Computational practices in student learning of Earth systems

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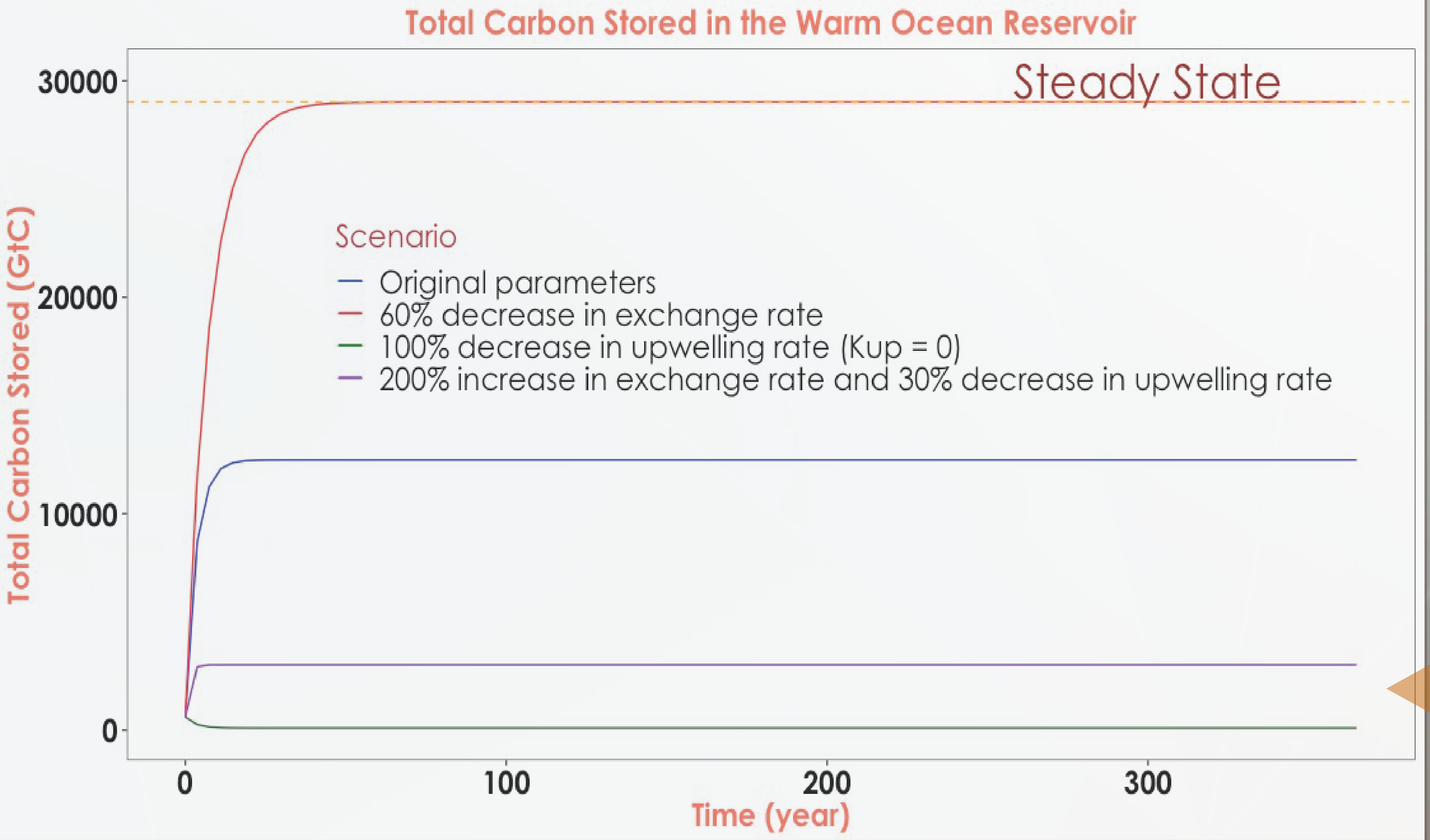
Introduction to Earth systems thinking

