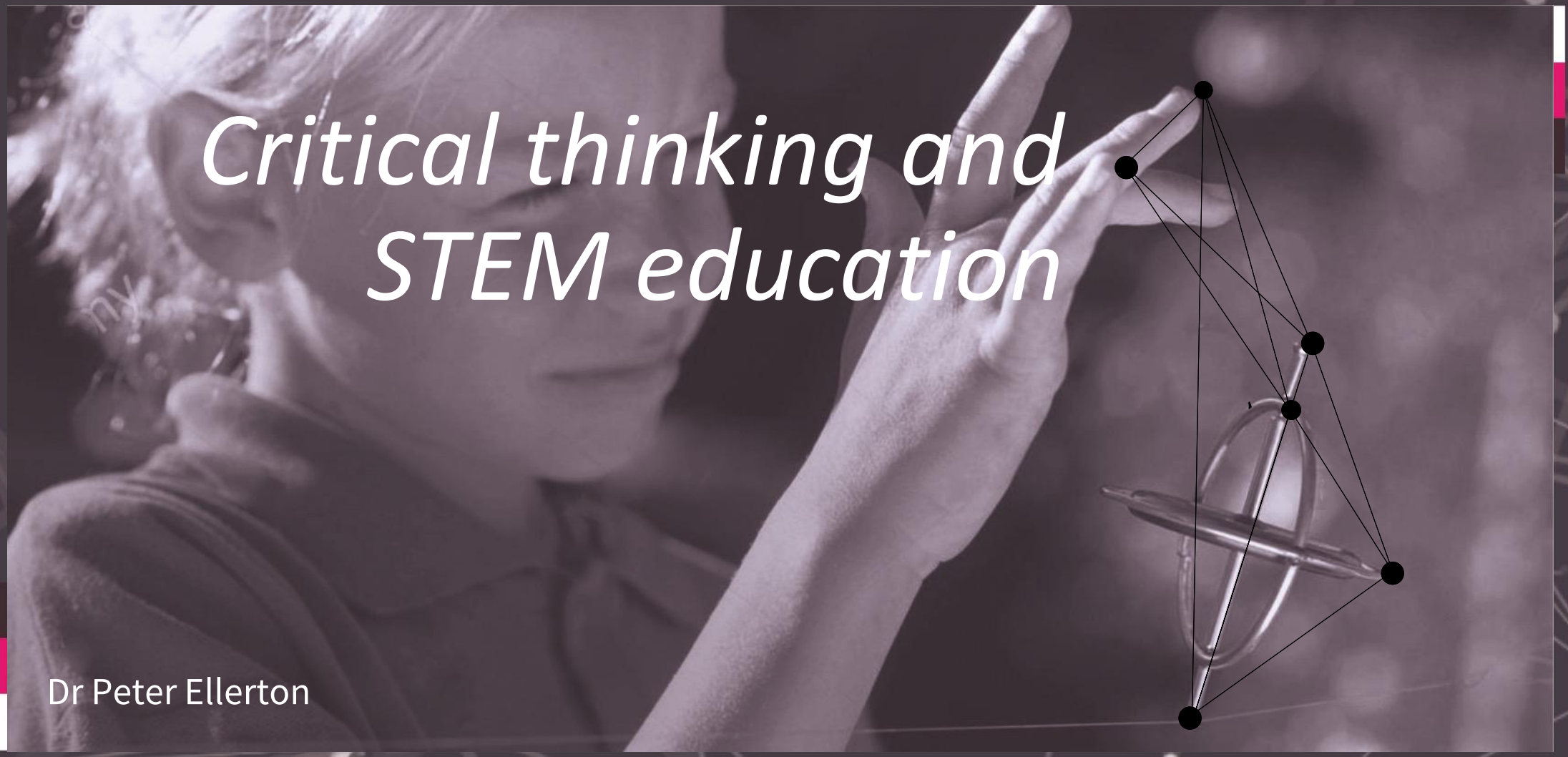
Critical thinking and STEM education



Dr Peter Ellerton

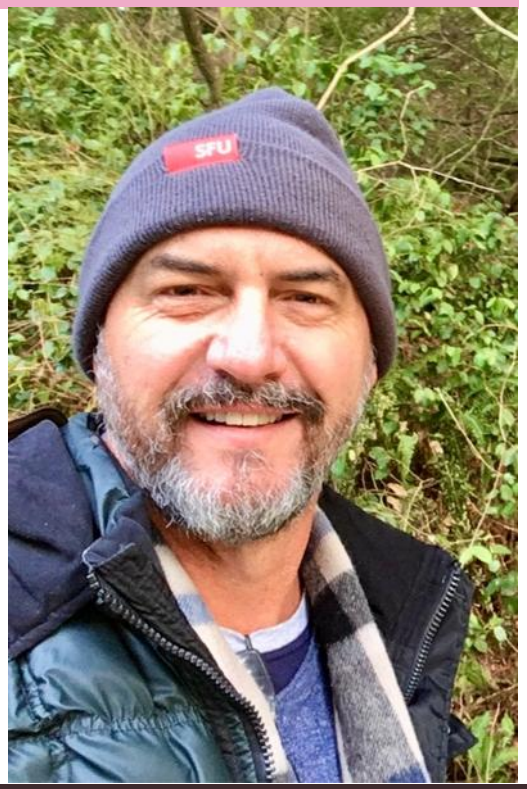
+ DR PETER ELLERTON +

Affiliations and research focus

- Curriculum Director, University of Queensland Critical Thinking Project
- Senior lecturer in Philosophy, Affiliate Academic in Education
- Senior Research Fellow, Centre for Critical and Creative Thinking
- Fellow of the Rationalist Society of Australia

Research focus

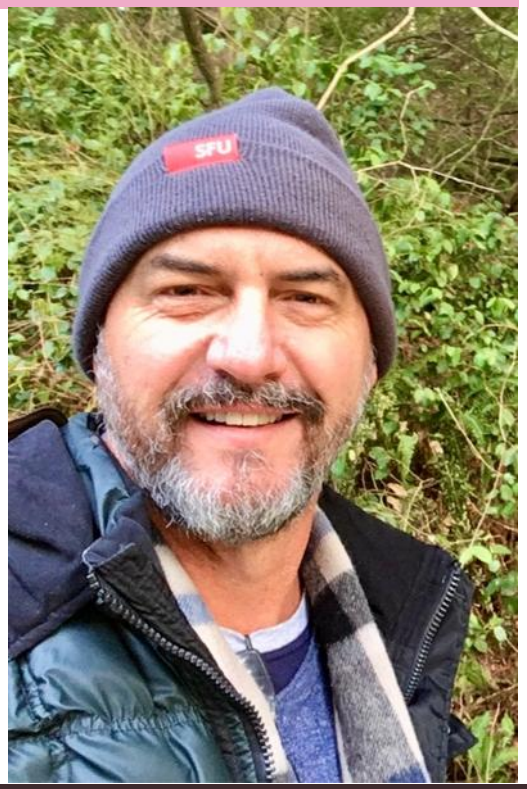
Teaching critical thinking, Public reasoning, Public understanding of science, Collaborative reasoning

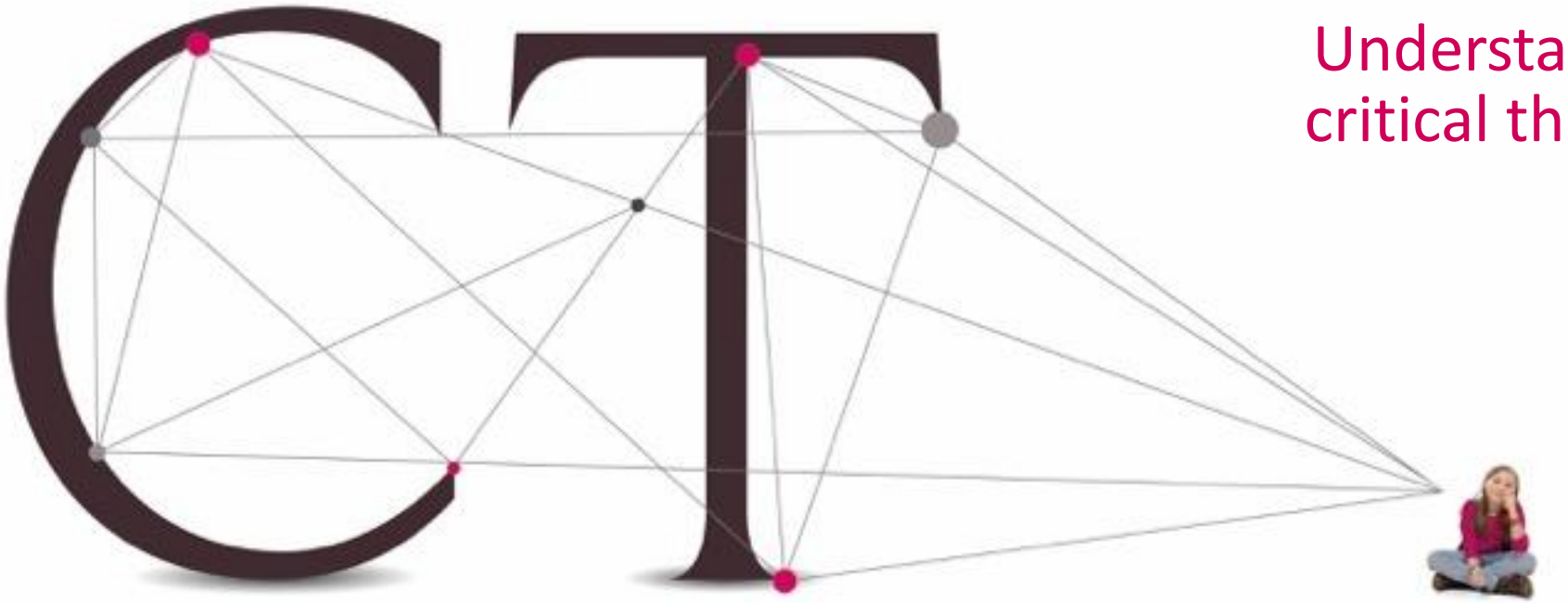


+ DR PETER ELLERTON +

Consultancy

- Queensland Policy Service
- Australian Federal Police
- NSW Ombudsman
- European Commission Joint Research Centre
- Department of Defence
- Brisbane City Council
- Queensland Coordinator General
- Australian Curriculum and Assessment Authority
- NSW Department of Education
- Queensland Curriculum and Assessment Authority





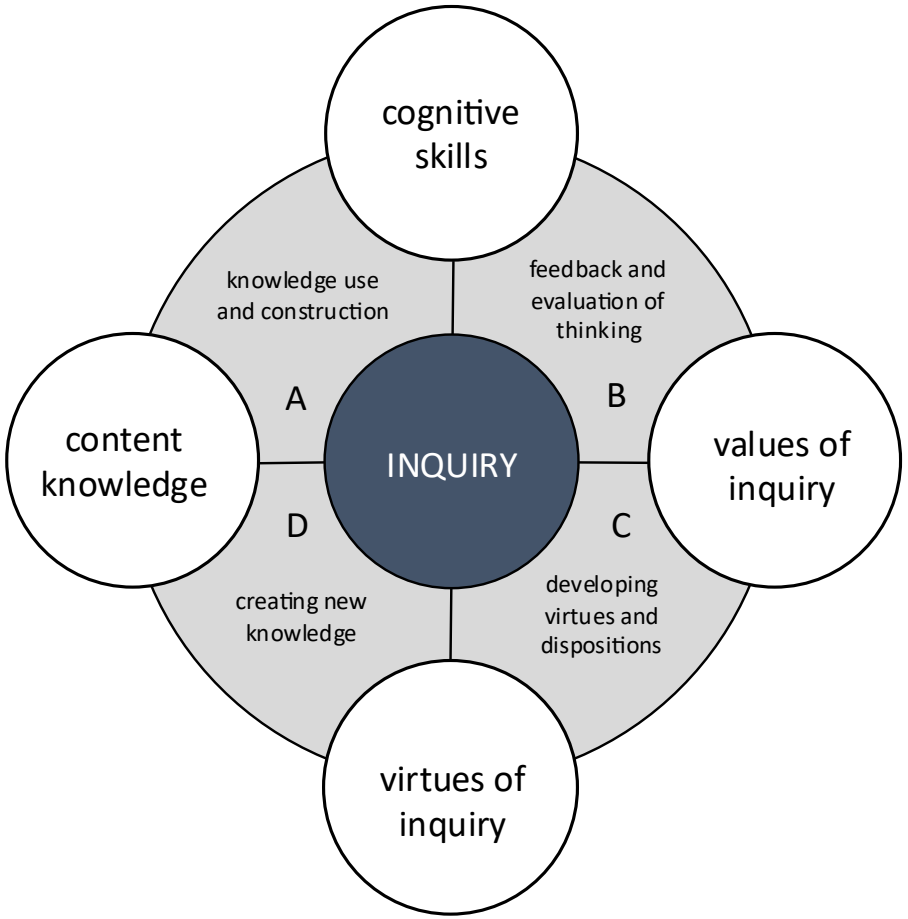
Understanding critical thinking

We are drowning in information, but clarity is rare.

