Curriculum development and the use of a digital framework for collaborative design to inform discourse: A case study

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This paper reports on a new initiative of collaborative work between the Australian Curriculum, Assessment and Reporting Authority (ACARA) and Cambridge University as part of the 2020-21 review of the Australian Curriculum: Mathematics Foundation – Year 10. The ACARA mathematics curriculum development team worked with the Cambridge Mathematics team using the Cambridge Mathematics Framework, which incorporates summaries of the research literature, to inform the review of Statistics and Probability in the mathematics curriculum as part of ACARA's program of research.

The Australian Curriculum, Assessment and Reporting Authority (ACARA), during the 2020-21 review of the Australian Curriculum: Mathematics Foundation (pre-Year 1) to Year 10, identified an opportunity to trial a new approach to coherent curriculum design. A team of curriculum specialists incorporated the *Cambridge Mathematics Framework* (CMF) into the Statistics and Probability areas of the curriculum review as an analytical tool for examining content revisions, making decisions, and providing justification to other stakeholders based on consolidated interpretations of relevant research. Teams from ACARA and the University of Cambridge developed ways of incorporating the CMF which led to areas of validation and areas of change in the curriculum and recommendations for use and support of the CMF for the Cambridge team to apply in the future. This paper presents an outline and some details of this new initiative and discusses implications for the Australian Curriculum, the CMF, and curriculum review more broadly.

Challenges for domain coherence in curriculum design

Learning mathematics has been described as the process of building a scaffold from the ground up, a rising and expanding network of ideas supported by the synthesis and consolidation of ideas students have already developed (Tall, 2013; Thurston, 1990). Day to day in the classroom, this process is non-linear, as teachers and students visit related ideas back and forth, retracing steps, making connections, bringing new ideas to bear on old ones, and vice versa. A coherent mathematics curriculum seeks to provide a substantive

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progression within key organising constructs, structuring the process in time across years of study while supporting the underlying conceptual structure of the domain (Jameson et al., 2018; Schmidt et al., 2005).

The extent to which this is possible depends on what knowledge can be brought to bear about the underlying structure of the domain. Each teacher, curriculum designer, and researcher in mathematics education, from their own education and professional experience, has developed a sense of the ideas and the relationships between them that make up parts of this scaffold, though perspectives on some areas will be based on more information than others due to individual specialisations. However, opportunities for sharing these perspectives to assemble a larger coherent picture are often limited.

The importance of connecting research and practice is well recognised in mathematics education, but there are challenges to making these connections successfully (Flessner, 2012). These challenges stem in part from how research is designed and the investment it takes to bring professional judgment from practice and research together. First, much of this research is structured around developing particular theories of learning and understanding of surrounding issues, and produces knowledge in a very different framework to pedagogical knowledge (McIntyre, 2005). Each study is intended to address a specific gap in knowledge, to make a unique or complementary contribution with respect to existing research and experience. This means that studies typically do not result in unambiguous recommendations for practice individually, and the collective picture can be even more complex.

Secondly, in order for research to contribute to practice, teachers and educational designers need practical access to it. Some barriers to access are physical or financial, while others have simply to do with the time it takes to find, read, and synthesise reports of multiple studies, and the study or training required to be familiar enough with research practices and strands of work in the field for critical analysis (van Schaik et al., 2018).

Another challenge is that curriculum design involves agents and stakeholders who are members of different communities of practice (Pinto & Cooper, 2018; Remillard & Heck, 2014), with differences between their priorities and perspectives on mathematics. Pinto and Cooper (2018) reported that in curriculum design discussions between different types of stakeholders, people with backgrounds in more than one camp act as knowledge brokers - people who can translate between perspectives and help the group to make decisions based on shared understanding. Shared objects of discussion can also help. However, discussions which are not successfully mediated may not end with meaningful agreement, whether about structuring principles or scope and sequencing.

Lastly, a challenge lies in the compressed selection of objectives which occurs distinctively in every curriculum due to time and resource constraints. Different decisions guide this selection under different circumstances, but it always involves trade-offs – for example, depth and breadth, this set of key ideas or that set of key ideas, ordered along in this sequence or that sequence. It is not possible or even necessary to include everything, but the choices which are made affect the coherence of mathematical experiences in the classroom and opportunities for teachers to develop a more connected perspective of the domain (Schmidt et al., 2005). Whatever selection is made, the curriculum aims to have its own sense of completeness, coherence, consistency, correctness and relevance, in particular as it is developed to provide access to educational entitlement for students.