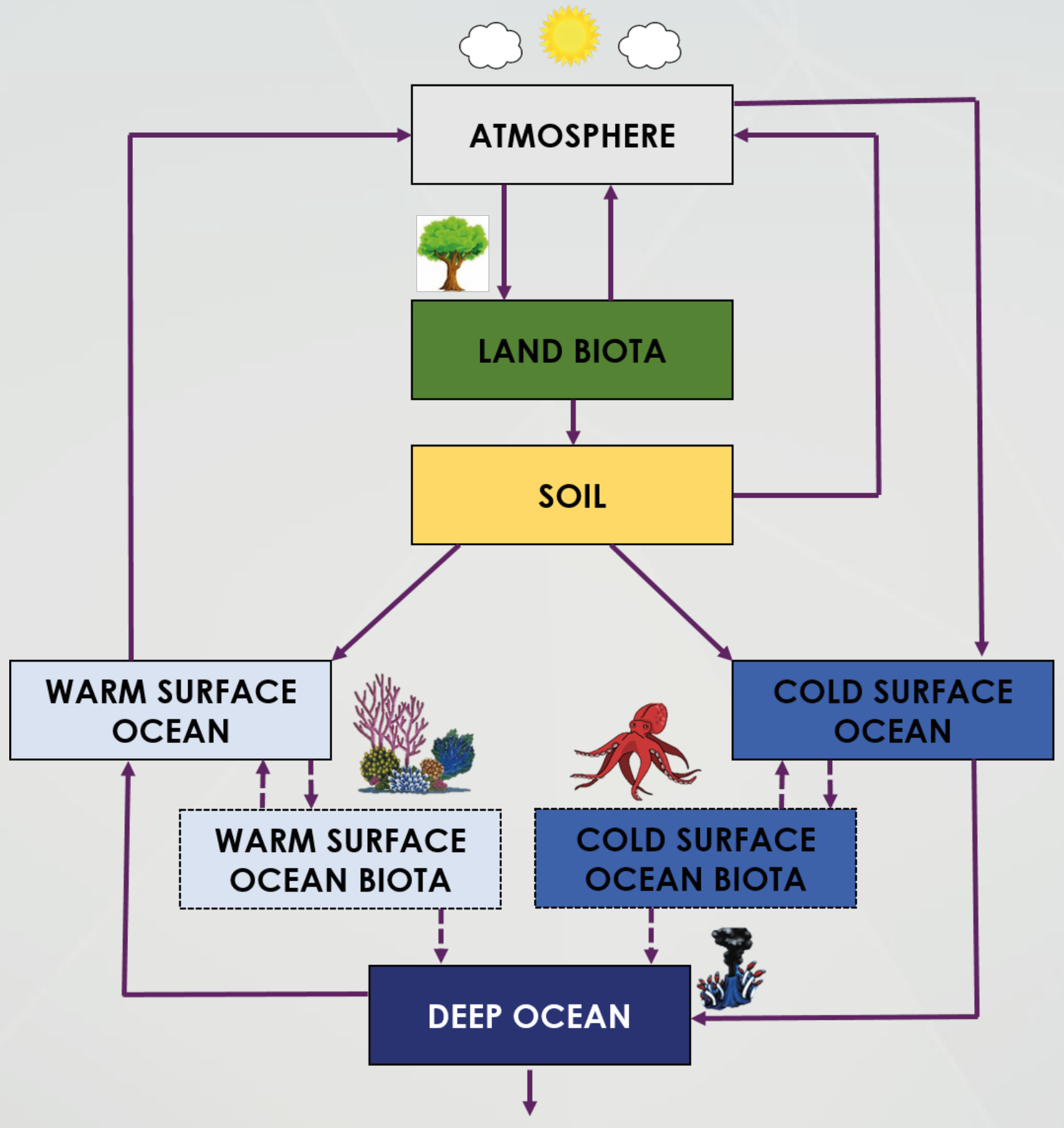
- Understanding the Earth System and the major interconnected processes that govern its complex behaviour is a key skill for geoscientists of tomorrow.
- Novices in Systems Thinking often perceive events sequentially, rather than as an interconnected, dynamic whole (Raia 2008).
- Understanding of central concepts, such as feedback, causality, and equilibrium, is a cornerstone in Systems Thinking theory (Holder et al. 2017)
- Computational thinking aids students' perception of dynamic, interconnected systems; it fosters Systems Thinking (Grotzer et al. 2013; Weintrop et al. 2016).

We want to develop an study to be run in an fifth semester geosciences course, and aim to investigate the impact of computational practice on student capability of Systems Thinking, through understanding of threshold concepts, when faced with an ill-structured computational problem.

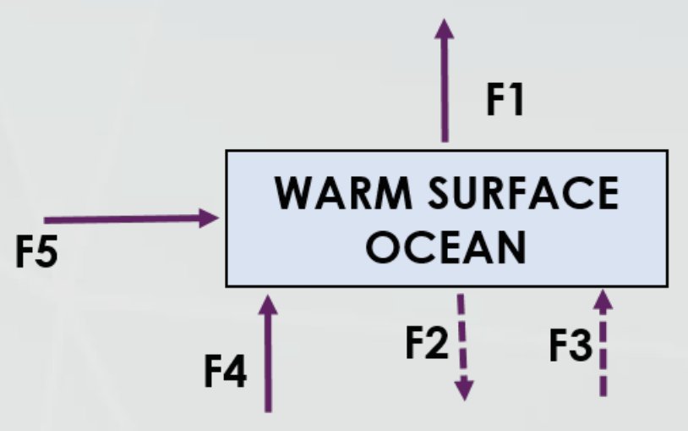


Contextualised systems: The carbon cycle

- Past experience with modelling a hypothetical system highlighted the necessity of applying contextualised problems to activate students' affective domain (Camelia et al. 2015).
- The carbon cycle represents a highly relevant context for discussion of one of the major problems of our time: Understanding the evolution of the Earth System and the role of the biosphere, particularly in relation to global climate change.
- The carbon cycle is often translated into a box model system where each carbon reservoir can be visualised as a box, and the flux between each reservoir is represented by an arrow (Slingerland and Kump 2011).