Education’s role is to teach students how to navigate uncertainty and think critically, not just consume and respond.

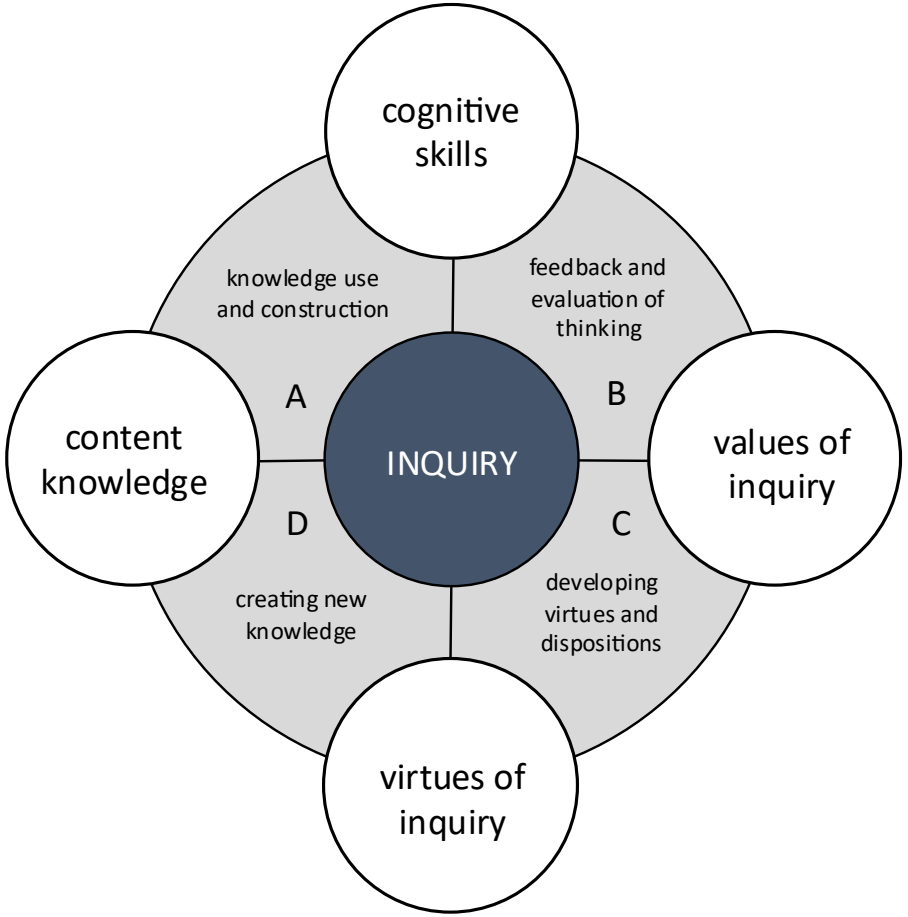
People must not just be informed, they must have agency.

UQ Critical Thinking Project Thinking Schools Network (TSN)



- Over 400 Schools, Universities and other institutions
- Over 5000 Educators
- Pacific Partnership: ULCA and Pepperdine universities, California; Simon Fraser University, British Columbia
- Australia, Singapore, South Africa, Belgium, USA, Canada
- Strong research output

Pedagogical expertise in Teaching for Thinking



Content Knowledge: discipline area, year level, curriculum based

Cognitive skills: things we do with knowledge (analyse, justify, evaluate, explain, etc.)

Values of inquiry: things we value in good inquiry/thinking (clarity, accuracy, precision, relevance, significance, breadth, depth, coherence, etc.)

Virtues of inquiry: things we value in effective inquirers/knowledge makers (resilience, open-minded, curious, persistent, humility, etc.)

Inquiry: the opportunity to use and develop cognitive skills and inquiry values and virtues

Did the dingo go around the goanna?

Pedagogical Imperative #1

Focus on student thinking

Inquiry is the means of production of knowledge

Three key questions in the classroom

1. How do you know students are *thinking* in your classroom?

2. How do you *plan* for that thinking to occur with the same *precision* and *intentionality* that you use for planning content?

3. How do you give students feedback on the *quality* of their thinking?


Explicit focus on content knowledge
Explicit focus on student thinking

The idea that deep and lasting learning is a product of thinking provides a powerful case for the teaching of thinking. Indeed, we venture that the true promise of the teaching of thinking will not be realized until learning to think and thinking to learn merge seamlessly.

Ritchart & Perkins

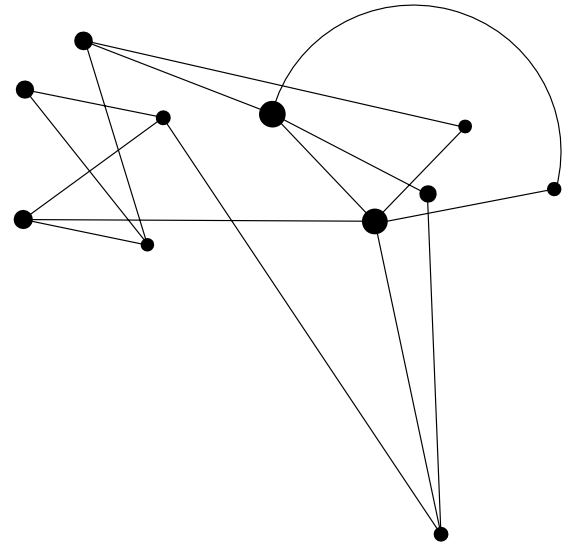
Thinking is the method of intelligent learning

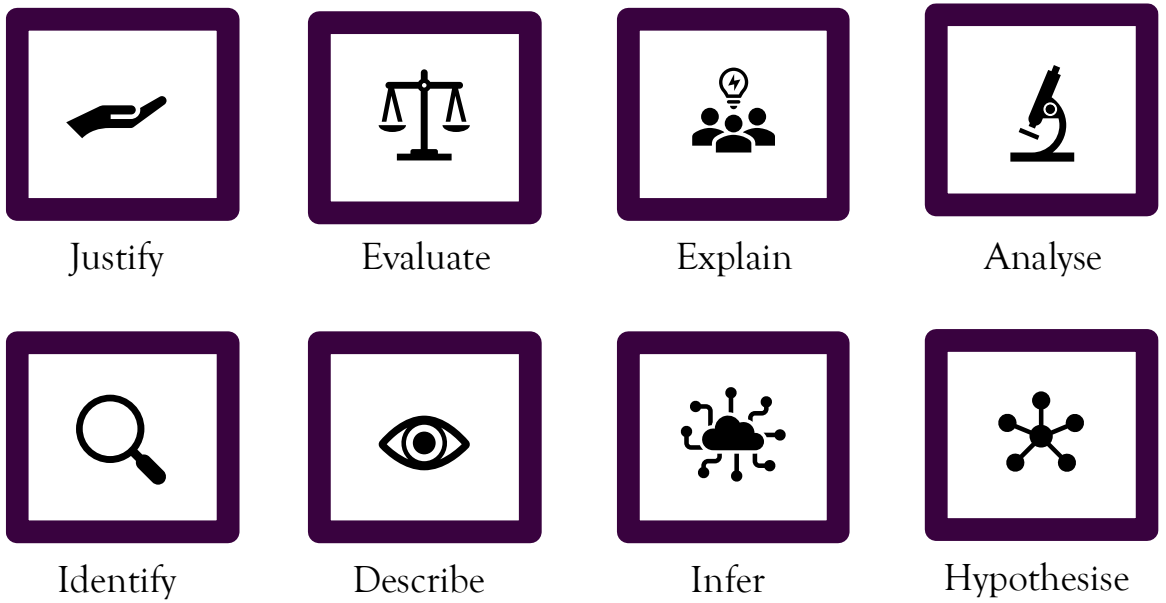
John Dewey

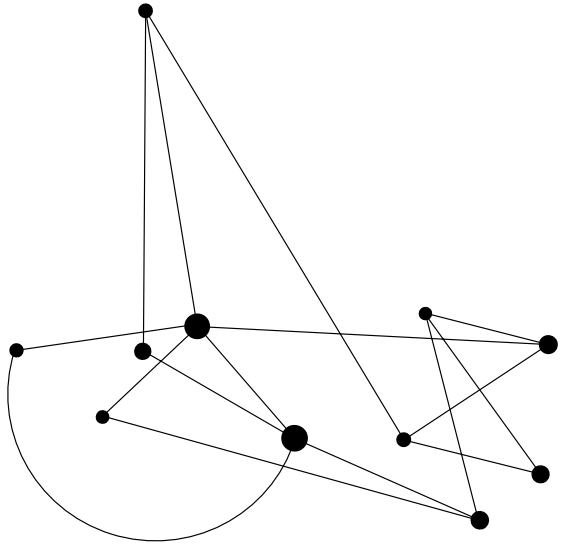
Connecting thinking and learning

Rethinking cognitive skills

What do you want your students to do when they….







What do you expect students to *do* when they analyse?

ANALYSE
JUSTIFY
EVALUATE
EXPLAIN

What do you expect students to *do* when they justify?

ANALYSE
JUSTIFY
EVALUATE
EXPLAIN

What do you expect students to *do* when they evaluate?

ANALYSE
JUSTIFY
EVALUATE
EXPLAIN

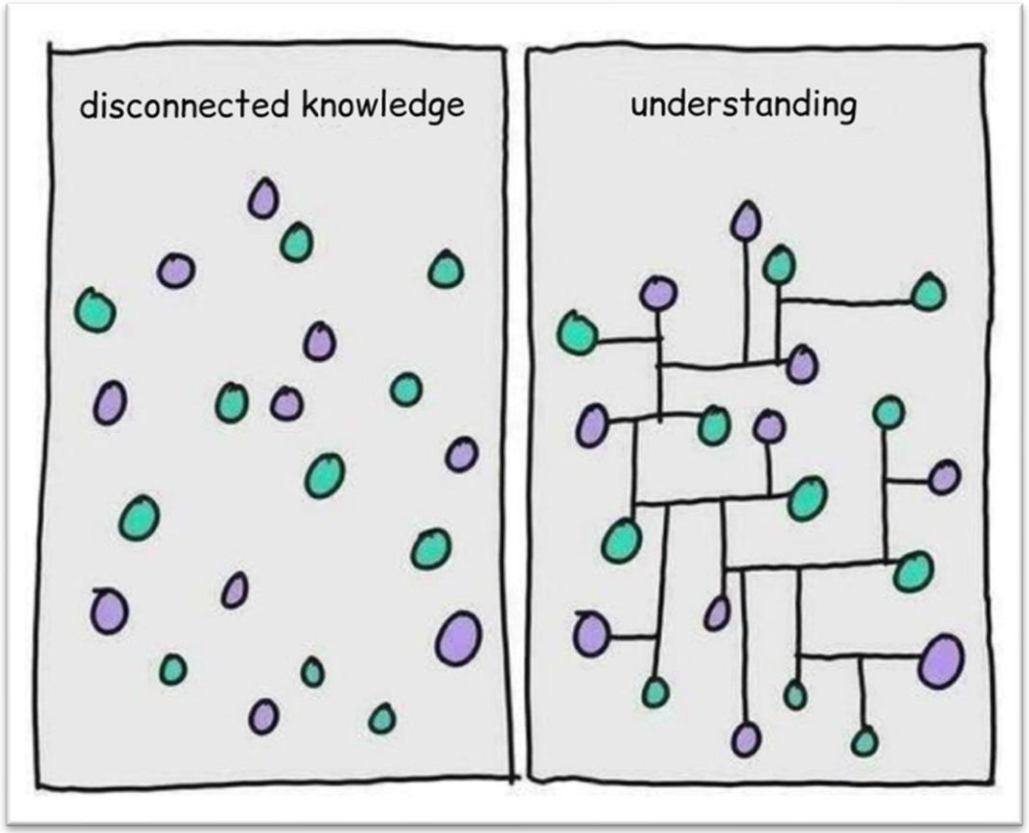
What do you expect students to *do* when they explain?

ANALYSE
JUSTIFY
EVALUATE
EXPLAIN

~~What do you expect students to do when they explain?~~

What is the difference between ‘explain’ and ‘describe’?