Conceptual mapping has been used in multiple instances to address curriculum challenges. Confrey et al. (2017) have designed "learning maps" based on learning trajectories, which are empirically supported conjectures of the network of constructs students experience as they build understanding of mathematical concepts. Learning maps are designed to show details which help teachers to provide learner-centred instruction (Confrey et al., 2017). Koch et al. (in press) have developed a network representing teacher knowledge of mathematical topics for middle grades in Canada, derived from empirical work with teachers rather than students. The CMF has some similarities with each of these and also key differences. It allows maps to be generated from a network of mathematical ideas which, similar to Confrey et al.'s (2017), represent concepts building on one another, but these concepts in the CMF are derived from interpretation and synthesis of research literature. They represent not professional knowledge itself, as in Koch et al.'s (in press) work, rather what the reviewed research suggests is useful for designers to know about students' conceptions.

Context

Review of the Probability and Statistics component of the Australian Curriculum

The current F-10 Australian Curriculum review process began in June 2020 when Australian education ministers through the Education Council agreed to the terms of reference, and a guiding paper, *The Shape of the Australian Curriculum*, was developed. From there, content review began, as well as consideration of how the proficiencies could be further developed and incorporated with this revised content. The Cambridge Mathematics team were introduced to the project in June 2020 and began working with the team of curriculum specialists tasked with reviewing content in the Statistics and Probability strands, with both teams using the CMF to explore questions and inform regular discussions.

The review was structured around the organising ideas of Mathematising, Structure, and Approaches and took place in four steps: (1) identifying core concepts at the Learning Area level, (2) identifying core concepts at the Strand (branch) level, (3) using identified core concepts to curate essential content for the learning area and identifying any gaps, redundancies or imbalances, and (4) organising content with embedded proficiencies into strands using core concepts and/or core concept organisers within the wider Mathematics scope and sequence, also relying on an initial programme of research. Once this process was initially completed, the result was sent out for feedback from teacher and curriculum specialist reference groups. The next stage in the process is public consultation.

The ACARA team had in place its own programme of research which made them aware of key issues they wanted to look at further in Statistics and Probability. However, work with outside groups, like the Center for Curriculum Redesign, and drawing on Australian research in the field (Bargagliotti, 2020; Callingham & Watson, 2005; Callingham & Watson, 2017; Franklin, 2007; Watson & Callingham, 2020), led them to seek additional feedback on aspects of the work. Their two guiding questions for the collaboration were: (1) *In what way would engaging with the CMF and the Cambridge team support/validate the revisions to the Statistics and Probability strands of the revised curriculum?* And (2) *If adjustments/additions are made based on engagement with the CMF, what led the ACARA review team to make these changes?*

The Cambridge Mathematics Framework (CMF)

The CMF is a tool for conceptual mapping in educational design which supports research-informed design decisions in mathematics education. It consists of a searchable network of key mathematical ideas and the relationships between them in the domain of school mathematics, along with a set of tools for exploring and analysing the network and descriptions of what these ideas look like in the classroom. These ideas are ordered in relation to their interdependence, not tied to year ranges, and this provides the opportunity for designers to make choices of their own with respect to temporal sequencing.

The network is derived from interpretation and synthesis of mathematics education research carried out by the Cambridge Mathematics team. The ideas in the network are linked to underlying research sources and can be accessed in the form of dynamic maps which are presented with corresponding Research Summaries, which tell and reference the stories of the map representations with respect to the research sources. External content, like curriculum statements, tasks or assessment items can be linked to the network to help designers to analyse how the ideas underlying their work depend on each other, as was the case with the ACARA collaborative work.

The goals of Cambridge Mathematics involve domain coherence at different levels of educational design, and the CMF is intended to inform design work at different scales: national, regional, and school-level curricula, resources, and even lessons in some contexts. All levels are important for optimal impact, but opportunities to trial the CMF are more frequent for smaller resources. The Cambridge team viewed this collaboration as a valuable contribution to its current formative evaluation goals. In this case, they wanted to examine whether the CMF as a reference tool was meaningful, trustworthy, useful, and usable for curriculum design spanning a range of years in school mathematics.

The CMF situates statistics education as learning how to understand variability in data (Macey et al., 2018). This variability is expressed through the concept of a distribution and exploration of its graphical and mathematical representation. Figure 1 shows an example of this and illustrates the materials the ACARA team was working with; the map shows the highly connected waypoint "knowing simple distributions" which draws together the sometimes-disparate ideas that underpin the concept of a distribution, and establishes a stepping point for more advanced statistical concepts that rely on it.