CONCEPTUAL DIAGRAM



RATE EXPRESSIONS (Units: Gt C / year)

$$Exchange(F1) = k_l * S_{wo} * (P_{wo} - P_{atm}) * Area_{wo}$$

$$Primary\ production(F2) = k_{pwo} * C_{wo} * Volume_{wbo}$$

$$Respiration(F3) = k_{rwo} * C_{wbo} * Volume_{wbo}$$

$$Upwelling(F4) = k_{up} * C_{do} * Area_{wo}$$

$$Runoff(F5) = k_w * C_s * Volume_s$$

MASS BALANCE

$$\frac{dC_{wo}}{dt} = F3 + F4 + F5 - F1 - F2$$

Students modelling the carbon cycle can focus on one of its major components, for example the warm surface ocean, during one geologic period. We hypothesise that programming will accelerate students' understanding of key concepts, such as mass balance and steady state, in Systems Thinking. Crucially, this will help them understand the dynamic behaviour of complex systems, and the impact the system's components have on its total behaviour.

Study design: Computational practice

- Students will develop their own models in a stepwise manner, each step resulting in a progressively more complex model.
- Within each step, problem solving will attempt to follow the steps outlined by Weintrop et al. (2016; fig. 2).
- Contextualisation of the problem is maintained by working within the Problem Solving in Practice environment sketched by Holder et al. (2017), developed to make problem-solving more similar to that carried out by professionals and experts.
- Programming the model is a compulsory and graded part of the course. Additional participation in the study is voluntary.

Assessment of systems thinking

- Pre- and post-study tests to map students' prior knowledge and attitudes.
- Focus group interviews, targeting experiences and learning outcome, immediately after the study is over.
- Each student writes and hands in a learning log or reflective diary for their work and learning process.
- Rubrics, following the components underscoring students' understanding of Earth Systems thinking as suggested by Assaraf and Orion (2005), and complemented by the rubics suggested by Hung (2008), are being developed to assess the individual reflections.
- Logs and transcripts of focus group interviews will be sent to independent experts to be evaluated by the same rubrics.

Suggested rubrics

	Low	Mid	High
The ability to identify the components of a system and processes within the system.	The model lacks major components and processes, or contains insignificant ones. Presence or absence is not substantiated or explained.	The model contains the major components, and they are connected correctly. Components and processes are somewhat substantiated.	Major and minor components and processes alike are present, or their absence is reasonably explained.
The ability to identify relationships among the system's components.	Relationships between components are arbitrary, highly linear, unidirectional, and unsubstantiated.	Relationships between components are precise, and somewhat bi/multidirectional and substantiated.	Relationships between components are deliberate, precise, and well substantiated using systems thinking terminology.
The ability to organize the systems' components and processes within a framework of relationships. Code.	Code: The code does not compile, and is not easily read/understood by outsiders.	Code: The code compiles, and its main structure is discernible to outsiders.	Code: The code compiles, and is easily read and understood by outsiders.
The ability to organize the systems' components and processes within a framework of relationships. Reflection.	Reflection: Cannot sketch a realistic framework for the system's components.	Reflection: Sketches a realistic framework for the system's components, but cannot motivate or substantiate choice of components.	Reflection: Clearly sketches a realistic framework for the system's components and motivate choice of components.
The ability to make generalizations.	No realistic suggestions for analogue scenarios. Cannot reasonably explain why a suggested analogue is or is not realistic.	Suggests realistic analogues, but within the scientific discipline.	Suggests realistic analogues in- and outside of the scientific discipline.
The ability to identify dynamic relationships within the system.	Struggles or fails to identify and characterise major dynamic relationships.	Identifies and characterises a broad spectrum of dynamic relationships.	Identifies, characterises and validates the majority of significant dynamic relationships. Highlights absent relationships.
Understanding the hidden dimensions of the system.	Does not see obvious shortcomings in the model. Draws invalid conclusions based on system behaviour.	Identifies obvious shortcomings in the model, but cannot implement them. Draws reasonable conclusions based on system behaviour.	Identifies obvious and hidden shortcomings, and suggests strategies for implementing them. Makes and justifies conclusions about the system.
Thinking temporally: retrospection and prediction.	Cannot reasonably predict past and future behaviour of the system.	Reasonably predicts past and future behaviour of the system, but cannot evaluate the relative importance of individual components or processes.	Evaluates the effect of components and processes, and minor adjustments on total system behaviour in past, present and future.

The road ahead: Your thoughts!

- How do we formulate meaningful rubrics for assessment of computational thinking?
- What questions would YOU ask these students?
- How do we motivate students to partake in the study?
- Do we conduct the study with groups or individuals?
- Are there any ethical challenges?

References

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