Knowing how to learn is a critical future competence. It affords people the regenerative capacity to reinvent themselves as knowledge becomes obsolete.

Micro-competences

- Curiosity
- Creativity
- Critical thinking …

Are these competences or capabilities?

Macro-competence 2: Self-agency

Self-agency is about confidence and facility to face the known and the unknown, and to emerge accomplished and fulfilled.

Micro-competences

- Initiative/Drive/Motivation
- Endurance/Grit/Resilience
- Responsibility …

Macro-competence 4: Interacting with others

Increasing complexity demands collaboration to resolve complex problems. It is also a key competence for social interaction, social cohesion, harmony, justice.

Micro-competences

- Teamwork
- Collaboration
- Negotiation …

Macro-competence 7: Multi-literacies

Beyond basic literacy and numeracy, this competence includes micro competences like digital, cultural, financial, health, and media literacies.

- Reading & writing
- Numeracy
- Multi-modal text and visual literacies

International Bureau of Education (UNESCO)
Listing of micro-competences

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Micro-competences

- Curiosity **
- Creativity **
- Critical thinking … **

** Micro-competence that has domain specific forms

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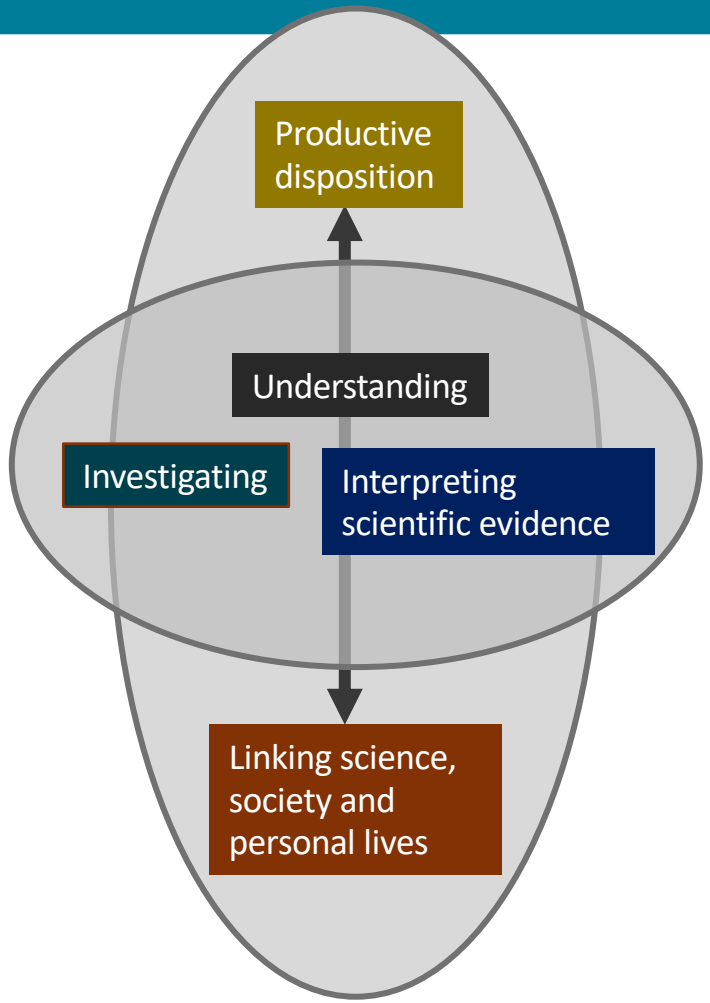
Framing STEM knowledge and skills
Tytler, OECD, 2018

Knowledge	
• Disciplinary knowledge	Concepts such as energy, geometric relations, material and structural properties, ecosystem principles …
• Epistemic knowledge	How knowledge is built in the STEM disciplines, social and personal settings of STEM knowledge building, nature of models in maths and science, design processes, algorithmic coding processes …
• Interdisciplinary knowledge	Interdisciplinary processes, links between mathematics and science, technology, STEM and other knowledges- societal, humanities and arts …
• Procedural knowledge	Investigative and problem solving approaches, design knowledge, coding knowledge …
Skills	
• Cognitive / metacognitive	Complex and creative problem solving, design thinking, critical thinking, systems analysis, computational skills, complex, model based reasoning …
• Social / emotional	Interpersonal skills, cooperation/ collaboration, persistence and optimism …
• Physical / practical	Technical skills, coding, manipulation …
Attitudes	Productive disposition, curiosity, aesthetic preferences, open mindedness, respect for evidence, commitment to learning ...
Values	Care for animals, objectivity, cooperation, responsibility … (Personal-global)

Many of these are specific to STEM. Each of these should be promoted within STEM.

SCIENCE PROFICIENCIES
(Tytler & van Driel, 2018)



Productive disposition: Developing curiosity, objectivity and resilience in relation to science ideas, commitment to sustainability and other ethics, and an increasing propensity to value and utilize scientific knowledge.

Understanding: Developing the capacity to draw on key science concepts to interpret, explain and reason about phenomena

Investigating: Developing increasing independence to propose, pursue and interpret a variety of types of scientific investigation.

Interpreting scientific evidence: Developing the capacity to reason through linking ideas with evidence and to understand how knowledge is built in science.

Linking science, society and personal lives: Developing increasing understanding of interactions between science, technology and society, the ways science can inform our personal decisions, and how science interacts with other knowledges and values in socio-scientific issues.

Questions about assessment of capabilities

- What is the distinction between a ‘competence’ and a ‘capability’?
- To what extent are these capabilities general, as distinct from having different forms in different domains?
- How can we decide on the set? Can it be complete?
- Should these capabilities be assessed, or are they inevitably rolled into other measurement of more specific knowledges/competences?
- If we think of these capabilities as ‘habits’ (Dewey, Peirce) then what does that imply about assessment?
- How critical is context in the development, and expression of a capability?

