Rodrigo, M. M. T. et al. (Eds.) (2021). Proceedings of the 29th International Conference on Computers in Education: Asia-Pacific Society for Computers in Education

The M in STEM and Issues of Data Literacy

Khalid KHAN & Jon MASON*
College of Indigenous Futures, Education, and Arts, Charles Darwin University, Australia
khalid.khan@cdu.edu.au
*jon.mason@cdu.edu.au

Abstract: This article examines post-pandemic scenarios that combine an emerging research agenda with three distinct topics relevant to the changing requirements of education systems worldwide: STEM education, mathematical thinking, and data literacy. In addition, how these topics are collectively positioned within the context of the digital environment is discussed. We examine the social usefulness of data literacy as may be embedded within a STEM paradigm and consider it as reaching beyond this paradigm into domains of civics and ethics. We propose that a meaningful strategy on 'data literacy' requires complex practical development and a curriculum presence explicitly within the Mathematics content area and across all STEM subjects, while also aligned to skills development typically associated with 21st century education together with emergent skills now associated with the fourth industrial revolution. In a similar way to how computational thinking has emerged as reaching beyond the formalities of computer science, the 'M' in STEM in this paper signifies 'mathematical thinking' is relevant beyond the discipline of Mathematics.

Keywords: STEM, inquiry, questioning, data literacy, curriculum, mathematical thinking

1. Introduction

In terms of calibrating teaching and learning to meet post-pandemic challenges, we question whether the core competencies of creativity, critical thinking, collaboration, and communication are sufficient to mitigate current and future societal challenges. Commonly known as the 4Cs that underpin many 21st century skills frameworks (World Economic Forum, 2016), such competencies have provided clear alignment with post-schooling employability requirements for the last two decades. But with characterizations of our times in terms of the 'misinformation age' (O'Connor & Weatherall, 2019), the 'black box society' (Pasquale, 2015) and 'surveillance capitalism' (Zuboff, 2019) the 'fourth industrial revolution' looks to be unleashing much more than technological innovation (Miller & Wendt, 2021). Even in the pre-pandemic world, data was easily sourced and routinely used to profile individuals and populations with the aim of predicting and modifying behaviors for financial gains (Zuboff, 2019; Couldry & Mejias, 2019). Post-pandemic, these practices will make more extensive use of student data. It is therefore timely to understand the challenges to traditional rights of individual privacy and social norms around behavioral modification that probably will be more technology directed from now. What does it mean to have agency and free will in a society with data as the key currency of transaction – and for some, seen as the 'new oil' (Humby, 2006)? There are several reasons why our societies should be concerned by the increasing dominance of data-driven epistemologies in social educational policies and marketing. One key reason is the diminishing control that students of all ages now have over how they are inscribed and profiled by 'smart' systems using such data and its influence of on their behaviors. How our on-line interactions, may potentially give rise to social justice and power issues due to data-driven decision-making, on education and governance and society. The question *who decides what for me?* has never been as prominent as it is now.

How can mathematical thinking and data literacy help? We know that computational thinking, design thinking, and systems thinking are all now embedded within STEM curricular, and that these modes of thinking are not enough in online educational environments where information and data tools can be easily manipulated. Within and beyond the STEM disciplines there are ethical and civic considerations. As Cowie and Cooper (2016) argue, 'every citizen needs to be data literate'. We also need to scaffold questioning techniques that probe deeper than simple Internet searching. A key issue this paper explores is how to focus STEM curricula on questioning techniques that shift traditional pedagogies from ‘thinking in answers’ to ‘thinking in questions’. Previously (Mason, Khan & Smith, 2020), we proposed a research question: *in what ways can we articulate a systemic approach to embedding data literacy within a STEM curriculum?* This paper represents a conceptual examination of aspects of mathematical thinking related to this question.

2. STEM and Data Literacy

In previous research we established that many definitions of data literacy are not fit for purpose since they don’t justify nor account for the changes data sets in recent times (Khan & Mason, 2016, 2017; Mason, Khan & Smith, 2019). As technology develops, an increasing number of common use objects are becoming ‘smart’. Various podiums silently collect our data. With innumerable children’s educational platforms in the post-pandemic world, safety and privacy issues will broaden in scope. This means that data literacy requires a better presence within school education. Without a clear framework and direction in curricula on data literacy and subjects where it needs embedding, this becomes challenging. Science now has moved to the ‘fourth paradigm’, where data-intensive investigations are becoming the norm (Tansley & Tolle, 2009). Little data that these days is collected with small gadgets like rulers, thermometers and stop watches has morphed into big data (Lohr, 2012, Mason et al., 2019). Data analysis is moving to investigate ‘big problems’ of the society through patterns in data.