ANALYSE
JUSTIFY
EVALUATE
EXPLAIN



ANALYSE
JUSTIFY
EVALUATE
EXPLAIN

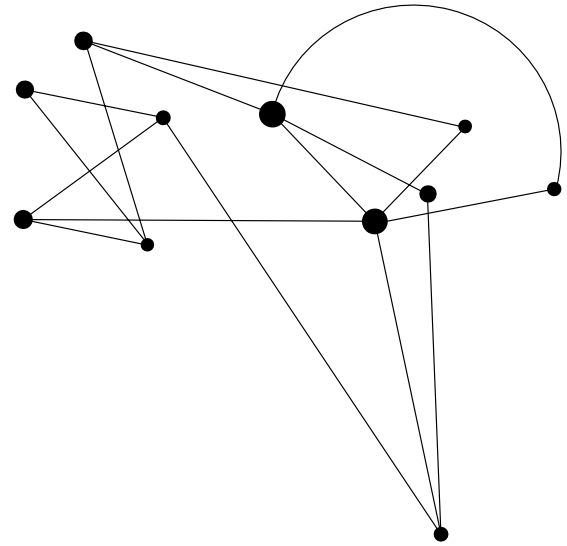
Things that are cognitive skills

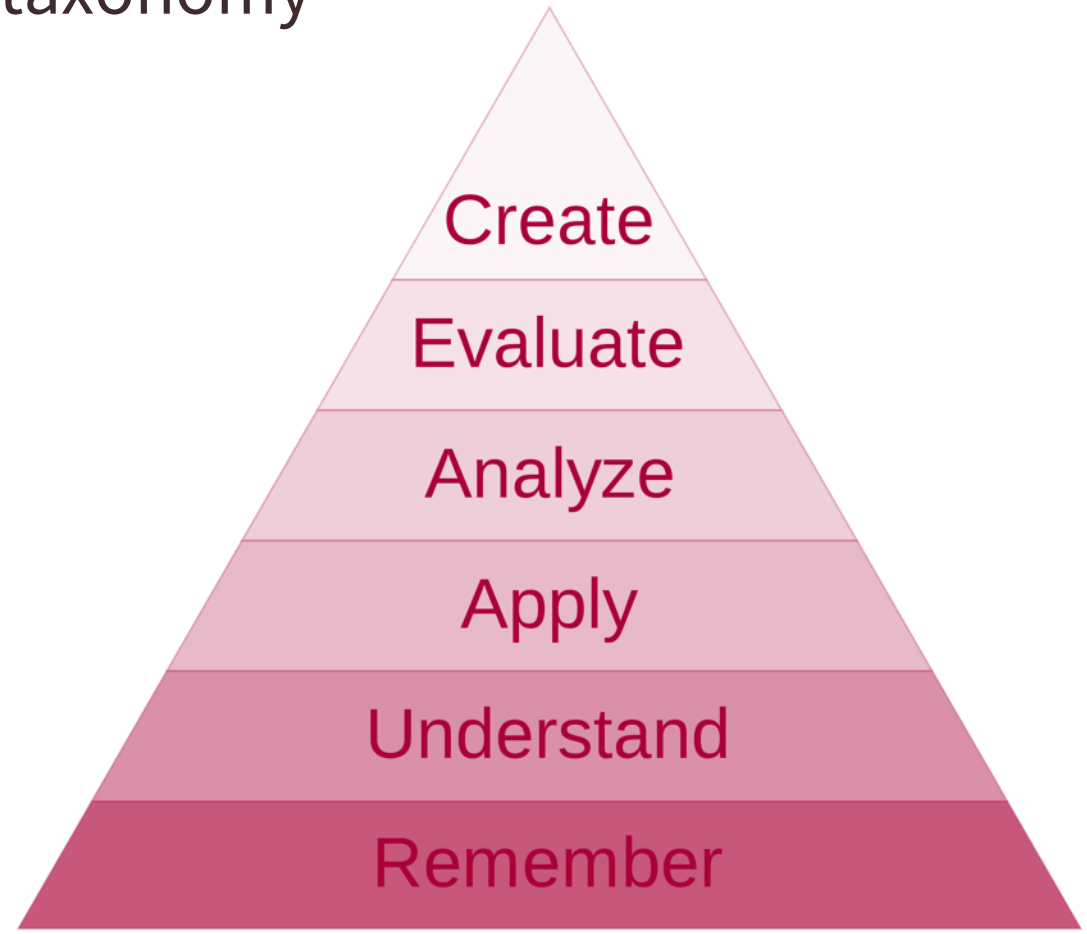
ANALYSE
JUSTIFY
EVALUATE
EXPLAIN

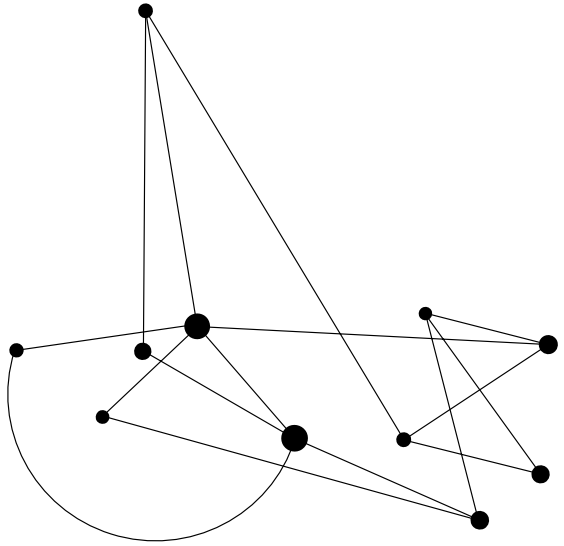
Things that are not cognitive skills

SNORING
UNDERSTANDING
BANANAS

Beyond Bloom’s taxonomy

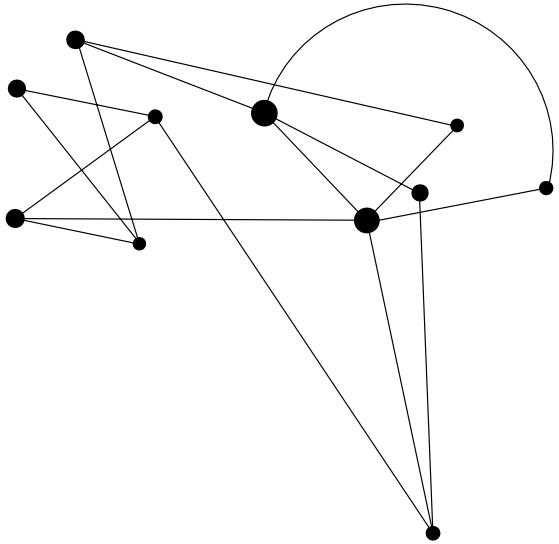


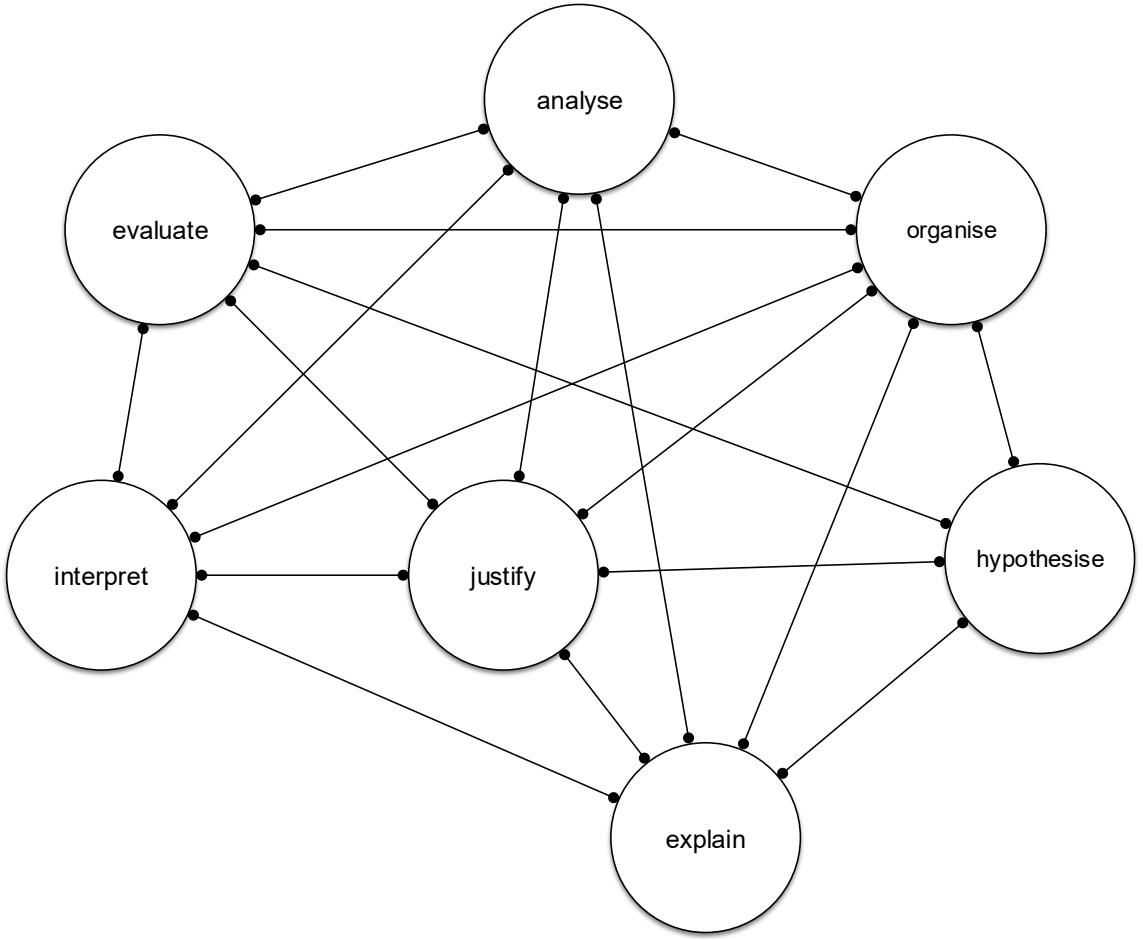


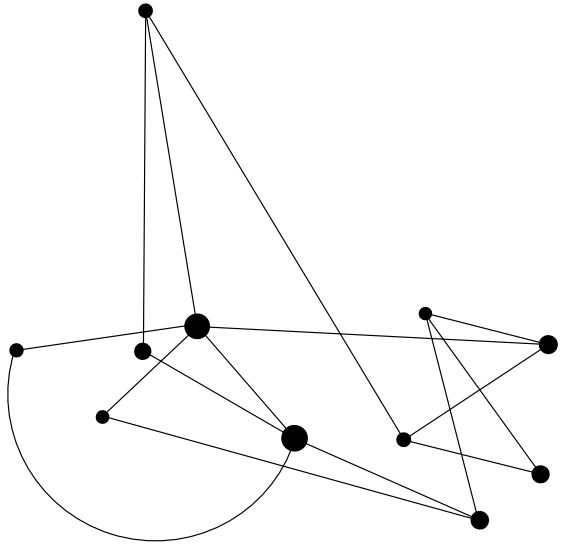


The problems with Bloom's Taxonomy were indirectly acknowledged by its authors. This is evidenced in their discussion of analysis: "It is probably more defensible educationally to consider analysis as an aid to fuller comprehension (a lower-class level) or as a prelude to an evaluation of the material" . The authors also acknowledged problems with the taxonomy's structure in their discussion of evaluation: "Although evaluation is placed last in the cognitive domain because it is regarded as requiring to some extent all the other categories of behavior, it is not necessarily the last step in thinking or problem solving. It is quite possible that the evaluation process will in some cases be the prelude to the acquisition of new knowledge, a new attempt at comprehension or application, or a new analysis and synthesis" (p.185). In summary, the hierarchical structure of Bloom's Taxonomy simply did not hold together well from logical or empirical perspectives. (Marzano, 2006, pp.8–9)