Implications for research

Research into capabilities/competences is needed:

1. To define what they entail, in different domains, and contexts
2. To investigate approaches to supporting their development
3. To investigate valid approaches to their assessment and critique superficial approaches that might currently prevail

What are the methodological issues surrounding such a research program?

Panel Members

Russell Tytler: Setting the context

John Cripps Clark: Vygotskian perspectives on capabilities

Joseph Ferguson: A pragmatist account of creativity

Vaughan Prain: Researching critical and creative thinking in science

What are capabilities and how do students learn them

John Cripps Clark

Perezhivanie: Vygotsky and Emotion

Create a 3D model of the Sun, Earth and Moon which can help teach about their sizes, shapes and distances from each other

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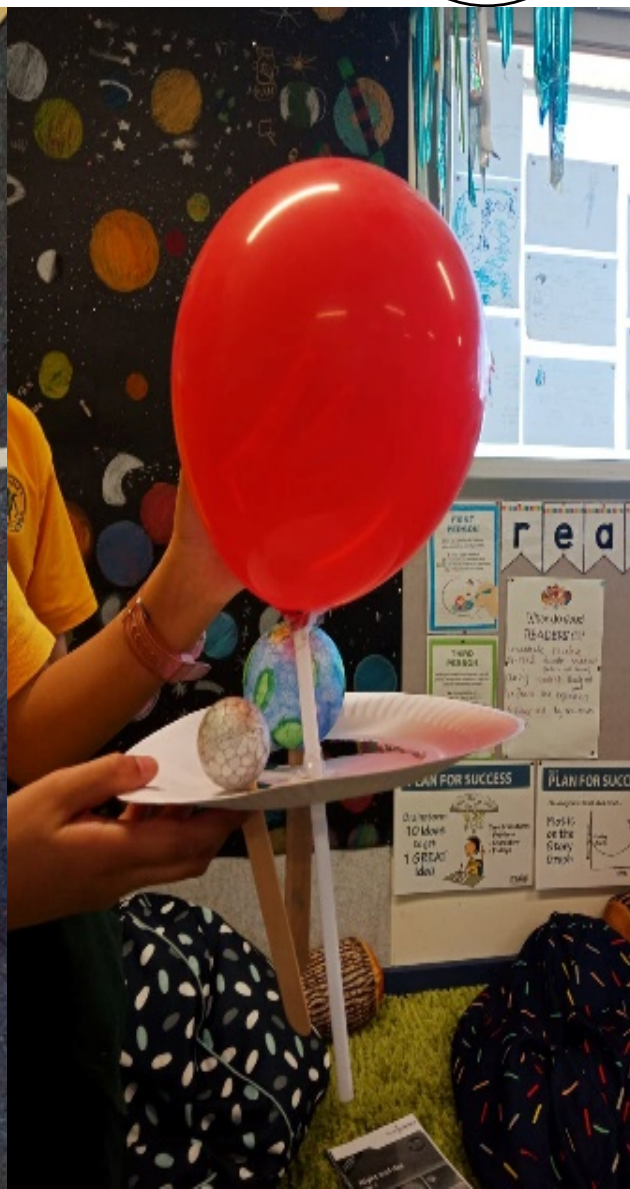

Basil Bernstein (1924-2000)

A pragmatist account of creativity

Joseph Ferguson

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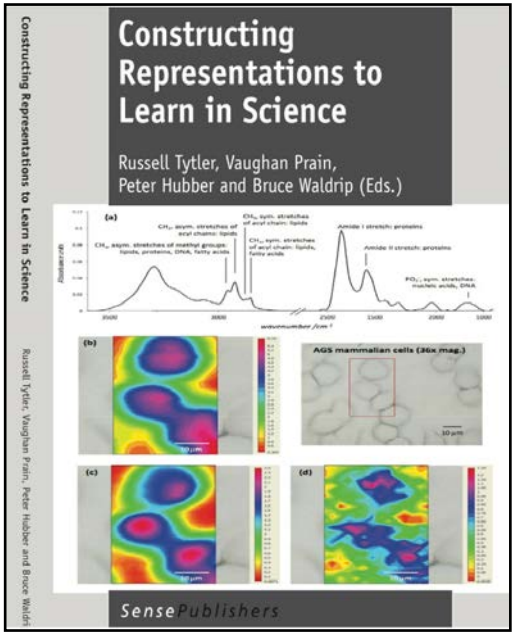
I wish to begin by acknowledging the Boon Wurrung people of the Kulin nations, the traditional owners of the land on which we are gathered today. We pay our respects to the local people for allowing us to have our gathering on their land and to their Elders: past, present and future.

RCA & Pragmatism

- Representation construction approach has its roots in pragmatism (in particular Peirce)
- RiLS, CRISP, SLRC, RemSTEP, IMS
- Meaning making as a representational process through/as reasoning
- Practically altering the situation to solve problem at hand



Tytler, R., Prain, V., Hubber, P., & Waldrip, B. (2013). **Constructing representations to learn in science**. Rotterdam: Sense Publishers.

A pragmatist account of creativity

"Pragmatism is a philosophical tradition that – very broadly – understands **knowing the world as inseparable from agency within it.** This general idea has attracted a remarkably rich and at times contrary range of interpretations, including: that **all philosophical concepts should be tested via scientific experimentation**, that **a claim is true if and only if it is useful** (relatedly: **if a philosophical theory does not contribute directly to social progress then it is not worth much**), that **experience consists in transacting with rather than representing nature**, that **articulate language rests on a deep bed of shared human practices that can never be fully 'made explicit'.**"

Legg, C. (2018). https://plato.stanford.edu/entries/pragmatism/

A pragmatist account of creativity

…presents **a growing third alternative** to both analytic and 'Continental' philosophical traditions worldwide.