Because data is produced and collected in diverse ways across all disciplines particularly under STEM areas, a systemic way of dealing with it across the curriculum is required. However, an inquiry problem in STEM often proceeds as: understanding the scope of the question or problem; data generated, analyzed, results interpreted and visualized, conclusion; more precise measurements, more variables, more data and the cycle repeats. (Mason, Khan & Smith, 2019).

In connecting STEM and Data Literacy, Cook and Bush (2015) used an integrated approach across their science and mathematics methods undergraduate courses to “support [pre-service teachers’] understanding of how to analyze and interpret data and their ability to teach it in their future classrooms” (p. 31). While not foregrounding the STEM acronym in the Australian Curriculum, the modes of thinking underpinning it (design thinking, systems thinking, and computational thinking) are presented as working together within the Technologies learning area.

The current Australian Curriculum touches upon on issues concerning data usage, though ‘data production’ (‘upstream’ data) is not yet explicit, nor is any provenance dealt with in terms of the origins and destinations of data. Given that data can be produced automatically and intentionally within digital environments, a good understanding of data literacy requires attention to the full scope of data production.

3. Methodology

In the current study, we have analyzed recent reviews and proposed recommendations for the Australian Curriculum *Foundations to Year 10*. Specific focus included inquiry and reasoning proficiencies within the Science, Technology and Mathematics learning areas. These were considered from a STEM perspective as an integrated problem-solving skill for innovative solutions. *Data Literacy* is the common thread that connects inquiry and questioning-based pedagogical practices in STEM.

4. The Australian Curriculum Review

In early 2021, the Australian Curriculum, Assessment and Reporting Authority (ACARA) initiated a public consultation to support its third review of the Australian Curriculum (AC). Two of the key recommendations include “mathematics classes need to have more units on financial literacy… and that primary school students are taught to have a greater awareness of online security” (Davies, 2021). However, focus has remained mostly on semantics – for example, during the public consultation of the AC review, ACARA has proposed renaming ‘ICT Capability’ as ‘Digital Literacy’.

Obviously, curriculum review requires more in-depth analysis when connecting Mathematics and Science Curriculums with data literacy and computational thinking that digital literacies require.

4.1 Australian Science Curriculum

The Australian Science curriculum consists of three strands – Science Understanding, Science as a Human Endeavour, and Science Inquiry Skills. The inquiry strand is presented as: 'Identifying and posing questions; Planning, conducting and reflecting on investigations; Processing, analyzing and interpreting evidence; and Communicating findings. This strand is concerned with evaluating claims, investigating ideas, solving problems, drawing valid conclusions *and developing evidence-based arguments.'* (ACARA, 2012)

The proposed revision of science curricula puts some focus on the role of data by including analysis of diverse data and information to identify and explain patterns, trends, relationships and anomalies (ACRC, 2021). Inquiry skills, as constructivist pedagogy requirements, are a key feature of the Australian Curriculum in Science, History and Geography. Inquiry learning considers teachers and students as co-learners and co-constructors of knowledge (Callison, 2006). Apart from developing questioning skills, inquiry processes include collecting and analyzing data and information for higher order problem solving. These include critical thinking, reasoning, and reflecting. Issues concerning data literacy are not foregrounded in questioning or examining data to identify ethical considerations, biases, personal and private data, etc. In other words, issues related to data literacy aren't explicit and do not (yet) have a clear presence in the curriculum.

4.2 Australian Mathematics Curriculum

The Australian Mathematics Curriculum consists of four 'general proficiencies' – Understanding, Fluency, Problem Solving, and Reasoning. The proposed revision within the Australian Curriculum suggests removing outdated and non-essential content and replacing it with content that is more contemporary. The critical processes of reasoning and problem-solving have been suggested to have more identifiable presence within content and achievement standards now. The proposed revision also gives teachers better clarity and guidance about what they are expected to teach. (ACRC, 2021).