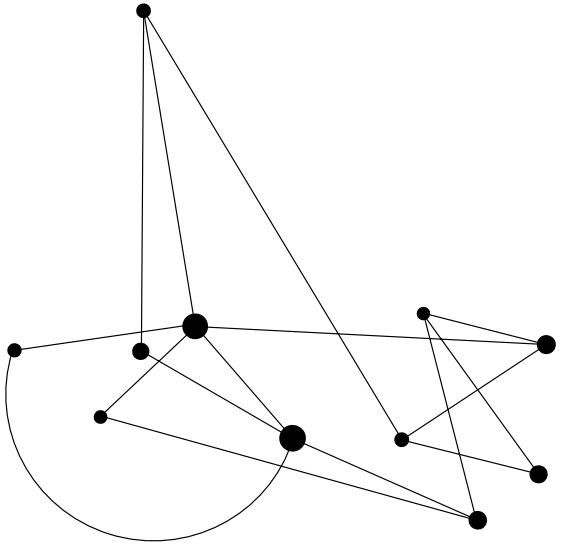
The Cognitive Web model

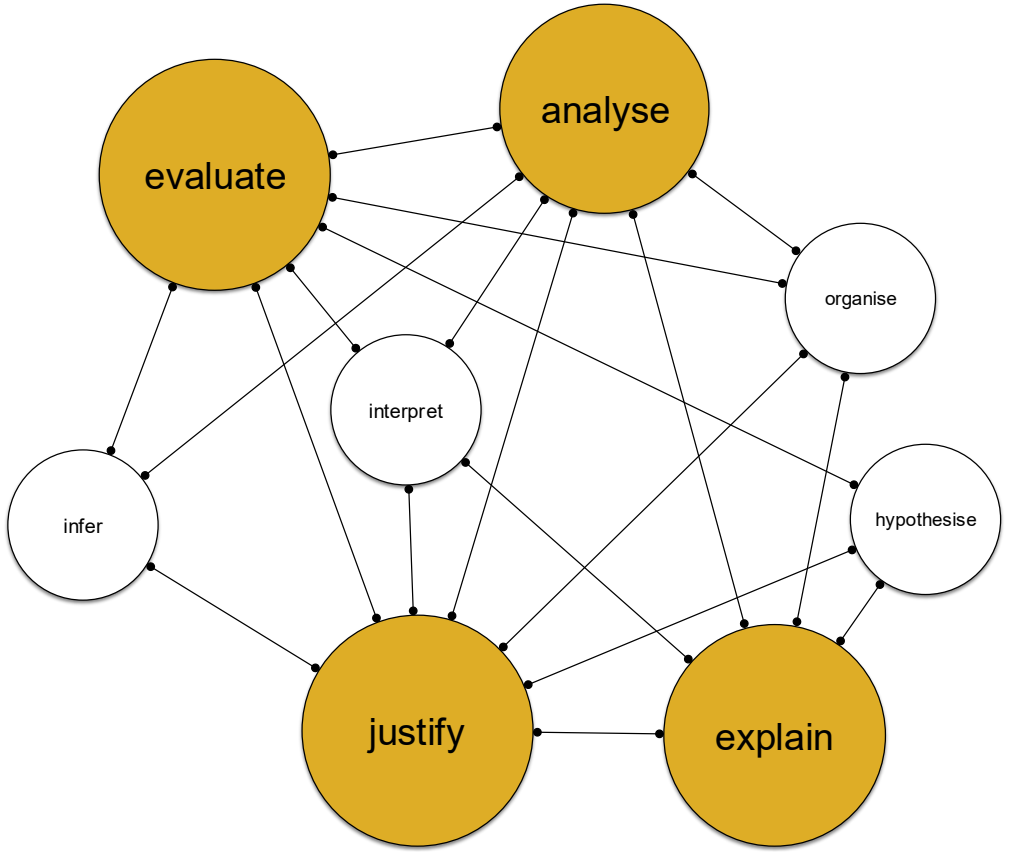


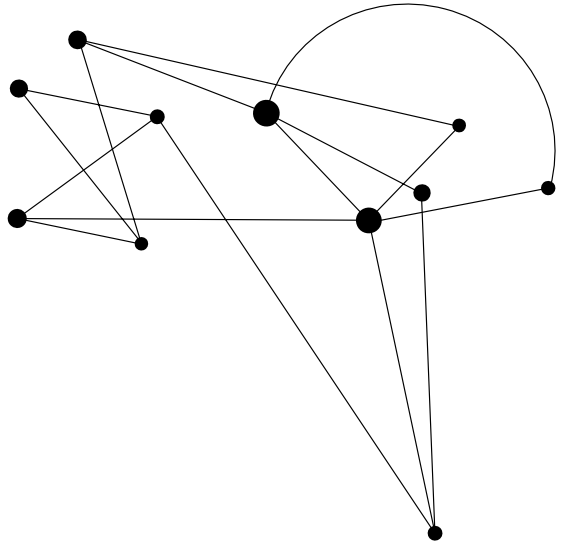


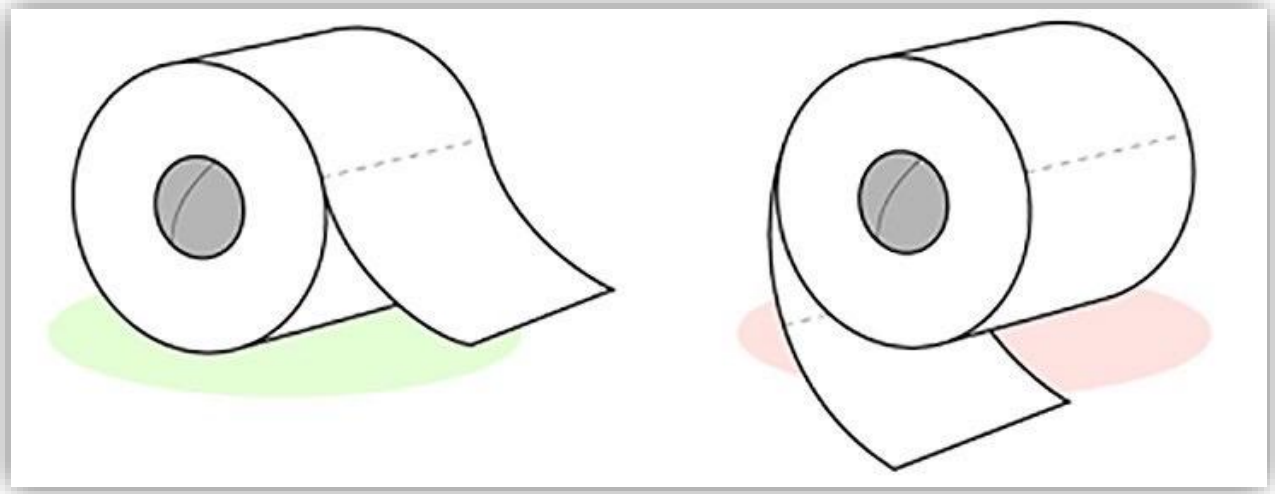


The Golden Tetrad of cognitive skills





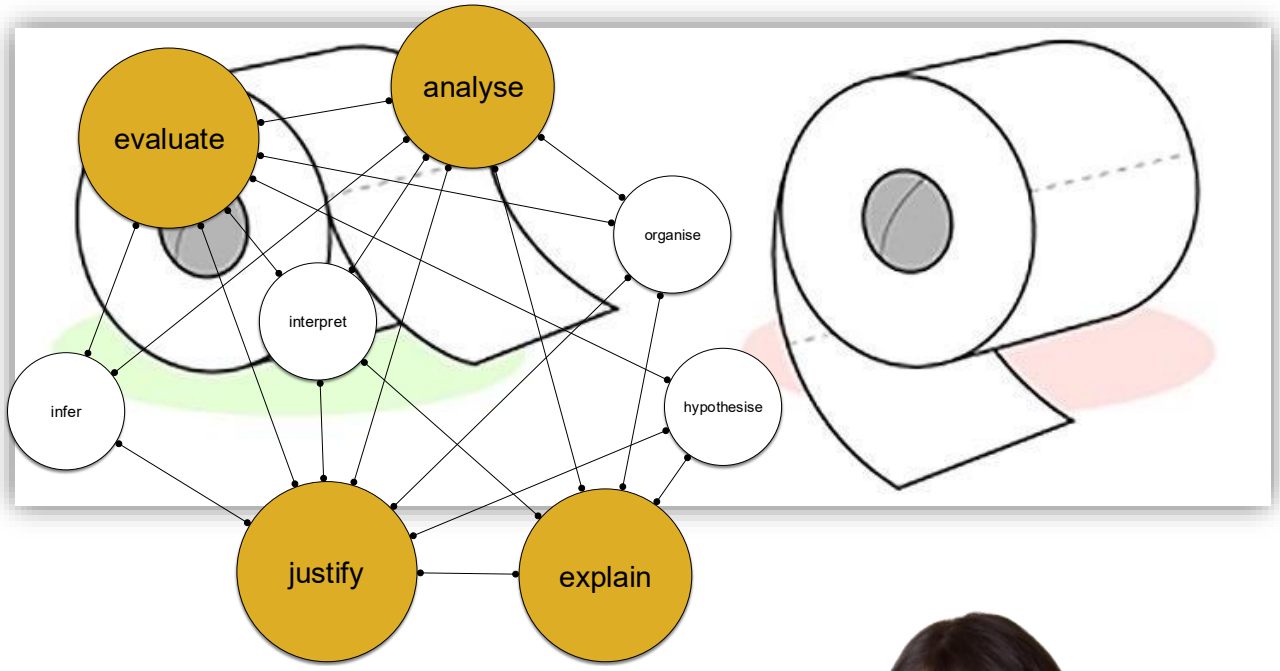




the Golden Tetrad

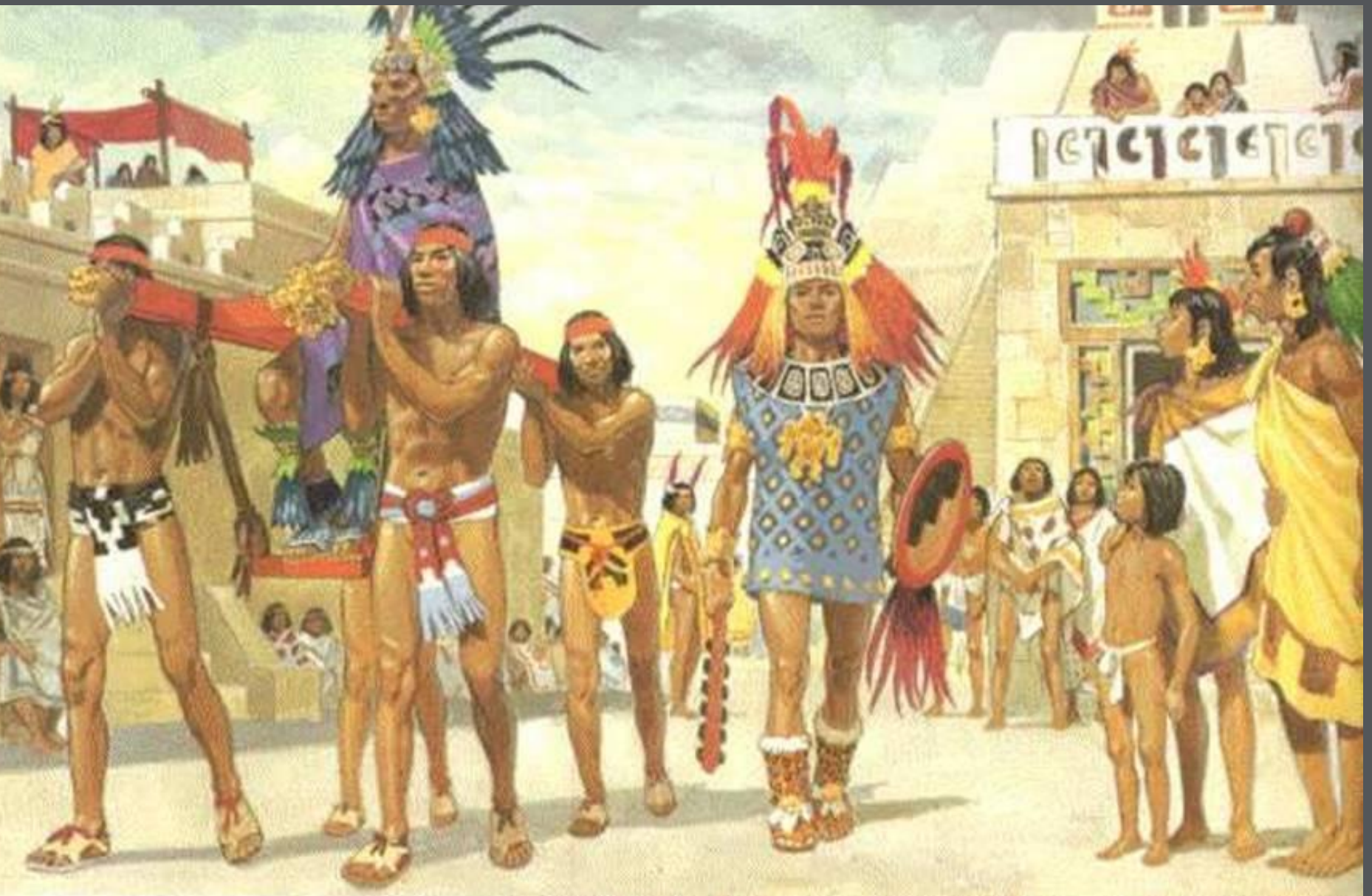
discuss…

the Golden Tetrad



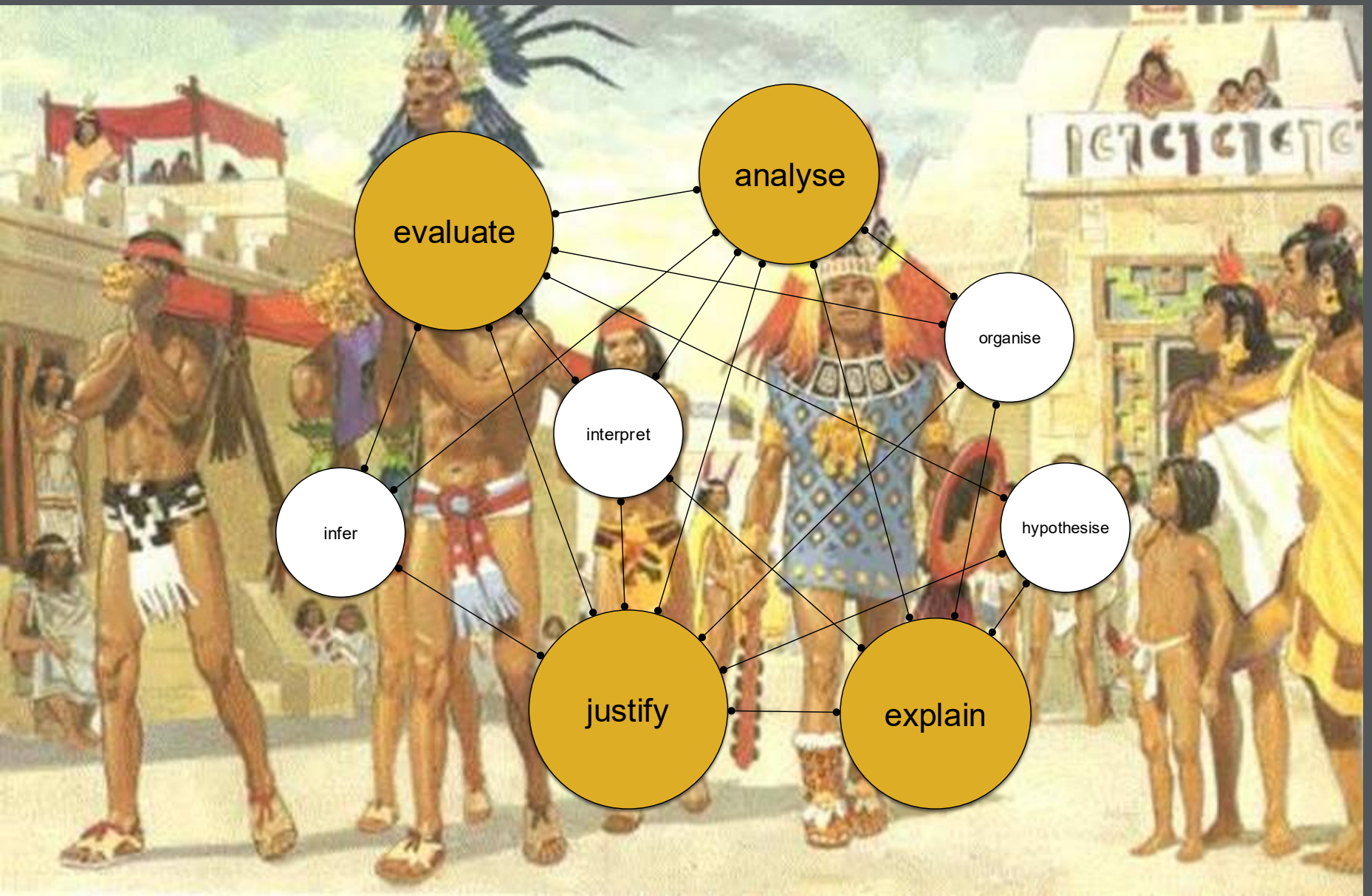
discuss…

What can you infer about this civilization?



Analyse
Construct
Evaluate
Explain
Generate
Hypothesise
Identify
Infer
Interpret
Justify
Organise
Speculate
State
Synthesise

What can you infer about this civilization?



Analyse
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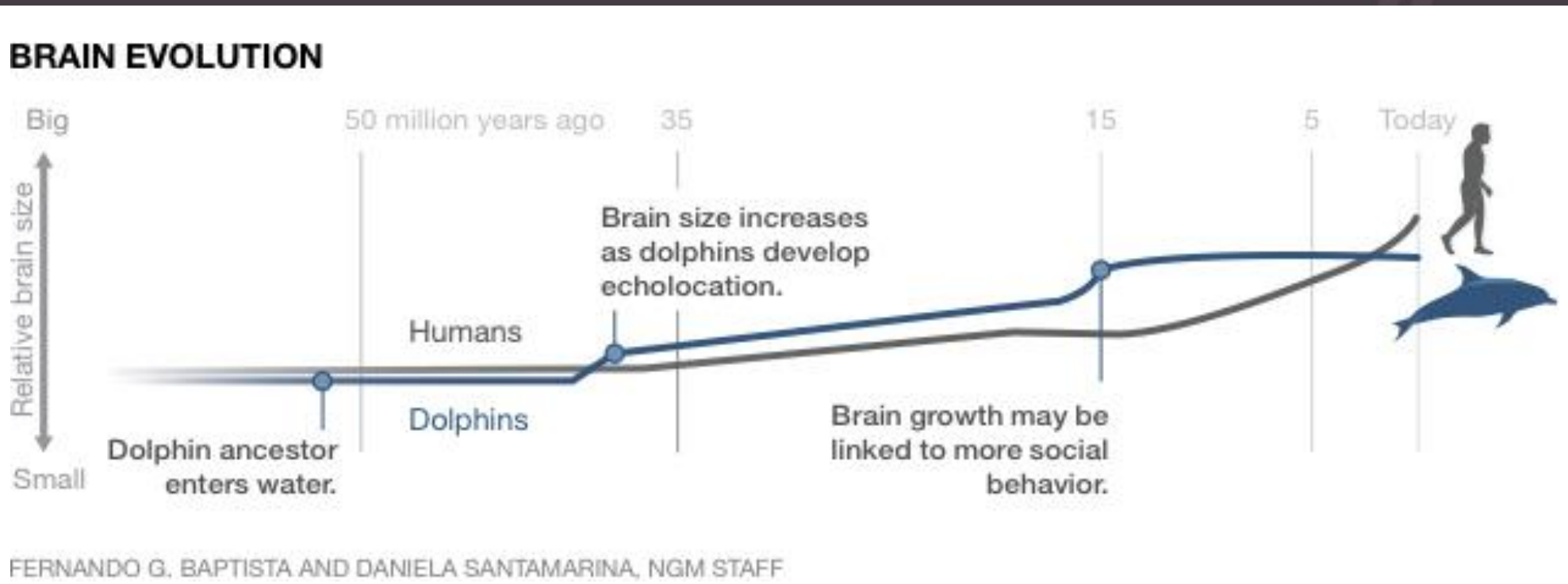
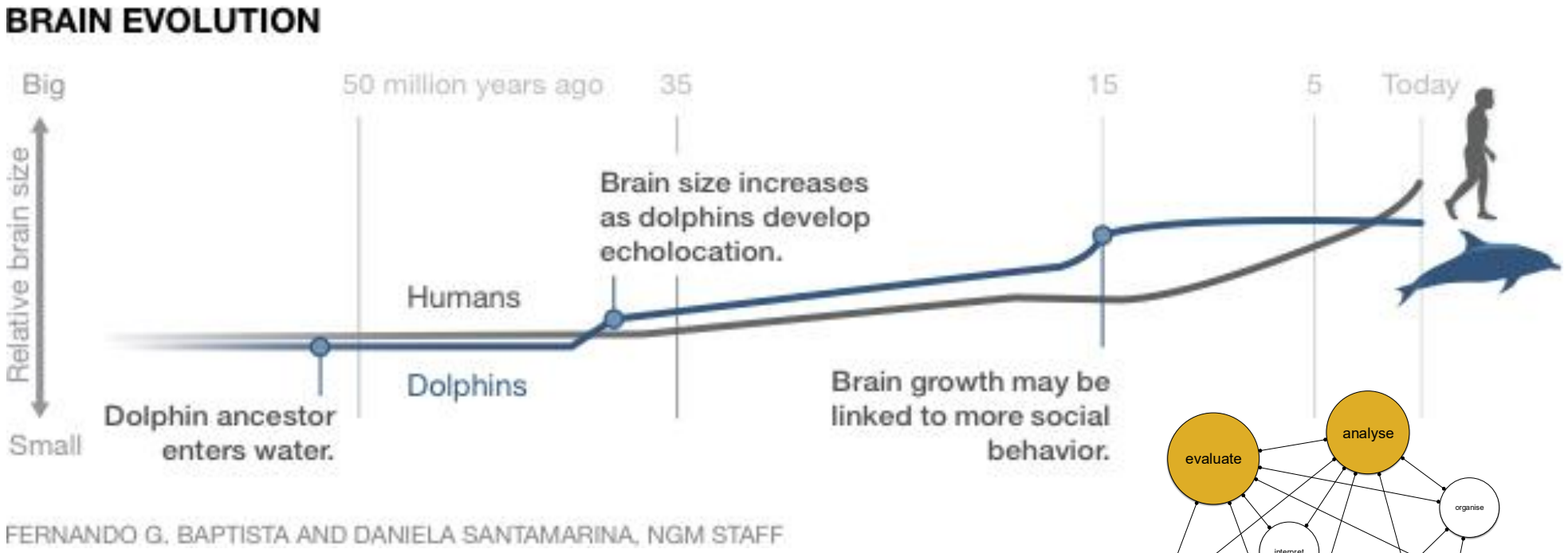
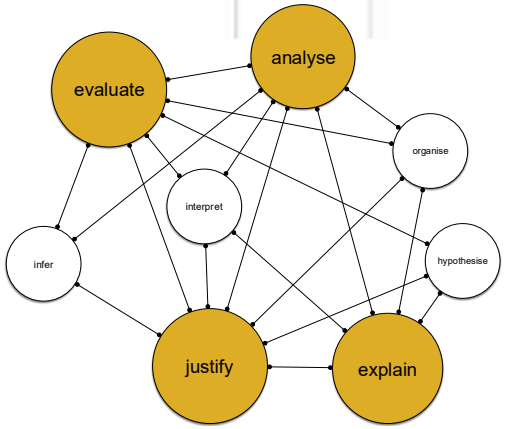


What might explain the closing of the gap between dolphin and human brain size from 15 M years ago?

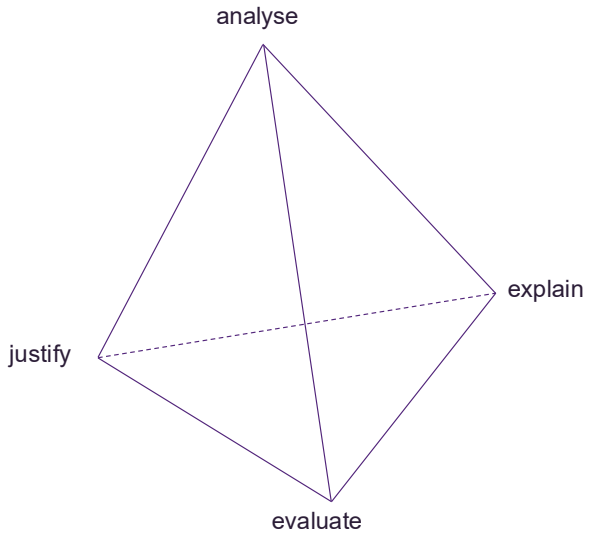




What might explain the closing of the gap between dolphin and human brain size from 15 M years ago?

Some relationships between the cognitions

- Some relationships between the cognitions:
- The extent of understanding and quality of explanation is a function of the depth and breadth of analysis.
- The strength of a justification is often a function of the quality of analysis.
- The persuasiveness of a justification is often a function of the quality of explanation
- The criteria of evaluation are used to justify and explain decisions (and themselves require justification).



The Golden Tetrad and Problem Based Learning

Open Access Article

Principles of Problem-Based Learning (PBL) in STEM Education: Using Expert Wisdom and Research to Frame Educational Practice

by Kathy Smith [1], Nicoleta Maynard [2], Amanda Berry [1,*], Tanya Stephenson [1,†], Tabetha Spiteri [1], Deborah Corrigan [1], Jennifer Mansfield [1], Peter Ellerton [3] and Timothy Smith [3]

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[2] Faculty of Engineering, Monash University, Clayton 3800, Australia
[3] Faculty of Humanities and Social Sciences, The University of Queensland, Brisbane 4072, Australia
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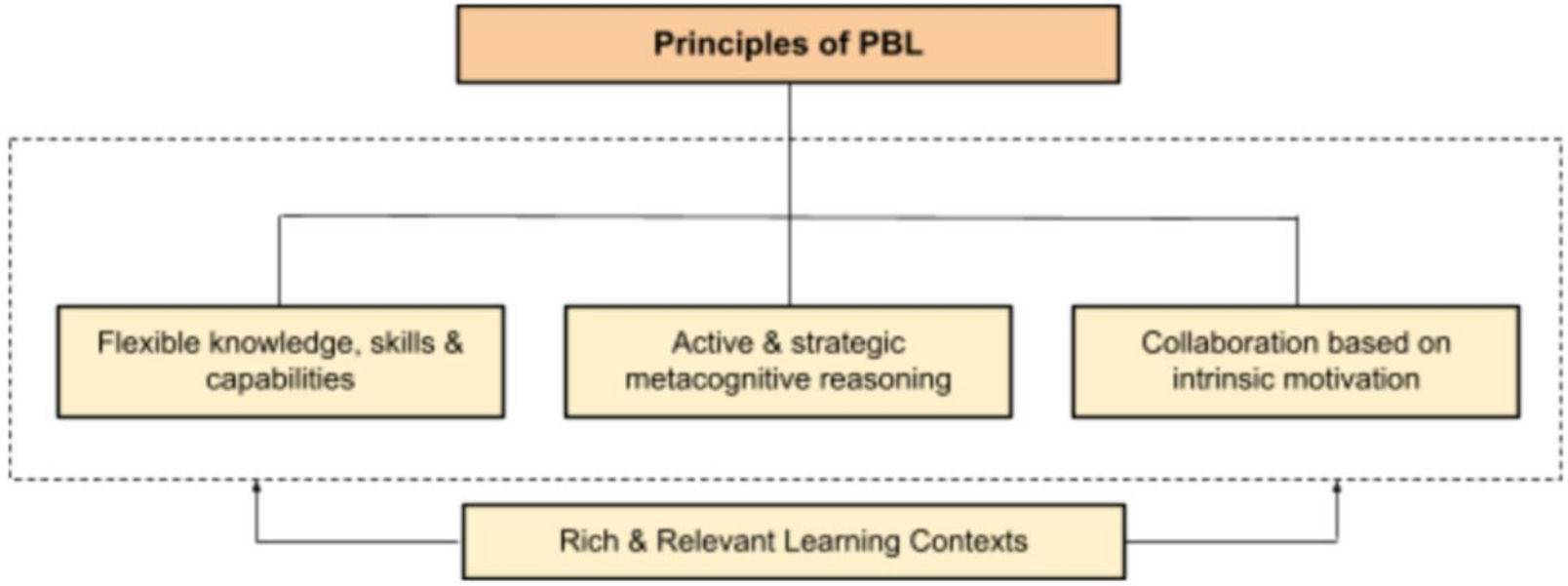
† Current address: Australian Council of Educational Research, Camberwell 3124, Australia.