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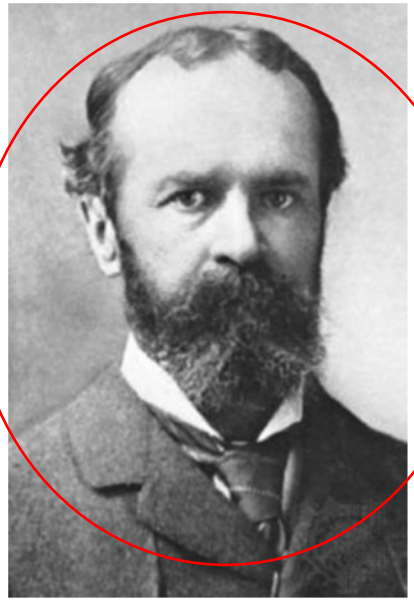
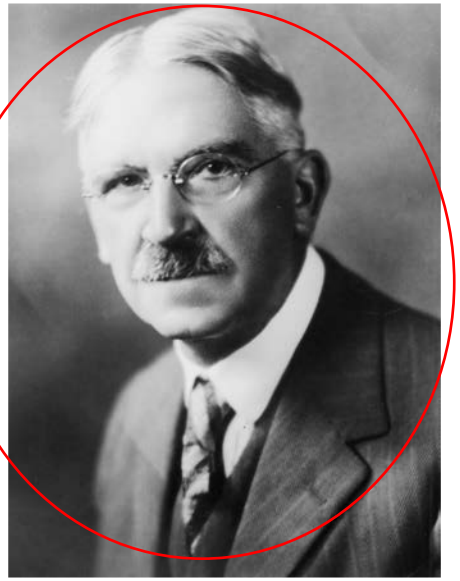


https://www.britannica.com/biography/William-James/images-videos#/media/1/299871/1204

https://www.britannica.com/biography/Charles-Sanders-Peirce/images-videos#/media/1/448884/122622



https://www.britannica.com/biography/John-Dewey/images-videos#/media/1/160445/136338

A pragmatist account of creativity

https://en.wikipedia.org/wiki/Jane_Addams#/media/File:Jane_Addams_-_Bain_News_Service.jpg

A pragmatist account of creativity

"Consider what effects, that might conceivably have practical bearings, we conceive the object of our conception to have. Then, **our conception of these effects is the whole of our conception of the object**."

Peirce, C. (January, 1878)**. How to make our ideas clear**. *Popular Science Monthly***.**

"This offers a distinctive method for becoming clear about the meaning of concepts and the hypotheses which contain them. We clarify a hypothesis by identifying **the practical consequences we should expect if it is true**."

Legg, C. (2018). https://plato.stanford.edu/entries/pragmatism/

IDEAS & PRACTICES; KNOWLEDGE & ACTION

A pragmatist account of creativity

Inquiry:

- …"struggle to attain a state of belief" in response to the "irritation of doubt." Peirce, C. (November, 1877)**. The fixation of belief**. *Popular Science Monthly***.**
- "…in order to relieve our doubt, to 'make up' our minds, we have to modify in some way, in imaginative or overt experimentation, the situation in which uncertainty is expressed" and "this change implies definite acts." Dewey, J. (1928)**. The quest for certainty**. New York: Capricorn Books.
- "Peirce aimed at 'fixing' belief, Dewey aimed at 'fixing' the situation." Smith, J.E. (1978). **Purpose and Thought**. Chicago: University of Chicago Press.

Belief and action, not certainty:

- "…we seek for a belief that we shall think to be true" not "a true opinion." Peirce, C. (November, 1877)**. The fixation of belief**. *Popular Science Monthly***.**
- "…knowledge is the fruit of the undertakings that transform a problematic situation into a resolved one" not ascertaining "fixed and immutable objective Being." Dewey, J. (1928)**. The quest for certainty**. New York: Capricorn Books.

A pragmatist account of creativity

Creativity as reasoning:

- "Abduction is the process of forming an explanatory hypothesis. It is the only logical operation which introduces any new idea; for induction does nothing but determine a value and deduction merely evolves the necessary consequences of a pure hypothesis." Peirce, C. (May, 1903)**. The nature of meaning**. *Sixth Harvard Lecture***.**

Degrees of creativity in/as abduction:

- "Abduction as a driver of creativity is (1) most original in its bringing forth an entirely new and distinct element, while it is less original (but original nonetheless) in its: (2) actively excluding certain elements, (3) rendering more distinct existing elements, (4) constructing systems for shedding light on existing elements and their relationships, and (5) critiquing the work of others exploring elements." Ferguson, J., & Prain, V. **Revisiting Peirce's account of creativity to inform classroom practice**. *Educational Philosophy & Theory,* doi.org./10.1002/tea.21590 based on Anderson, D. R. (1987). **Creativity and the philosophy of C.S. Peirce.** Dordrecht, The Netherlands: Kluwer Academic Publishers.

A pragmatist account of creativity

Deduction and induction are also creative, but in different ways:

- "…deductive thinking around implications of generalising, and inductive thinking about testing (including the kind and amount of sampling required to justify a claim)…" Ferguson, J., & Prain, V. **Revisiting Peirce's account of creativity to inform classroom practice**. *Educational Philosophy & Theory,* doi.org./10.1002/tea.21590 based on Pietarinen, A.-V., & Bellucci, F. (2014). **New light on Peirce's conceptions of retroduction, deduction, and scientific reasoning.** *International Studies in the Philosophy of Science, 28* (4), 353–373.