Data Literacy has an explicit presence within Mathematics. Some (e.g., Gould, 2017) argue Data Literacy is essentially equivalent to Statistical Literacy. Data Literacy makes a clear presence under Statistics and Probability. Overall, the basic skills that students (and teachers both) need for improving decision making skills using data are: (1) Knowledge of diverse data collection protocols; (2) Selecting protocols best suited to answer (students' and teachers') questions; (3) Collating and graphing data; (4) Discerning trends and differences in data; (5) Using data in team problem solving; and (6) Selecting evidence-based interventions The following tables provide a comparison of actions that Australian Curriculum Science Inquiry Skills and Problem Solving and Reasoning in Mathematics:

Table 1. *Science Inquiry Skills (adapted from ACARA, 2012)*

Science Inquiry Skills	Attributes
Questioning and Predicting	Identify, chose, select, pose, formulate Questions (everyday life contexts). Identify and investigate data in familiar and unfamiliar contexts. Use previous investigations and existing data. Hypothesize, predict, revise and refine questions. Think" what will happen if…". Take into consideration the social, cultural, economic, environmental or moral aspects.
Planning and Conducting Investigations	Gather, explore, sort, classify information. Manipulate objects and make observations. Research ideas collaboratively. Consult. Explore multiple ways to collect and record data. Use informal measurements. Explore multiple ways to approach a problem. Be fair. Accuracy vs Approximations. Consider safe processes. Use primary and secondary sources. Understand fair investigation methods. Know that equipment may influence the reliability of collected data and results. Model and Simulate.
Processing and analyzing data and information	Use drawings to represent observations. Use a range of methods to sort data. Identify similar, odd-one-outs and opposites. Group items using similarities and differences. Analyze. Compare predictions with results. Identify patterns/trends. Suggest reasons for the findings. Use a range of representations. Construct tables, graphs. Use digital organizers of data such

	as, spreadsheets. Identify data that support/ negate the hypothesis. Understand there could be more than one possible explanation for results. Review scientific understanding.
Evaluating and Reflecting	Compare and evaluate observations. Discuss similarities/ differences. Consider indicators of quality of the data. Describe experiences. Reflect whether a test was fair? Research methods used by scientists. Suggest improvements. Evaluate conclusions. Identify sources of uncertainty & possible alternative explanations. Identify gaps or weaknesses. Identify alternative explanations consistent with data. Critically analyze the validity of information. Describe how scientific and data driven arguments can be used to make decisions.
Communicating	Represent and communicate in a variety of ways. Use formal and informal representations. Acknowledge and explore 'other' ways of communication. Label diagrams. Present research and results using other forms of representation of data and scientific language appropriate for the target audience. Use secondary sources and students' own findings to help explain a scientific concept. Use internet and on-line data to facilitate collaboration and discussion.

Table 2. *Problem Solving & Reasoning strands in Mathematics (adapted from ACARA, 2012)*

Reasoning	Develop capacity for logical thought and actions. Analyze, prove, evaluate, explain, infer, justify and generalize. Deduce /justify strategies and conclusions reached. Adapt the known to the unknown. Transfer learning from one context to another. Prove something is true or false. Compare related ideas and explain choices.
Problem-Solving	Make choices, interpret, formulate, model and investigate problem situations. Communicate solutions effectively. Use mathematics to represent unfamiliar or meaningful situations. Design investigations and plan approaches. Apply existing strategies to seek solutions. Verify reasonableness of their answers.

One of the key recommendations under the revised Australian Curriculum is for year 10 students to critically analyze media in terms of the claims and conclusions, noting limitations and potential sources of bias. Table 3 is constructed for Data Literacy attributes:

Table 3. *Data Literacy under Statistics and Probability F-10 (adapted from ACARA (2012)*

Mathematical Thinking	Attributes
Representation and Interpretation	Collect information, make inferences. Question. Collect categorical/numerical data. Determine questions. Identify categories. Represent data with/without digital technologies. Compare various representations, describe similarities and differences. Describe/interpret different data sets. Identify questions. Identify data sources. Plan methods of data collection and recording data. Construct, interpret and compare a range of data displays. Summarize data by calculating measures of center and spread. Make sense of the data. Construct stem-and-leaf plots and histograms. Use these to compare two like sets of data. Describe the shape of the distribution. Understand key terms. Describe and interpret data sets using location (center) and spread. Compare means, medians and ranges of two sets of data.
Uncertainty	Identify and describe chance events. Understand and describe outcomes. Assign probabilities. Identify variations. List outcomes. Justify. Investigate. Construct sample spaces. Conduct repeated trials. Investigate probabilities. Compare experiments which differ. Calculate relative frequencies. Use Venn diagrams & two-way tables. Investigate reports in digital media (and elsewhere) use data to estimate population means and medians. Analyze claims, inferences and identify ethical considerations.