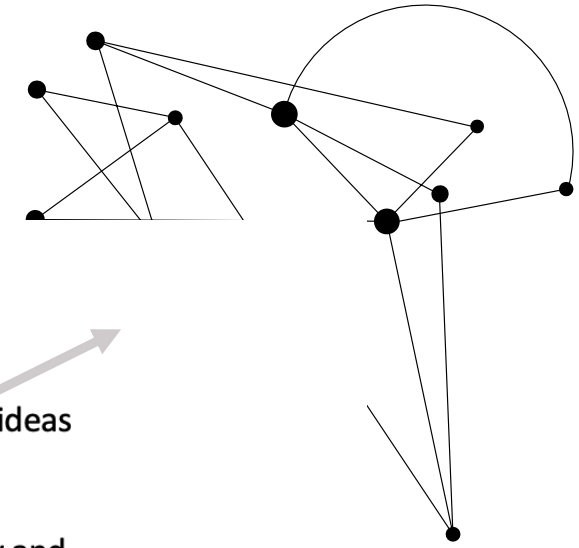
Educ. Sci. **2022**, *12*(10), 728; **https://doi.org/10.3390/educsci12100728**

Submission received: 30 August 2022 / Revised: 13 October 2022 / Accepted: 15 October 2022 / Published: 21 October 2022

(This article belongs to the Special Issue **Project-Based and Problem-Based Instruction in STEM Classroom Environments**)


Principles of PBL
Flexible knowledge, skills & capabilities
Active & strategic metacognitive reasoning
Collaboration based on intrinsic motivation
Rich & Relevant Learning Contexts

Problem types and cognitive requirements



complex

- Use complex algorithms
- Recall, analyse, identify, explain
- Strategically deployed procedural knowledge
- Recognition of complex structures and concepts

- Justify, synthesise, evaluate
- Apply sophisticated and complex ideas and concepts
- Collaborate to frame and identify problems, develop lines of inquiry and test solutions

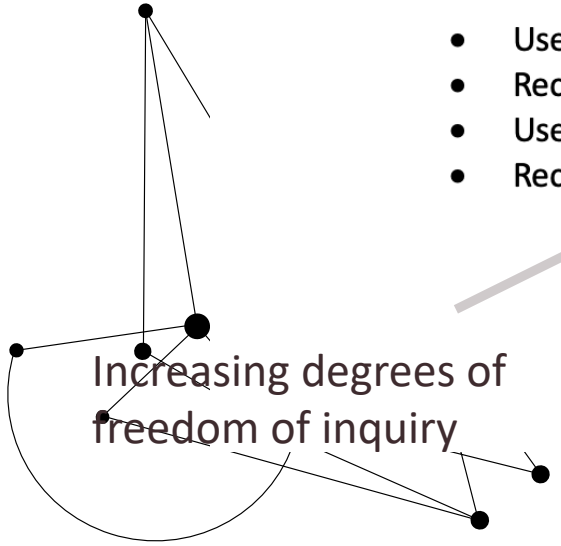
well-structured

ill-structured

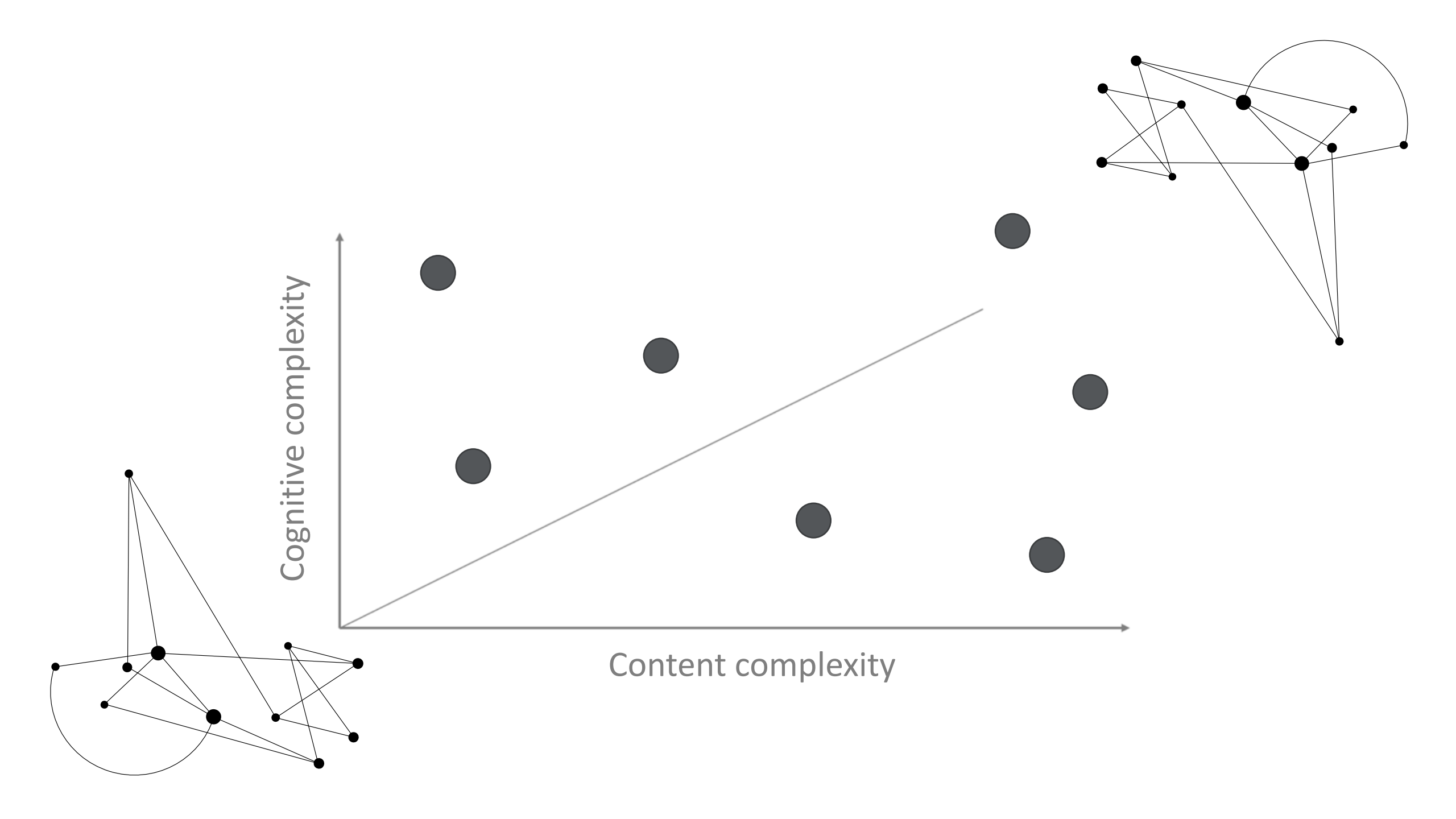
- Use basic algorithms
- Recall, identify
- Use rote learned procedural knowledge
- Recognise simple structures and concepts

- Analysis, identification, explanation
- Apply basic ideas and concepts
- Use existing knowledge to frame and identify problems, develop lines of inquiry and test solutions

simple



Increasing degrees of freedom of inquiry


Cognitive complexity
Content complexity


The more scalable, procedural and replicable education becomes, the easier it is done by AI.

Pedagogical Imperative #2

Provide feedback on student thinking

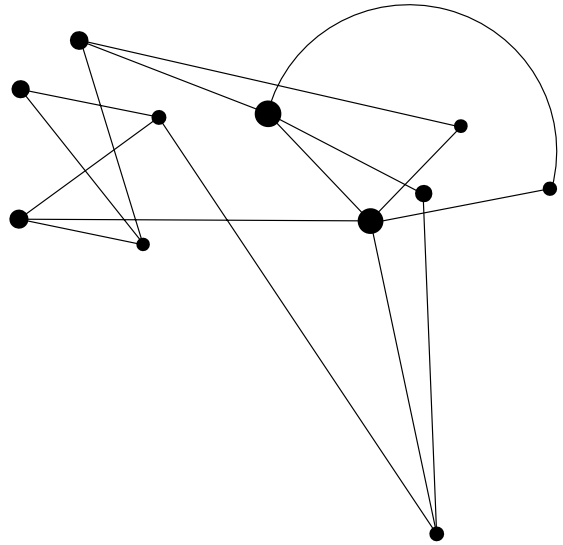
Explicitly address thinking using appropriate language and concepts

The values of inquiry

The root of the word *evaluate* is *value*. The values of inquiry represent those things we value in the act of inquiry and therefore in thinking, since thinking is inseparable from inquiry.

The values of inquiry provide criteria to evaluate the quality of our thinking.

Inquiry values



Clarity

Precision

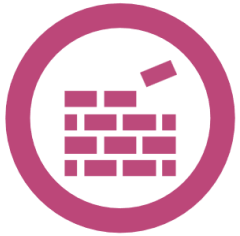
Breadth

Significance

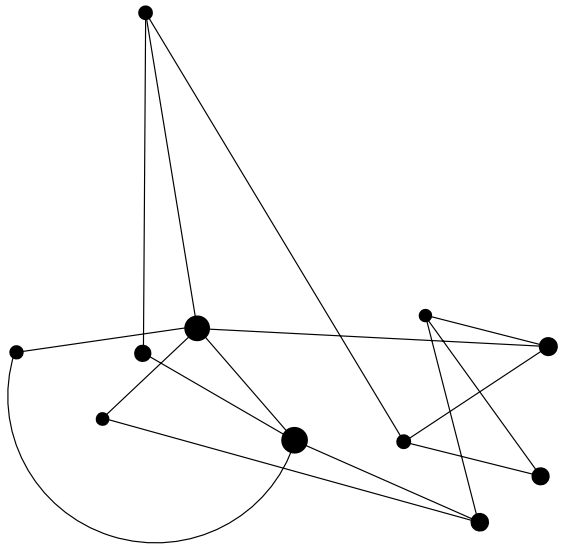
Accuracy

Depth

Relevance



Coherence



The Values of Inquiry: explanations and supporting questions

Dr Peter Ellerton, the University of Queensland. https://critical-thinking.project.uq.edu.au

"The values of inquiry represent things that we value in the act of inquiry and hence in thinking. They provide a language for providing feedback on the quality of student thinking and so help us to ***evaluate*** thinking."