Creativity is disciplinary and disciplined (it's critical reasoning):

- "…disciplinary in the sense that students reason in creative ways to develop their knowledge of the natural world…" Ferguson, J., & Prain, V. **Revisiting Peirce's account of creativity to inform classroom practice**. *Educational Philosophy & Theory,* doi.org./10.1002/tea.21590

- "…disciplined in the sense that students require appropriate background knowledge and sign competence to generate plausible scientifically informed explanations." Ferguson, J., & Prain, V. **Revisiting Peirce's account of creativity to inform classroom practice**. *Educational Philosophy & Theory,* doi.org./10.1002/tea.21590

A pragmatist account of creativity

Agency and freedom of ideas:

- "Suppose, for example, that I have an idea that interests me. It is my creation. It is my creature;…it is a little person. I love it; and I will sink myself in perfecting it. It is not by dealing out cold justice to the circle of my ideas that I can make them grow, but by cherishing and tending them as I would the flowers in my garden." Peirce, C. (January, 1893). **Evolutionary love**. *The Monist*.

Musement:

- "A pretty wild play of the imagination is, it cannot be doubted, an inevitable, and probably even a useful, prelude to science proper." Peirce, C. (?). **On science and natural classes**. *?*.
- "In fact, it is Pure Play. Now, Play, we all know, is a lively exercise of one's powers. Pure Play has no rules, except this very law of liberty. It bloweth where it listeth. It has no purpose, unless recreation." Peirce, C. (October, 1908). **A neglected argument for the reality of God**. *The Hibbert Journal*.

Researching Creative and Critical Thinking (in Science)

Vaughan Prain

Researching Creative and Critical Thinking in Science

1. What should count as knowledge, skills and dispositions in each capability?
2. How is each capability developed?
3. How is each enacted within and across subjects over time?
4. How should these dimensions be assessed and researched?

Conceptualizing Creativity: A Cognitive Generic Model

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Critical and Creative Thinking

Questions and Possibilities

- Investigate the characteristics of effective questions in different contexts to examine information and test possibilities
- Suspend judgements to allow new possibilities to emerge and investigate how this can broaden ideas and solutions
- Challenge previously held assumptions and create new links, proposals and artefacts by investigating ideas that provoke shifts in perspectives and cross boundaries to generate ideas and solutions

Reasoning

- Examine a range of rhetorical devices and reasoning errors, including false dichotomies and begging the question
- Examine how to identify and analyse suppressed premises and assumptions
- Investigate the nature and use of counter examples structured as arguments
- Consider ambiguity and equivocation and how they affect the strength of arguments
- Investigate use of additional or refined criteria when application of original criteria does not produce a clear conclusion

Meta-Cognition

- Critically examine their own and others thinking processes and discuss factors that influence thinking, including cognitive biases
- Investigate how the use of a range of learning strategies can be monitored, evaluated and re-directed as necessary
- Investigate the kind of criteria that can be used to rationally evaluate the quality of ideas and proposals, including the qualities of viability and workability

Achievement Standard

By the end of Level 10, students construct and evaluate questions, including their own, for their effectiveness. They demonstrate a willingness to shift their perspective when generating ideas, resulting in new ways of perceiving solutions.

Students structure complex valid arguments. They explain and apply a range of techniques to test validity within and between arguments. Students identify, articulate, analyse and reflect on their own and others thinking processes. They use, monitor, evaluate and redirect as necessary a range of learning strategies. Students develop, justify and refine criteria to evaluate the quality of ideas, proposals and thinking processes.

Generic model of five core creative habits:

The creative student will be:

1. **Inquisitive** the student will wonder and question, challenge assumptions.
2. **Imaginative** play with possibilities, develop ideas, manipulate, test, improve, and make links.
3. **Persistent** dare to be different, tolerate uncertainty.
4. **Collaborative** share, give and receive feedback, cooperate.
5. **Disciplined** show knowledge and craft in shaping products, correct mistakes.

Lucas (2016)

Theorizing the Nature of Creativity

From a sociocultural perspective, creativity is “the production of meaningful novelties” (Glaveanu et al., 2019).

Creativity is always context-dependent, socially- and culturally-mediated action, where thought is “internalised action” (Glaveanu et al., 2019). Therefore creativity is about fit for purpose within a highly defined context.

Creativity is an embodied cognitive process of risk-taking, problem-finding and -solving (Le Fevre, 2004; Glaveanu, 2019; Nickerson, 2008; Oppezzo & Schwartz, 2014; Sternberg, 1999). Therefore in school science, students need relevant background knowledge and a meaningful creative challenge.

The study of creativity requires both quantitative and qualitative methodologies with strong theoretical grounding (Glaveanu et al., 2019). Therefore eliciting, identifying and assessing student creativity requires multiple sampling of students’ activity, their perspectives, and a detailed account of contextual influences.

If the findings and their representation are largely pre-determined in school science, what then is the point of creativity (and its scope) in this subject?

Representation Construction Approach (RCA)

- Students engage in guided representational challenges to explore and make claims about phenomena. Constructing representations operates in tandem with experimental processes to constrain reasoned exploration and explanations of material phenomena.

- Students are provided with some guidance in tackling the challenge.

- Representations actively mediate and shape reasoning where classroom activities focus on the representational resources used to instantiate scientific concepts and practices.

- Representations are understood as the reasoning tools *through which* students generate and refine ideas.

