**Co-designing Integrated Mathematics and Science Lesson Learning Sequences for Primary Education**

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**Abstract**

Integrating mathematics and science can enrich student learning by providing relevant, meaningful, and engaging learning experiences that promote positive attitudes towards both subjects. However, despite reported benefits in relation to student learning, various barriers to integration have also been identified, including limited teacher content and pedagogical content knowledge, and the need for professional learning support with planning and implementing integrated lessons. In this article, we report on the initial phase of a larger project in which mathematics and science education researchers and primary teachers collaborated to design two sequences of integrated mathematics and science lessons. We focus on the processes considered critical for success, including how knowledge was co-constructed by the design team to develop the integrated lesson sequences. Findings are communicated as a set of guidelines to support teachers and educators interested in replicating the process to integrate mathematics and science content.

**Introduction**

The idea of bringing together different subject areas has become increasingly popular as it seems like common sense; in the real world, people’s lives are not organised into separate subjects, but are interconnected (Czerniak & Johnson, 2014). Integrated curriculum “holds promise as a way of meeting … students’ developmental needs by making the subject matter connect to real life and thus engaging them in the learning process.” (St Clair & Hough, 1992, p. 1). Interdisciplinary teaching involves teachers making connections between subject areas obvious for students to see, instead of curricula being fragmented (Sdunekv & Waitz, [2017](https://stemeducationjournal.springeropen.com/articles/10.1186/s40594-019-0201-4#ref-CR63); St. Clair & Hough, [1992](https://stemeducationjournal.springeropen.com/articles/10.1186/s40594-019-0201-4#ref-CR67)). These connections make learning more natural and foster deep conceptual understanding (Capraro & Jones, [2013](https://stemeducationjournal.springeropen.com/articles/10.1186/s40594-019-0201-4#ref-CR15)). Honey, Pearson, and Schweingruber (2014) argue that the “implied goals for students’ learning related to connections underlie many integrated STEM initiatives” even if not explicitly stated in the learning materials (p. 37). Yet planning for integration can be challenging for teachers, due to insufficient teacher content knowledge and pedagogical content knowledge, teachers’ beliefs and attitudes, school-based factors such as time for planning, curriculum constraints, and a strong focus on testing and examinations (Ríordáin, Johnston, & Walshe, 2016; Johnston, Walsh, & Ríordáin, 2020). In this article, we report on the experiences of mathematics and science education researchers and primary teachers who collaboratively developed lesson sequences that integrated mathematics and science, and who identified from their experiences a set of guiding principles to support teachers when faced with similar challenges.

One way to conceptualise the integration of mathematics and science is to visualise an inclined plane of increasing levels of integration, starting at disciplinary and ending with a transdisciplinary approach (Vasquez, 2015). Situated between are multidisciplinary and interdisciplinary approaches. According to Vasquez (2015), multidisciplinary approaches involve the learning of disciplinary specific concepts and skills that are connected through a common theme (e.g., learning about the distribution of living things in science, and sampling and scales in mathematics brought together in the theme of investigating living things in the school yard) whereas interdisciplinary approaches bring together “closely linked concepts and skills … from two or more disciplines with the aim of deepening knowledge and skills.” (p.2). For example, the Australian curriculum mathematics for Year 2 under the Data Representation and Interpretation content substrand expects students to “identify a question of interest based on one categorical variable”, to “gather data relevant to the question” and “check and classify [this] data” (Australian Curriculum, Assessment and Reporting Authority [ACARA], 2015). Similarly, the Australian curriculum Science Inquiry Skills for the same year level expects students to “participate in guided investigations to explore and answer questions” and to “use informal measurements to collect and record observations” (ACARA, 2015). An interdisciplinary lens might view the substantial overlap between the two curricula as suggesting both that the skills and knowledge involved in data representation and interpretation are fundamental for pursuing scientific inquiry; and that the pursuit of scientific inquiry is fundamental to providing appropriate context for developing the skills and knowledge involved in representing and interpreting data.