Meaning		Questions	Associated terms
Clarity	When we communicate with clarity, we ensure that our audience can understand what we mean. We are making our points as clear as possible to others.	• Are your examples useful? • Is your argument structure clear? • Are your diagrams easy to understand? • Is your paragraph structure well-developed? • Are your words well-defined and unambiguous?	Interpretation Meaning Shared understanding
Accuracy	When we communicate with accuracy, we seek to represent all information correctly and closely aligned with its original meaning.	• Is your argument sound? • Are your claims justified? • Is what you are saying true? • Have you represented ideas faithfully? • How could people check on your claim?	Truth Measurement Correctness
Precision	When we communicate with precision we are specific and intentional with our language and terminology in order to remove any potential for misunderstanding in meaning.	• Is your attention to detail sufficient? • Have you used technical terms appropriately? • Have you quantified your information where appropriate? • Are bullet points categorically distinct from each other? • Have you identified areas of vagueness or ambiguity ?	Exactitude Care
Depth	When we communicate with depth we provide detailed information and explanations to thoroughly develop our points.	• Are the complexities of the issue sufficiently described? • Are your analogies and generalisations well-justified? • Do you arguments consider premises that are themselves conclusions? • Have the problematic aspects of the issue been identified and dealt with?	Scope Perspectives Alternatives Detail Thoroughness
Breadth	When we communicate with breadth we aim to cover a diverse range of directly relevant content and considerations in relation to the topic. This helps us to ensure that we do not ignore any key components.	• Have you considered alternative perspectives? • Have you represented a broad range of alternative views? • Why have you preferred one perspective over another? • Have you sought out others for the purpose of testing your ideas?	Thoughtfulness Focus Empathy
Relevance	When we communicate with relevance we choose information that relates directly to the points we are developing. We do not incorporate any distracting or useless information that may confuse our audience.	• Have you focussed on the point at issue? • Have you selected information supporting the topic? • Is distracting or unhelpful information minimised? • Have you been able to identify why information is relevant? • Have you justified why your selection of material is relevant?	Importance Impact Discernment
Significance	When we communicate with significance we discuss the most important information that is related to the given topic. This allows us to focus on key ideas rather than distracting the audience with tangential information.	• Have you avoided superficial issues or arguments? • Have you identified and developed your core ideas? • Have you identified the most meaningful aspects? • Have you focused on substantive aspects?	Connections Understanding Application
Coherence	When we communicate with coherence we structure our arguments in a way that makes logical sense. Each point builds towards the overall intended meaning of the piece.	• Have you avoided using logical fallacies? • Have you avoided contradicting statements? • Are your ideas developed in logical manner? • Do all your premises support your conclusions? • Have you used transition phrases to identify logical progressions?	Logic Consistency Integration Argument Justification Persuasiveness

Values of inquiry modified from Intellectual Standards of Elder, L. and R. Paul (2001), Kuhn,T. SSR (1970), Lipman, M. TE (2003).

Meaning		Questions	Associated terms
 Clarity	When we communicate with clarity, we ensure that our audience can understand what we mean. We are making our points as clear as possible to others.	• Are your examples useful? • Is your argument structure clear? • Are your diagrams easy to understand? • Is your paragraph structure well-developed? • Are your words well-defined and unambiguous?	Interpretation Meaning Shared understanding Truth Measurement Correctness Exactitude Care
 Accuracy	When we communicate with accuracy, we seek to represent all information correctly and closely aligned with its original meaning.	• Is your argument sound? • Are your claims justified? • Is what you are saying true? • Have you represented ideas faithfully? • How could people check on your claim?	
 Precision	When we communicate with precision we are specific and intentional with our language and terminology in order to remove any potential for misunderstanding in meaning.	• Is your attention to detail sufficient? • Have you used technical terms appropriately? • Have you quantified your information where appropriate? • Are bullet points categorically distinct from each other? • Have you identified areas of vagueness or ambiguity ?	

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Relevance

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- Have you identified the most meaningful aspects?
- Have you focused on substantive aspects?

Scope

Perspectives

Alternatives

Detail

Thoroughness

Thoughtfulness

Focus

Empathy

Importance

Impact

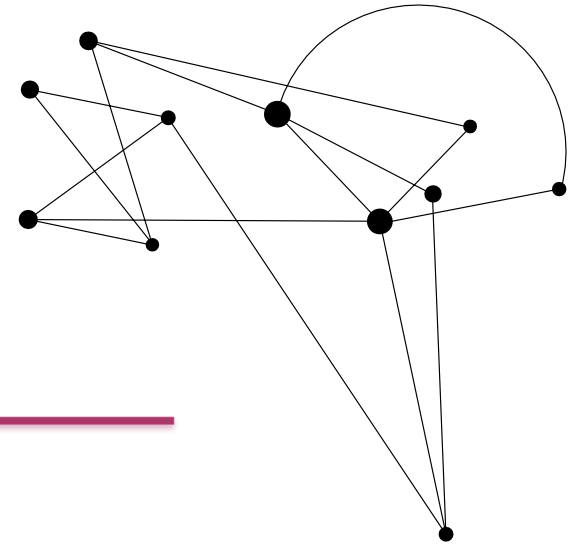
Discernment

Connections

Understanding

Application

The values of Inquiry act as feedback on cognitions

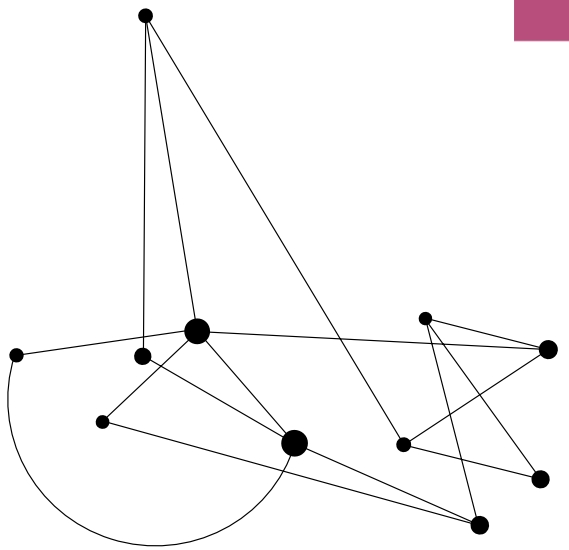


What do we *do* when we analyse?

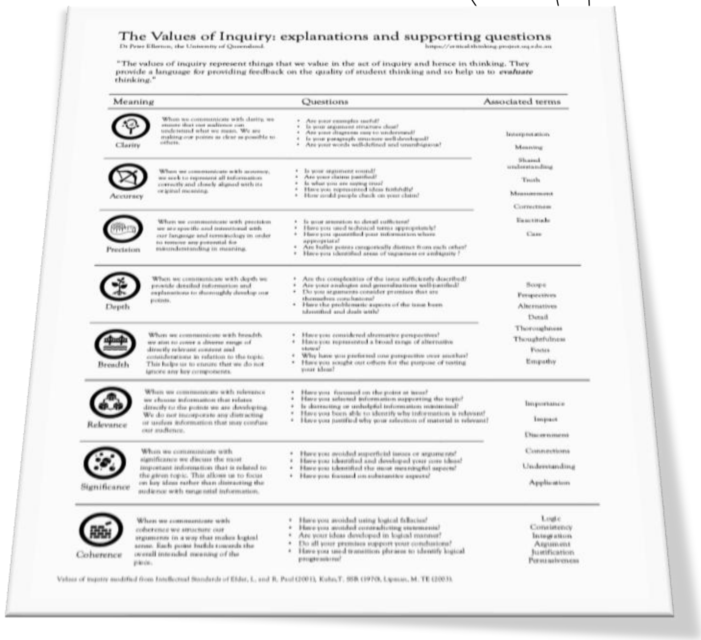
Breadth

Depth

Significance



Values of Inquiry poster



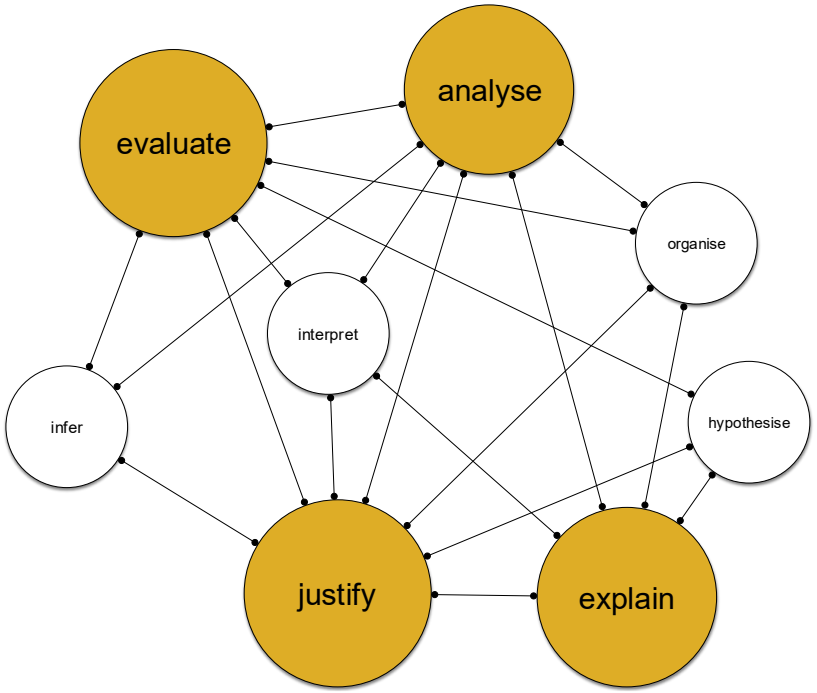
The Values of Inquiry: explanations and supporting questions

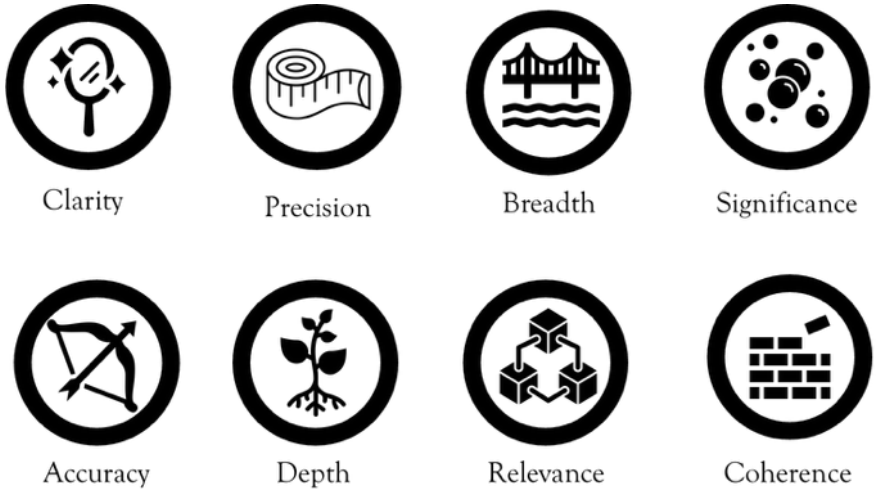
"The values of inquiry represent things that we value in the act of inquiry and hence in thinking. They provide a language for providing feedback on the quality of student thinking and so help us to *evaluate* thinking."

Meaning	Questions	Associated terms
Clarity	• Are your examples useful? • Is your argument structure clear? • Are your diagrams easy to understand? • Is your paragraph structure well-developed? • Are your words well-defined and unambiguous?	Interpretation Meaning Shared understanding Truth Measurement Correctness Exactitude Care
Accuracy	• Is your argument sound? • Are your claims justified? • Is what you are saying true? • Have you represented ideas faithfully? • How could people check on your claim?	
Precision	• Is your attention to detail sufficient? • Have you used technical terms appropriately? • Have you quantified your information where appropriate? • Are bullet points categorically distinct from each other? • Have you identified areas of vagueness or ambiguity?	
Depth	• Are the complexities of the issue sufficiently described? • Are your analogies and generalisations well-justified? • Do you arguments consider premises that are themselves conclusions? • Have the problematic aspects of the issue been identified and dealt with?	Scope Perspectives Alternatives Detail Thoroughness Thoughtfulness Focus Empathy
Breadth	• Have you considered alternative perspectives? • Have you represented a broad range of alternative views? • Why have you preferred one perspective over another? • Have you sought out others for the purpose of testing your ideas?	
Relevance	• Have you focused on the point at issue? • Have you selected information supporting the topic? • Is distracting or unhelpful information minimised? • Have you been able to identify why information is relevant? • Have you justified why your selection of material is relevant?	Importance Impact Discernment Connections Understanding Application
Significance	• Have you avoided superficial issues or arguments? • Have you identified and developed your core ideas? • Have you identified the most meaningful aspects? • Have you focused on substantive aspects?	
Coherence	• Have you avoided using logical fallacies? • Have you avoided contradicting statements? • Are your ideas developed in logical manner? • Do all your premises support your conclusions? • Have you used transition phrases to identify logical progressions?	Logic Consistency Integration Argument Justification Persuasiveness

https://critical-thinking.project.uq.edu.au/files/7212/VOI%20terms.pdf

The values are most effective when used as feedback on cognition





Pedagogical Imperative #3

Reason collaboratively

Reasoning is a social competence as much as an individual faculty

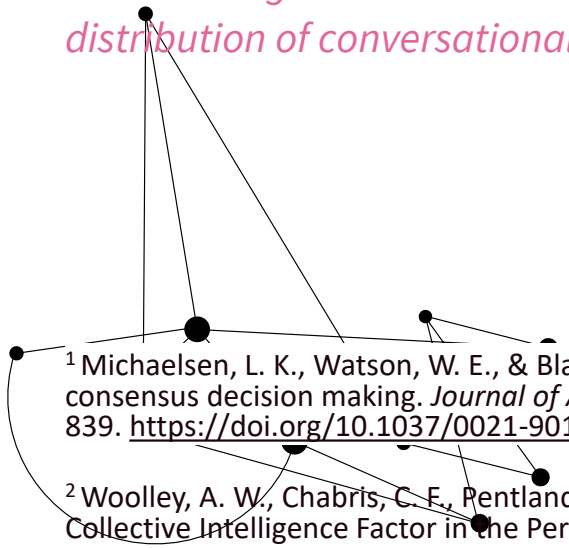

The future is
collaborative

Groupwork

Collaboration

The assembly bonus

In a seminal paper, Michaelson, Watson and Black (1989)[1] identified what they called an *assembly bonus* in teams working collectively (p.843). They found that the performance of the group (3-8 members) eclipsed that of the most able member 97% of the time. Woolley et al. (2010)[2] suggest that a general collective intelligence factor, c, analogous to individual general intelligence, exists for groups as measured across a wide variety of tasks. Their findings indicate that this so-called c-factor does not correlate well with individual or average general intelligence and is *most strongly aligned with "average social sensitivity of group members, [and] the equality in distribution of conversational turn-taking*" (p. 686).