(Tytler, Prain, Aranda, Ferguson & Gorur, 2019)

Multiple warrants for foregrounding a creative approach

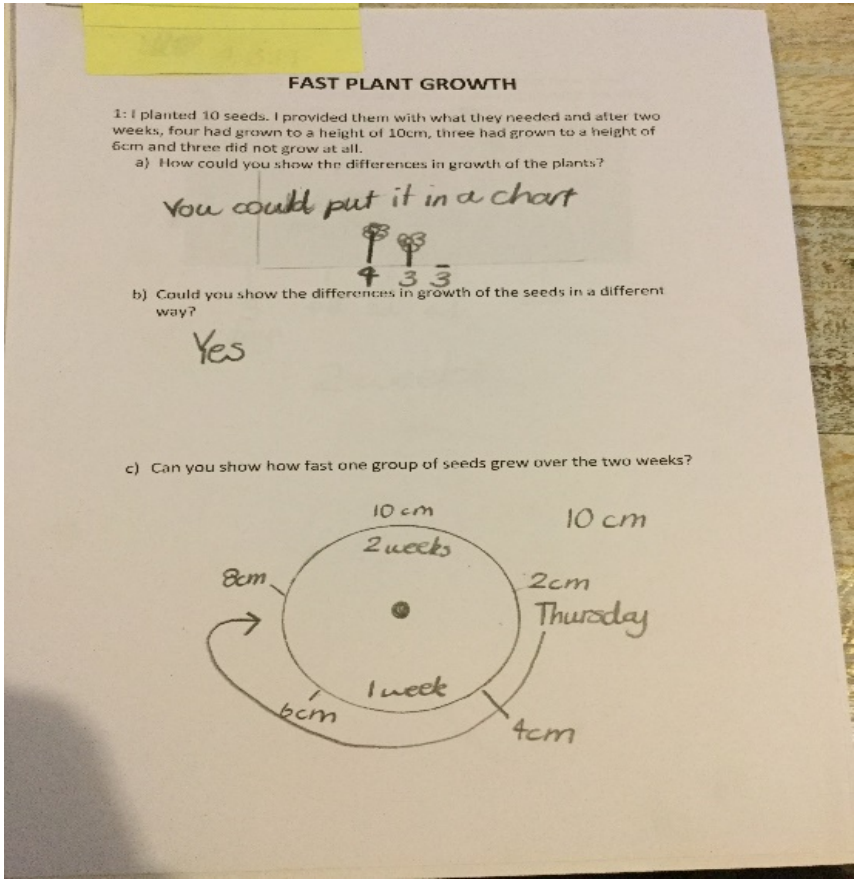
Epistemic Warrants

1. Aligns with representational challenges scientists face in making and communicating new claims;
2. Focuses on model-based reasoning;
3. The epistemological processes central to this approach mirror epistemic practices in science.

Pedagogical Warrants

1. Improved learning outcomes (Tytler, Prain, Hubber & Waldrip, 2013), resulting from student engagement with questions of representational adequacy and clarity, and through addressing issues of correspondence and coherence in representations;
2. Active role for learners in productive creativity;
3. Student gain first-hand experience of the aptness of representational conventions;
4. Enhanced student motivation.

Ella's responses to a representational challenge



FAST PLANT GROWTH

1: I planted 10 seeds. I provided them with what they needed and after two weeks, four had grown to a height of 10cm, three had grown to a height of 6cm and three did not grow at all.

a) How could you show the differences in growth of the plants?