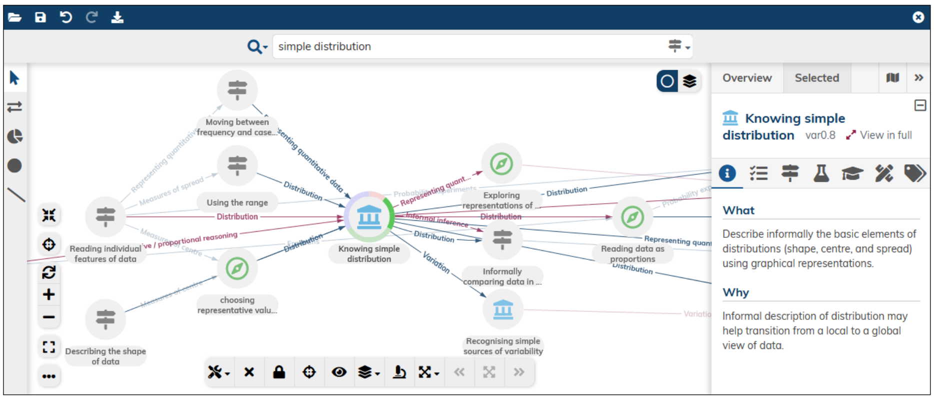

Figure 1. A view of a portion of a map within the CMF

Methods

The collaboration between the ACARA and Cambridge teams took place primarily in and between seven meetings from June - August 2020. After an orientation meeting in which the two teams discussed the context and established mutual goals, they met again for the Cambridge team to introduce the features of the CMF and demonstrate how to search and how to work between maps and detailed descriptions. The Cambridge team linked ACARA's original curriculum statements to mathematical ideas expressed in the CMF and produced underlying maps of ideas and relationships which they provided to the ACARA team for consideration. Having previously piloted the CMF in the design of the UNICEF Learning Passport mathematics curriculum (Oates et al., 2020), which spanned a wide year range, the team was able to apply ideas from that project to the ACARA review.

The ACARA team kept diaries and notes on a weekly basis as they worked with the CMF. The Cambridge team used the diary-interview method, adapted from Zimmerman & Wieder (1977) to develop a detailed picture of their activities. One ACARA team member kept a running diary, while others kept notes, and in each joint discussion the ACARA team would raise issues which had come up in their work over the past week, having to do with the content, use of the CMF, or both. In the final meeting before the revisions went out for initial review, the ACARA team debriefed the Cambridge team on the full diary and their sense of how things had gone overall relative to their interests and expectations.

Outcomes and discussion

Ways of working with the CMF

The ACARA team identified the location of core concepts in the CMF and explored similarities and differences in the way these concepts were represented and the landscape of other connected ideas. This process helped them to clarify what they thought the core concepts were and how things could be structured around them for students to approach and investigate. To do this, they used search features and structural cues in CMF maps. After reflecting on this process, they noted that "there was sufficient detail" in the map "to provoke further exploration of ideas but without predicating the outcome, so it can be a tool for critical inquiry". It was possible to find and recognise "big ideas writ small" and then continue to the next issue.

The higher-level core concepts, structure, approach and mathematising, had already been transformed to key organisers for a larger set of core concepts so that these could be revised and restructured more usefully. From this process, what it means to reason stochastically became a structural focus. Proficiencies like problem solving and reasoning are always embedded in specific content areas, and the ACARA team reported that the CMF helped them to do this more meaningfully, integrating content statements with proficiencies and bridging between the statements and the bigger picture.

Within the timeframe for the review, the ACARA team found themselves choosing what to pay attention to in the CMF based on what most surprised them based on their expectations and prior understanding. When they identified areas requiring particular attention, they used not only maps but some of the more detailed information in the CMF, including descriptions of ideas, rationale for structure and examples of what it looks like in the classroom when students are working with them. They referred to the research summary level of the CMF as applicable for more detailed investigation, however, as these summaries had already been reviewed by external researchers in general, they trusted that research had been reasonably and robustly interpreted.

Use of research synthesis for validation and change

The ACARA team found that research synthesis in the CMF provided further validation for many of the revisions they were planning based on the research they had already consulted. They found there was a high level of consistency with their existing understandings, but that some things stood out as being particularly surprising, and it was these that drew their attention for further investigation.

There were a few notable areas in which the ACARA team decided to adjust content and sequencing based on the implications of research synthesis in the CMF; four examples are given below.

- Before: There was initial concern that the pairings of measurement and geometry, statistics and probability was restricting development of other connections – the ACARA team knew there were connections between measurement and statistics which weren't being explored.
- After: Some of the connections they found in the CMF led to rich discussions around how connections between the mean, error and measurement could be made and actively furthered in the curriculum presentation on the website.