[1] Michaelsen, L. K., Watson, W. E., & Black, R. H. (1989). A realistic test of individual versus group consensus decision making. *Journal of Applied Psychology, 74*(5), 834–839. https://doi.org/10.1037/0021-9010.74.5.834

[2] Woolley, A. W., Chabris, C. F., Pentland, A., Hashmi, N., & Malone, T. W. (2010). Evidence for a Collective Intelligence Factor in the Performance of Human Groups. *Science*, *330*(6004), 686–688

Open Access Article

Understanding the Social and Cognitive Nature of Collaboration: Implications for Practice

by **Peter Ellerton** [1,*], **Kathy Smith** [2], **Timothy Smith** [1] and **Tanya Stephenson** [3]

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Educ. Sci. **2025**, *15*(11), 1493; **https://doi.org/10.3390/educsci15111493**

Submission received: 28 July 2025 / Revised: 21 October 2025 / Accepted: 24 October 2025 / Published: 5 November 2025

Socially extended cognition

Extending the unit of cognition from the individual to the group

…in Vygotsky's general genetic law of cultural development: "every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level; first *between* people (inter psychological), and then *inside* the child (intra psychological)"

Vygotsky, 1978; p. 57, emphasis in the original.

Wertsch (1991) provided an illustration of this law by considering the case of a young child who was assisted by his mother to remember where his toy was. He points out that it is impossible to say that either participant did the remembering, as neither the child could have effectively managed his memory resources nor the mother could have known the position of the toy. The cognitive act of remembering was carried out on the intermental plane.

As individuals reason together, their inputs and outputs can form a system that encompasses and extends what is possible as separate agents. Many people have experienced collaborative sessions in which someone's question or idea has sparked a thought in another, assumptions that were unconsciously held have been made public and actionable, one person's proposal has been built upon by another who would not have been able to do so otherwise, and so on.

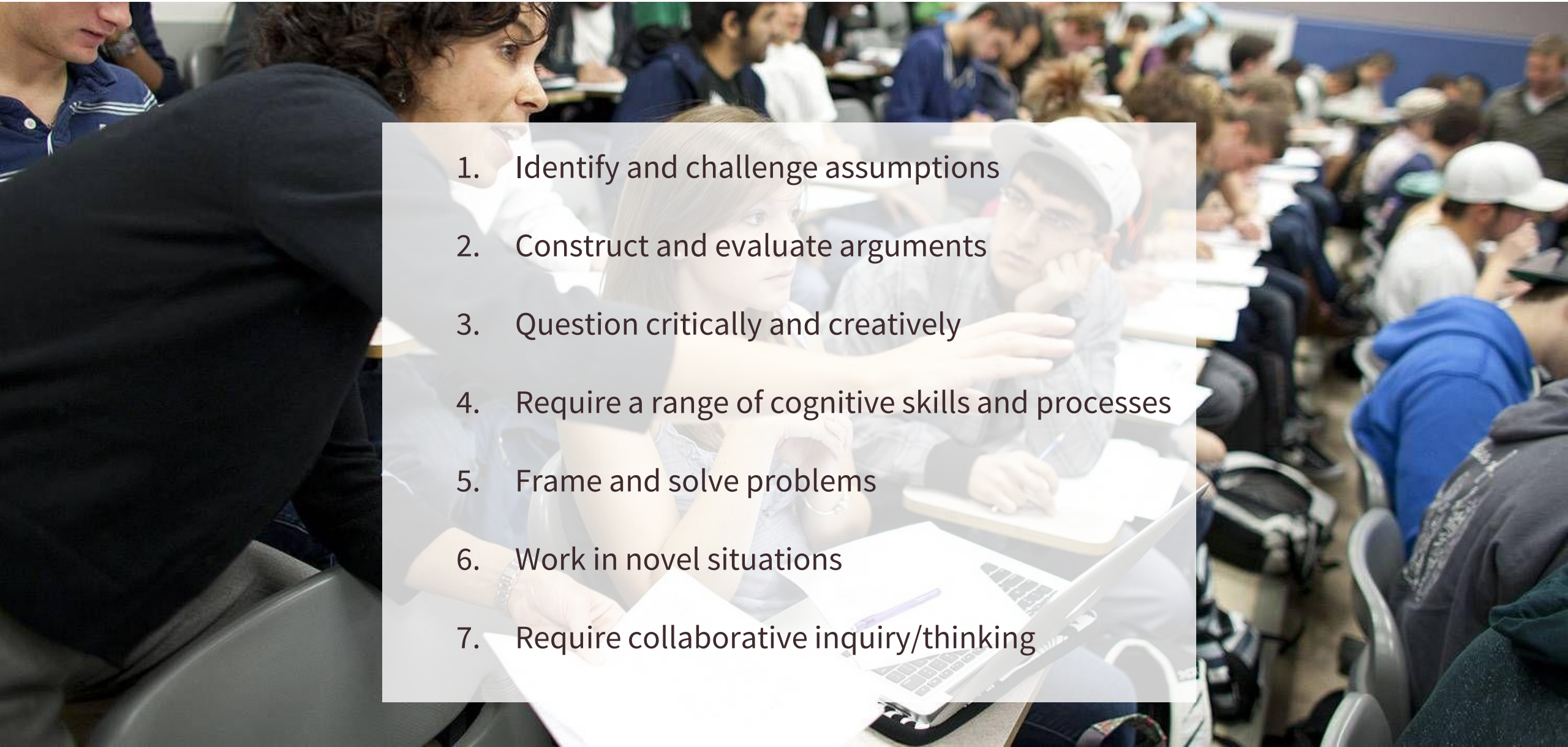
In these cases, other minds act as cognitive resources that are not available to us acting in isolation. We are not always just communicating the results of our completed cognition but are engaged in a flow of ideas and exchange of partially formed thoughts to see where they may lead. The exchange is a part of the cognitive process, and the result is more than the sum of the parts.

University of Queensland Critical Thinking Project: Collaboration Matrix

Criteria	1 - Poor	2 - Fair	3 - Good	4 - Very Good	5 - Excellent
Shared Goals and Vision	No clarity or alignment of objectives	Some alignment but objectives are not clear to all	Clear objectives but not all are aligned	Mostly aligned with clear objectives	Fully aligned with a clear and shared vision
Open Communication	Rarely communicates; many misunderstandings	Limited communication; some misunderstandings	Regular communication; occasional misunderstandings	Frequent and clear communication; few misunderstandings	Constant open and effective communication
Mutual Trust and Respect	Mistrust evident; no respect for contributions	Occasional trust issues; minimal respect	Generally trusting and respectful	High trust and respect with occasional lapses	Absolute trust; deep respect for all contributions
Active Participation	Rarely contributes; minimal involvement	Occasional contributions; limited involvement	Regular contributions but not fully engaged	Actively contributes most of the time	Fully engaged; consistently proactive
Flexibility	Resistant to change or feedback	Struggles with change; occasionally considers feedback	Adaptable but with some resistance	Often flexible and open to feedback	Always adaptable; embraces change and feedback
Diversity of Skills and Knowledge	Homogeneous skills; no diversity	Limited diversity; some overlapping skills	Balanced skill set but lacks diversity	Diverse skills with some unique expertise	Highly diverse and complementary skill sets
Joint Decision-making	Decisions made unilaterally	Some joint decisions but occasional exclusion	Joint decisions made regularly	Mostly inclusive decision-making	Always inclusive and collective decision-making
Shared Accountability	Blames others; avoids responsibility	Sometimes accepts responsibility; occasional blame	Generally shares responsibility but with lapses	Often accountable with minimal blame	Fully accountable; no blame culture
Conflict Resolution	Avoids conflicts; unresolved issues	Some conflicts addressed but not effectively	Regularly addresses conflicts; some unresolved	Effectively resolves most conflicts	Always addresses and resolves conflicts constructively
Feedback Loops	Rarely seeks or gives feedback	Occasionally seeks or gives feedback	Regular feedback but not always acted upon	Frequent feedback with most being actionable	Continuous feedback and always acts upon it
Shared Leadership	One dominant leader; no role changes	Occasional shared roles; limited leadership diversity	Shared leadership but with clear dominant figures	Often shared leadership with rotating roles	Fully shared leadership; roles adapt as needed
Synergy	Individual efforts; no combined value	Some joint efforts but limited synergy	Clear synergy but with some isolated efforts	High synergy with occasional individual efforts	Full synergy; combined effort exceeds individual contributions
Transparent Processes	Processes unclear and confusing	Some processes in place but lack clarity	Clear processes but not always followed	Mostly clear and often followed processes	Fully transparent and always followed processes

Dr Peter Ellerton, UQ Critical Thinking Project

Characteristics of critical thinking classrooms



1. Identify and challenge assumptions
2. Construct and evaluate arguments
3. Question critically and creatively
4. Require a range of cognitive skills and processes
5. Frame and solve problems
6. Work in novel situations
7. Require collaborative inquiry/thinking

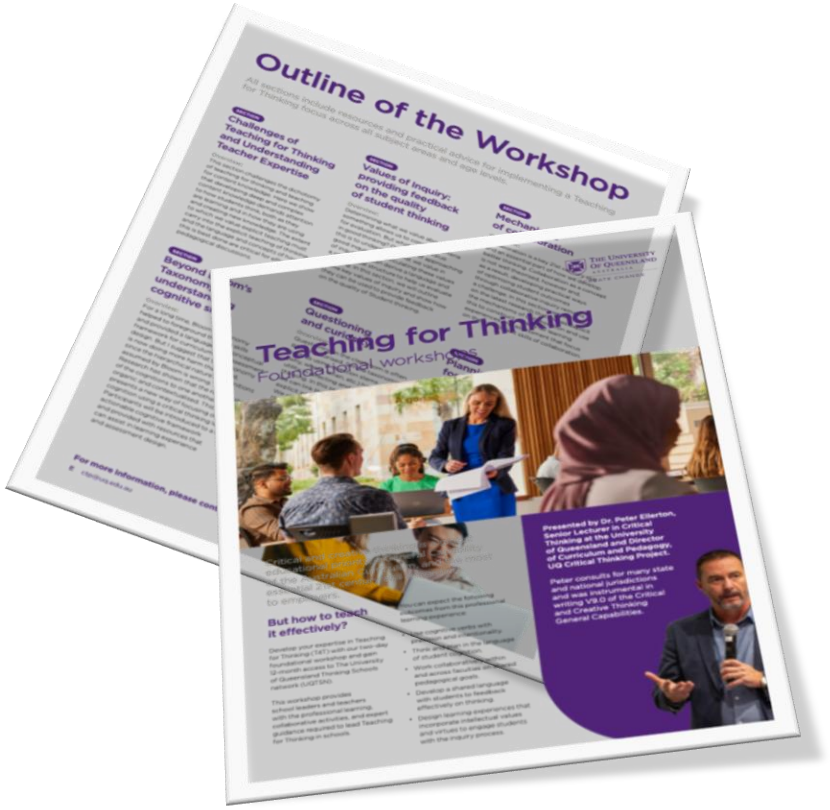
Other resources

THE Q MATRIX

	Event ***what***	Situation ***where/when***	Alternatives ***which***	People ***who***	Reasons ***why***	Means ***how***
Present ***is***						
Past ***did/was***						
Possibility ***can***						
Probability ***would***						
Prediction ***will***						
Imagination ***might***						
Decision/Choice ***should***						

Kialo.com
Reasons.io

University of Queensland Thinking Schools Network



https://critical-thinking.project.uq.edu.au/event/1337/2025-uqtsn-foundational-workshops-and-masterclasses

The Education Contrarian

https://critical-thinking.project.uq.edu.au/event/1337/2025-uqtsn-foundational-workshops-and-masterclasses

Some recent publications

- Leibovitch, Yael M., Beencke, Andrew, Ellerton, Peter J., McBrien, Craig, Robinson-Taylor, Cara-Lee, and Brown, Deborah J. (2025). Teachers' (evolving) beliefs about critical thinking education during professional learning: a multi-case case study. *Thinking Skills and Creativity* 56 101725 101725. https://doi.org/10.1016/j.tsc.2024.101725
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