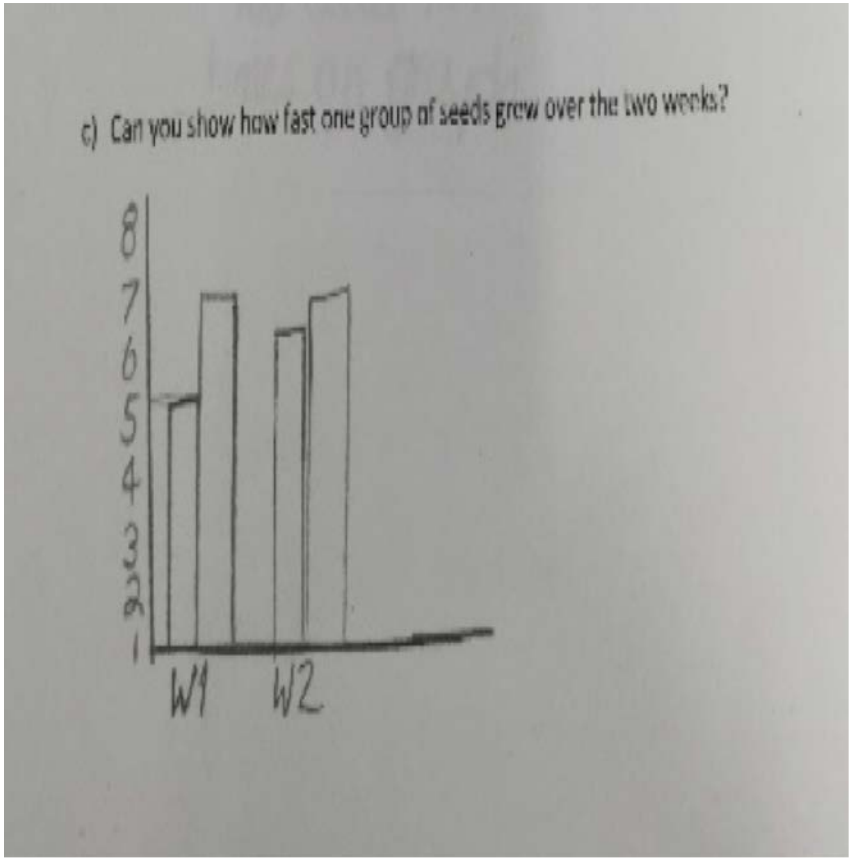
You could put it in a chart

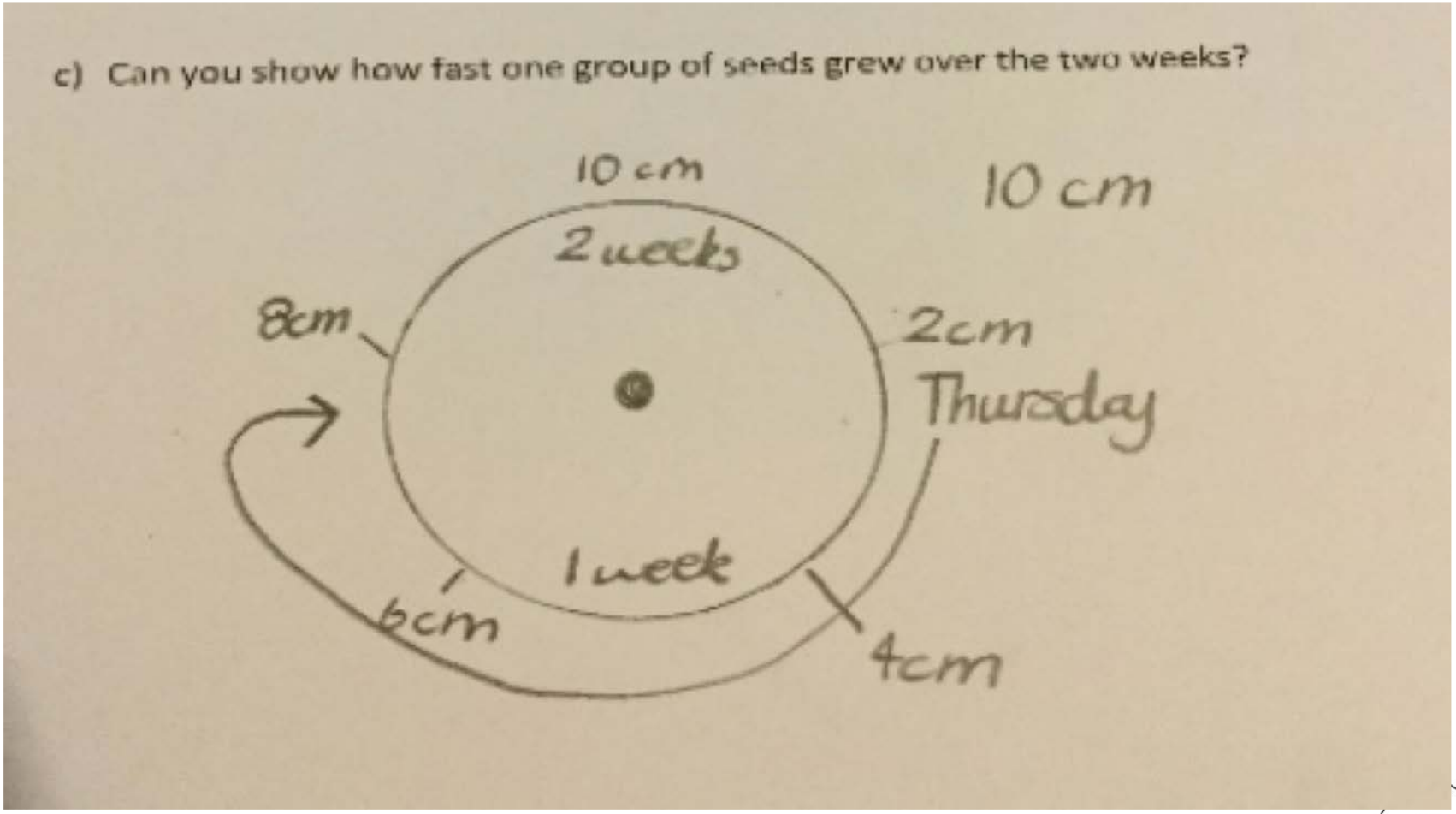
4 3 3

b) Could you show the differences in growth of the seeds in a different way?

Yes

c) Can you show how fast one group of seeds grew over the two weeks?




c) Can you show how fast one group of seeds grew over the two weeks?
10 cm
10 cm
2 weeks
8cm
2cm
Thursday
1 week
6cm
4cm

Mechanistic Reasoning in School Science Topics

Krist, Schwarz & Reiser (2018)

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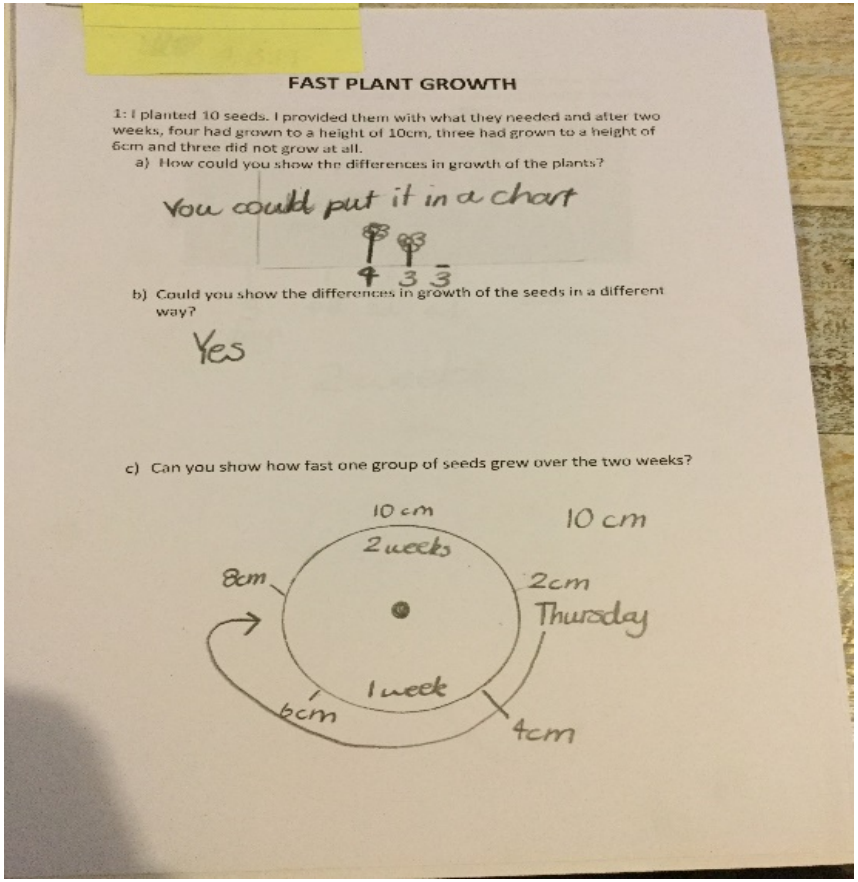
TABLE 3
Summary of Essential Epistemic Heuristics for Mechanistic Reasoning