4.3 Australian Technology Curriculum

The Technologies curriculum under ACARA aims to provide students opportunities to consider how solutions with future perspectives. It asks to identify benefits and risks and weigh impacts using critical and creative thinking (ACARA, 2012). Data Literacy is implicit as part of Computational Thinking (CT) within the Digital Technologies Curriculum, According to ACARA Computational thinking (CT) is:

> *a problem-solving method that is applied to create solutions that can be implemented using digital technologies. It involves integrating strategies, such as organising data logically, breaking down problems into parts, interpreting patterns and models and designing and implementing algorithms.*

Computational thinking is used when specifying and implementing algorithmic solutions to problems in Digital Technologies. For a computer to be able to process data through a series of logical and ordered steps, students must be able to take an abstract idea and break it down into defined, simple tasks that produce an outcome. This may include analysing trends in data, responding to user input under certain preconditions or predicting the outcome of a simulation.

This type of thinking is used in Design and Technologies during different phases of a design process when computation is needed to quantify data and solve problems. (ACARA, 2012).

The review requires meaningful connections with Mathematics through data representation (ACRC, 2021). With the current expectations changing, it is proposed students should be able to "*possess and be able to demonstrate computational thinking skills that include pattern recognition, decomposition, determining which (if any) computing tools could be employed in analyzing or solving the problem, and defining algorithms as part of a detailed solution*." (OECD 2018, p. 7). PISA2021 also points out that "*Long-term trajectory of mathematical literacy should also encompass the synergetic and reciprocal relationship between mathematical thinking and computational thinking*" (OECD 2018, p. 7). Extending these ideas, Ho (2021) explored Computational Thinking through the pedagogy of Mathematics and highlighted the 'data principle' as one of the four core principles for task design – which requires the educator to identify if the topic manifests instances and common traits/trends/patterns that can be observed, quantified, stored and treated as data?

Within the machine learning paradigm, algorithms learn from and recognize patterns (within the data) and when new data is received as an input, recognize, distinguish and identify the same patterns to define and match answers. This process is same as how a child learns from environmental contexts and in a mathematics class, e.g., identifying and naming. Figure 2 depicts how Data (and hence Data Literacy) is pivotal Computational Thinking, Mathematical Thinking and Scientific Inquiry.

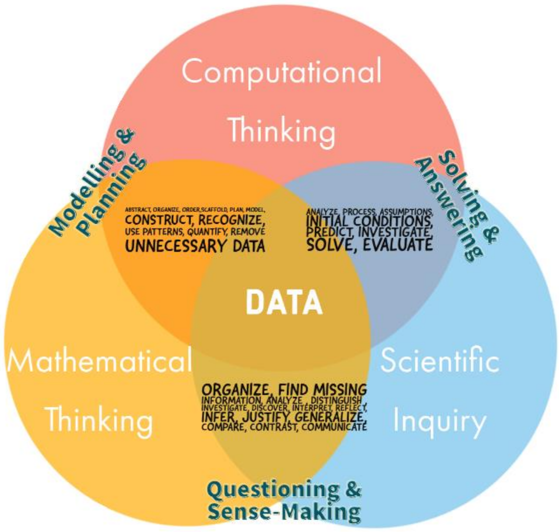

Figure 2. Data at the Intersection of STEM.

STEM is not just focusing on four key learning areas, but also designing learning and an interdisciplinary approach to problem solving that draws on deepening and comprehensive understanding of Mathematics, Science, Engineering and Technology. Salmacia (2017) points out that '...data literacy skills were some of the most important that a teacher could possess [... and that] becoming an outcome-driven, data-literate teacher was absolutely necessary [...]' (p. 140) Additionally, he concludes that addressing culturally responsive practices related to assessments and other data collection instruments, and as well as providing technology instruction with a view on the key role that technology and computers play with in data literacy paradigm (e.g., skills related to the use of data dashboards, data systems, spreadsheet functions, etc.) are critical.

5. Conclusion

While inquiry-based approaches are common to most subject areas across educational curricula, they are also shaped by the specific learning areas and in practice. Pedagogical approaches will vary, and no one approach whether student-centred or teacher-directed in emphasis is appropriate for all contexts. Understanding the scope of data and its implications in dealing with current and future challenges is a key theme in this paper. This requires that educational curricula and content are routinely reviewed and updated. The whole notion of '21st century skills' is thus becoming a questionable construct. Requirements for inquiry and reasoning using digital platforms are becoming more complex in nature requiring Data Literacy skills within Mathematics and STEM curriculum areas. Given the pace of change, we suspect that such a shift will take several iterations.