- Before: Summary statistics, which are introduced close together in the current curriculum, sometimes leading to students being unable to distinguish between mean, median and mode later on, as well as to 'procedural approaches' that lacked understanding of what the measures are and why they'd be of interest.
- After: The separation of these statistics as distinct ideas with distinct relationships to other topics in the CMF which built up to them prompted the ACARA team to make several changes. They moved mean and median around to get at deeper conceptual understanding of each and to introduce them at different times, shifted from frequency to mode, and introduced ordinal data, which wasn't included previously, so students would engage with these concepts sooner.

- Before: The notion of distribution was mentioned 11 times in content and achievement standards across 10 year levels, but nevertheless seemed procedurally driven and not conceptually connected for the ACARA team.
- After: After discussing research implications which were apparent in the CMF, they shifted to embedding expectation of reasoning about representations, conceptual understanding, and connections. Distribution is now mentioned only twice but it is richer in that it points to how to talk about distributions in terms of their characteristics (spread, skewness, etc.).

- Before: The ACARA team felt that some connections between probability and statistics were not being made.
- After: The idea in the CMF that probability estimates are the result of narrative frequency was used as a way to bring statistics and probability together more explicitly.

Use of maps as shared artefacts in discussing decisions with stakeholders

The ACARA team felt the maps they were working with would be a useful contribution to discussions with reviewers in which they might need to provide justification for their decisions. Not only did the maps link to research sources and research summaries (synthesis documents), but they also showed what some of the key sequencing decisions were as a result and allowed the conversation to focus on these areas. The full consultation with teachers has not yet begun, but the curriculum and teacher reference groups have provided initial feedback. Qualitative feedback from the combined teacher and curriculum reference group indicated they had seen a positive development in the statistics strand from the original version of the material.

Drawing on this, the ACARA team identified instances where the CMF was used to provide justification for decisions in a way that reference group members agreed was clear and helpful. In one example, CMF maps were used to illustrate the reason for separating statistics and probability as different strands. Some reference group members with a particular focus on statistics felt that the "end-game" or big picture was more apparent, and that it helped see the purpose and meaning of particular decisions. The ACARA team felt it gave them more confidence in laying out their perspective, knowing their reasons had research behind them and they could trace choices back to this in a discussion.

Formative evaluation

Just as the ACARA team found the CMF useful for analysing gaps, ordering, and coverage, the Cambridge team found the reverse was also true. The ACARA team's critical engagement with the CMF as curriculum designers provided valuable formative feedback on the representation of mathematical ideas in the CMF, the tools available for working with relevant information and how these could be efficiently accessed and effectively used. Several points from the Cambridge team's evaluation themes are below:

1. *Meaningful*: Overall, the ACARA team recognised within the CMF concepts which they were working with, realised implications, and made meaningful decisions. There were particular areas in which it became clear during discussion that some implications were not explicitly represented in the CMF. In such cases, CMF content was further refined and possibilities for other supporting documents were raised.
2. *Trustworthy*: The ACARA team themselves felt the CMF provided them with good justifications for their curriculum revisions. Other stakeholders agreed.
3. *Useful*: (a) Because the CMF is a dynamic digital online tool, the collaboration demonstrated that it was productive for two teams across the world from each other to interact virtually around the same artifacts. (b) A theme running throughout the joint discussions was the notion of perspectives from research being represented explicitly vs. implicitly; the Cambridge team realised some perspectives needed more explicit and actionable support, either in the network or the guidance documents. Discussions like this are useful to identify whether other assumptions about what is implicit in design need to be made more real for designers.
4. *Useable*: (a) From the ACARA team's perspective, the CMF "made the research usable" and "did the heavy lifting in a limited time frame". They noted the CMF helped them to overcome time and resource constraints to bring new and well-synthesised research influences into the review. (b) The ACARA team found their first exposure to the CMF mapping environment to be demanding, but it progressively became more comfortable and they felt it had been worth getting over the initial familiarisation hump. The Cambridge team could provide additional support to streamline this process. (c) The ACARA team concluded that using the CMF was not a shortcut in terms of time spent, but they felt the output reflected a broader range of research and was more coherent, helping them meet review goals.

Conclusions

The ACARA team entered the collaboration seeing potential in the CMF as a tool for validation, conceptual insights, construction and exploration, and they agreed that these goals had been met. The process that worked for them involved using the CMF for a combination of individual exploration, group decision-making and justification activities, providing some evidence that the design of the CMF supports active professional decision-making. Reflecting on the outcomes, the ACARA team identified opportunities where the CMF could be used in other strands beyond statistics and probability. The Cambridge team continues fine-grained analysis of interview data which can inform refinement and future use of the CMF for curriculum design, and is in the process of following up on suggestions which emerged from the process. This collaboration demonstrated the value of the CMF as a map-based design tool to support mathematics curriculum design, and processes emerged which will streamline its use in future versions.

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