Heuristic	*Use Across Science Content Areas*
Heuristic 1: Multiple scalar levels Considering the scalar level below that of the observed phenomenon	• Concrete entities, such as particles • Abstract entities, such as energy
Heuristic 2a: Identifying factors Identifying the things that need to be reasoned about	• Entities, either concrete or abstract • System relationships, made up of entities and behaviors • Properties of entities or of systems
Heuristic 2b: Unpacking factors Characterizing the factors' behaviors, interactions, and effects	• Behaviors and interactions between entities • System transitions: the effect of system relationships on system properties • Bounded effects: the differential effect of properties on entity behavior or on system relationships
Heuristic 3: Linking Coordinating how the unpacked factors give rise to the observed phenomenon	• Connections between observed phenomenon and factors at the level below • Aggregating connections over time and/or space

Ella's responses to a representational challenge



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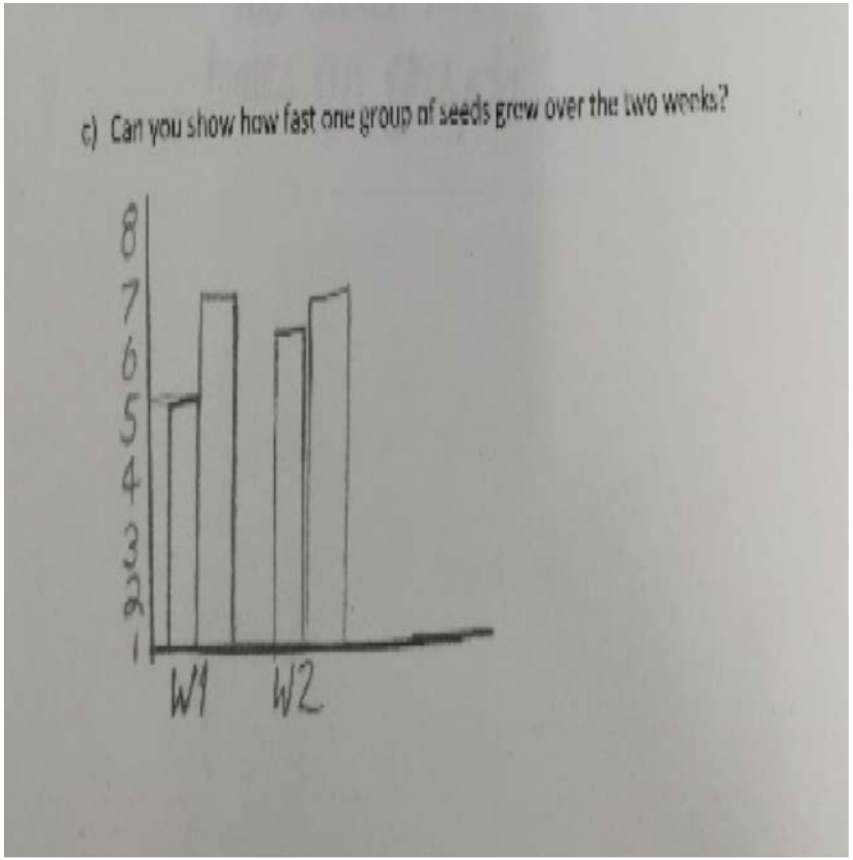
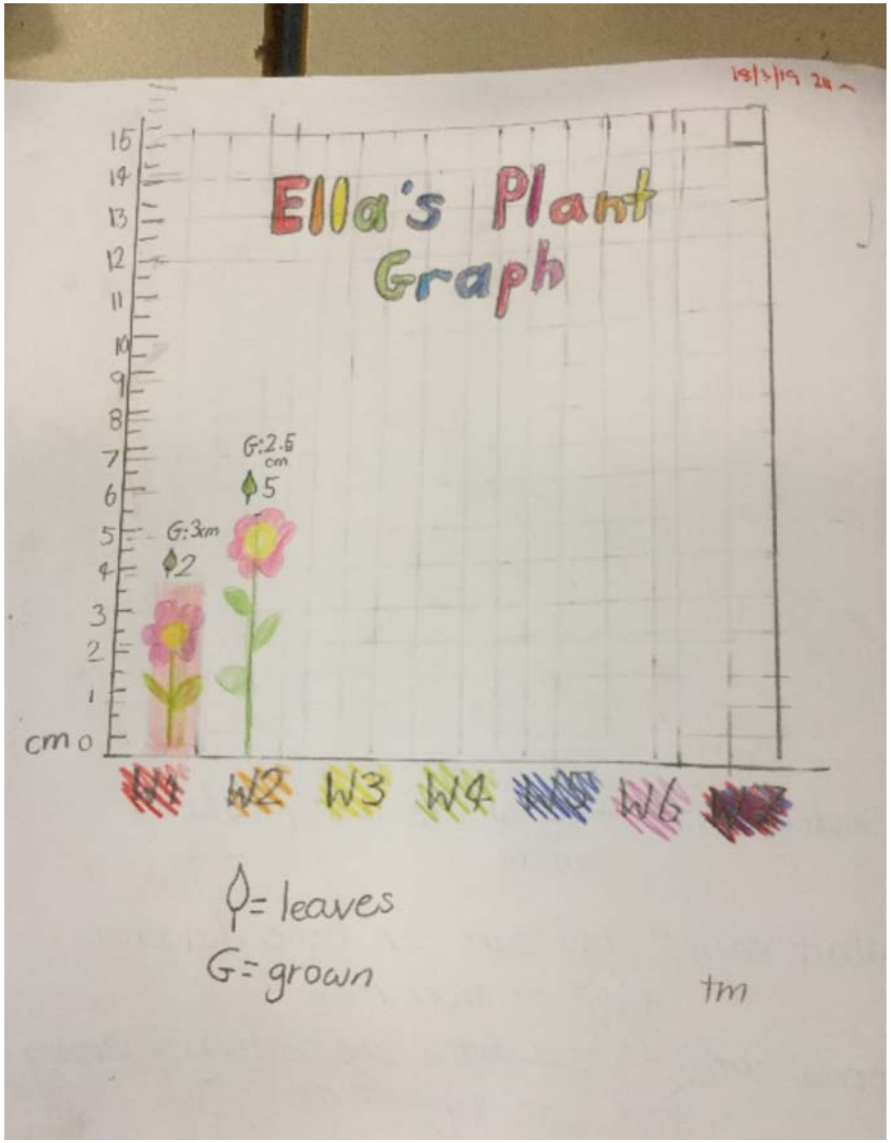
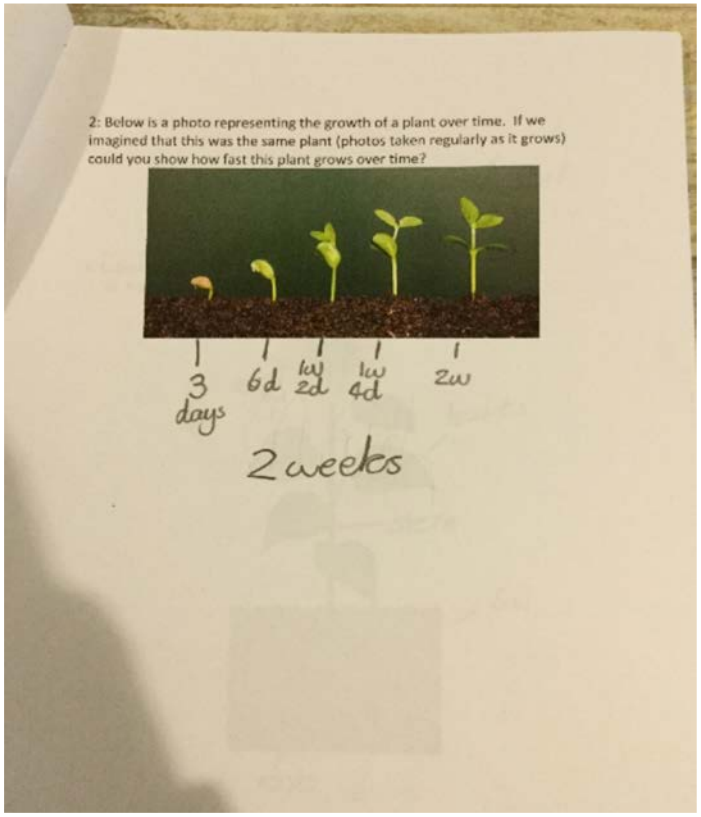
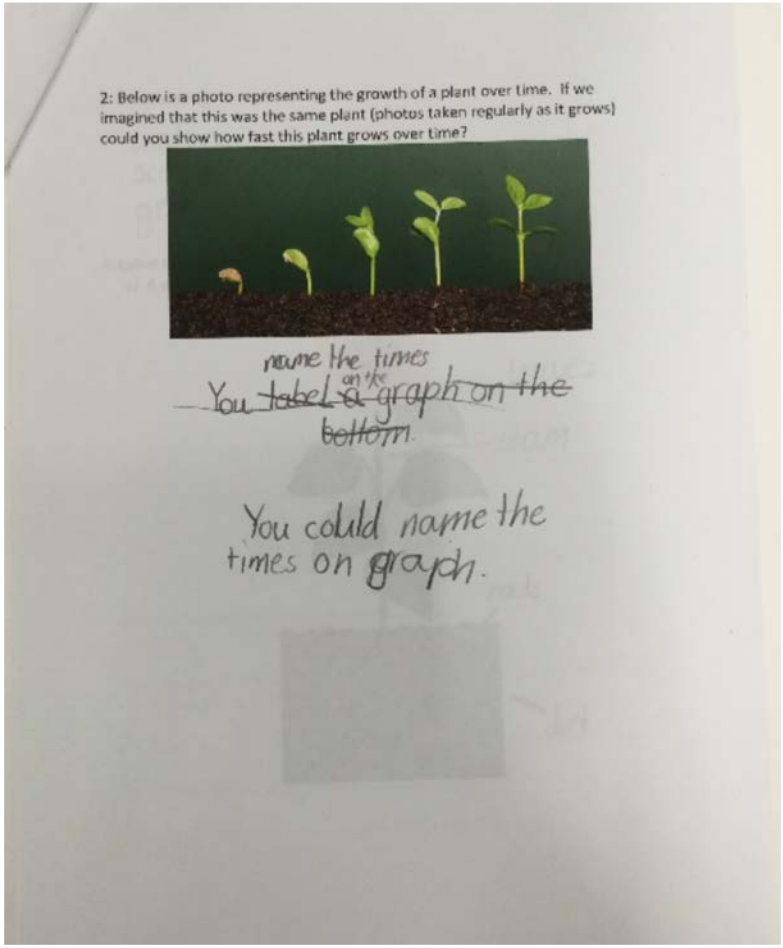


Ella’s plant graph



Pre- and post-test





Researching Creative and Critical Thinking

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Ongoing Methodological Questions

1. What are necessary pre-conditions for students to engage in science disciplinary creativity?

2. How should the teacher both nurture this creativity and guide students towards disciplinary representational conventions?

3. What should teachers view as productive student creativity in this subject, and on what basis?

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