References

Akinshin, A. (2021). Misleading histograms | Andrey Akinshin. Retrieved 14 May 2021, from https://aakinshin.net/posts/misleading-histograms/.

Australian Curriculum, Assessment and Reporting Authority (ACARA), (2021). The Australian Curriculum Review. Public consultation https://www.australiancurriculum.edu.au/consultation/mathematics/

Australian Curriculum Review consultation (ACRC), (2021). Retrieved 24 May 2021, from https://www.australiancurriculum.edu.au/consultation/

Callison, D., & Preddy, L. (2006). *The blue book on information age inquiry, instruction, and literacy*. Libraries Unlimited Incorporated.

Conn, C., Boham, K., Hernandez, N., Powell, P., & Luzader, J. (2020). Teaching and Assessing Data Literacy: Resource Guide for Supporting Pre-Service and In-Service Teachers. Ceedar. Education. https://ceedar.education.ufl.edu/wp-content/uploads/2020/10/Arizona_Data_Literacy_Resource_Guide.pdf

Cook, K. L., & Bush, S. B. (2015). Structuring a science mathematics partnership to support preservice teachers' data analysis and interpretation skills. *Journal of College Science Teaching, 44*(5), 31-37

Couldry, N. & Mejias, U. A. (2019). *The Costs of Connection: How Data Is Colonizing Human Life and Appropriating it for Capital*. Stanford, CA: Stanford University Press.

Cowie, B., & Cooper, B. (2017). Exploring the challenge of developing student teacher data literacy. *Assessment in Education: Principles, Policy & Practice, 24*(2), 147–163.

Davies, L. (2021). *Curriculum proposals deserve support, not another iteration of the history wars*. The Sydney Morning Herald. Retrieved 21 May 2021, from https://www.smh.com.au/education/curriculum-proposals-deserve-support-not-another-iteration-of-the-history-wars-20210502-p57o7a.html

Gould, R. (2017). Data literacy is statistical literacy. *Statistics Education Research Journal, 16*(1), 22-25.

Ho, W.K. (2021). *Computational Thinking Through the Lens of a Mathematics Educator*. CTE-STEM 2021 Keynotes. https://cte-stem2021.nie.edu.sg/keynote.html

Humby, C. (2006), quoted in Mavuduru, A. (2020). Is Data really the New Oil in the 21st Century? Towards Data Science. https://towardsdatascience.com/is-data-really-the-new-oil-in-the-21st-century-17d014811b88

Khan, K. & Mason, J. (2019). Examining the Data to Identify Essential Questions – Guilty before Innocent. *International Journal of Smart Technology and Learning. 1*, 3, p. 244-266 23 p.

Khan, K. & Mason, J. (2018). Faking it with Data – A Curriculum Perspective. Proceedings, 'Developing Real-Life Learning Experiences: Using Innovation and Enhanced Technologies', King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand. June 4-10.

Khan, K. & Mason, J. (2017). Learning to be Data Smart. *Workshop Proceedings of the 25th International Conference on Computers in Education*. New Zealand: Asia-Pacific Society for Computers in Education.

Mason, J., Khan, K. & Smith, G. (2020). A SySTEMic approach to Data Literacy. In Chang, M., So, H-J., Wong, L-H., et. al., (eds.). *Proceedings of the 27th International Conference on Computers in Education*. Asia-Pacific Society for Computers in Education, 665-667.

Miller, K., & Wendt, K. (Eds.). (2021). *The Fourth Industrial Revolution and Its Impact on Ethics: Solving the Challenges of the Agenda 2030*. Springer Nature.

O'Connor, C., & Weatherall, J. (2019). *The misinformation age: How false beliefs spread*. Yale University Press.

OECD. (2018). PISA 2021 Mathematics Framework (Draft). November 2018.

Pasquale, F. (2015). *The Black Box Society*. Harvard University Press.

Salmacia, K. A. (2017). *Developing outcome-driven, data-literate teachers*. Doctoral dissertation, University of Pennsylvania.

World Economic Forum. (2016). *New Vision for Education: Fostering Social and Emotional Learning through Technology* (p. 36). http://www3.weforum.org/docs/WEF_New_Vision_for_Education.pdf

Zuboff, S. (2019). The Age of Surveillance Capitalism: The Fight for a Human Future at the New Frontier of Power. New York, NY: Public Affairs