The role of mathematics in integrated STEM lesson sequences has raised concerns amongst the mathematics education community as the mathematics tends to disappear underneath the problem that is the focus (Williams & Roth, 2019). That is, science often leads and the mathematics follows; the science provides the context and the content and the mathematics becomes an add-on. Students practice mathematics procedures, for example, measuring and data collection, and have limited opportunity to develop understanding of mathematical concepts or develop problem solving and modelling skills (Czerniak & Johnson, 2014; Williams & Roth, 2019). The predominance of science learning goals also occurs because integration tends to be led by science teachers, rather than mathematics teachers (Berlin & White, 1994; Williams & Roth, 2019).

Interdisciplinary models of integration draw on a range of different approaches including content-based, thematic and project-based (Honey et al., 2014), problem-based (English & Mousoulidis, 2015; Mayes, 2019) and multi-modal approaches (Xu, Ferguson, & Tytler, 2019). Various continuum models (e.g., mathematics at one end, science at the other, and the centre representing a blended curriculum) and teaching the two subjects in sequence or in parallel, fit with the meaning of multi-disciplinary models for STEM.

In Australian schools, teachers regularly collaborate to set goals, and plan lessons and lesson sequences (Clarke, Clarke, & Sullivan, 2012), although the nature and extent of the collaboration varies. Lave and Wenger (1991) referred to groups of people engaged in mutual support and collaboration as “communities of practice”. Three dimensions of communities of practice include mutual engagement, joint enterprise and a shared repertoire. Mutual engagement captures the frequency and pattern of interaction amongst group members. Joint enterprise allows for diversity of knowledge and beliefs, but the enterprise needs to be negotiated by the group. Shared repertoire refers to the rituals, routines, tools and modes of operating the group has adopted or adapted as part of its practice over time.

In the project reported in this article, teachers and teacher educators with different subject specialisations engaged in a joint enterprise of planning two STEM lesson sequences for upper primary school. The project represented the first phase of a larger program of research investigating primary teachers’ integration of mathematics and science teaching. The team for this phase included five educators: two experienced primary teachers (one with a specialism in mathematics, another with a specialism in science), and three experienced education researchers/teacher educators (two mathematics teacher educators and one science teacher educator). They collaborated to develop interdisciplinary learning sequences in which science and mathematics concepts and skills were interwoven to deepen student knowledge and understandings (Honey et al., 2014; Vasquez, 2015). The team agreed that the lesson sequences needed to go further than simply linking content in both disciplines through a relevant theme. They aimed to involve students in applying knowledge and skills from mathematics and science to investigate a problem or scenario, that is, to use a problem-based approach to interdisciplinary learning. Furthermore, the teachers and teacher educators focused on ways in which the mathematics could foreground the learning and be substantive.

**The Collaborative Planning Process**

The education researchers and teachers collaborated across a series of planning sessions on two separate occasions, to produce two different integrated lesson sequences. The collaborative sessions were conducted via *Zoom* due to COVID-19 restrictions. The planning process was iterative in the sense that learning from each planning session influenced subsequent planning and discussions. Individual reflections on the planning process were shared orally at the end of each session and education researchers recorded written reflections at the end of each planning cycle. Furthermore, learning from the first sequence shaped the process for the second sequence of lessons, based on reflections from all members. Importantly, two different approaches to planning were adopted for each learning sequence; what follows is an overview of each.

The first sequence entailed identifying a ‘big idea’ in which mathematics and science were interconnected, with knowledge and skills for both subjects complementary and regarded as equally important, rather than one subject servicing the other. An immediate challenge of this approach was selecting a ‘big idea’ that was engaging for students and that ensured the mathematical connections were deep and centred on concepts considered reasonably challenging, or inherent with common misunderstandings for upper primary students. Another challenge of this approach was ‘reverse engineering’ connections to the Australian Curriculum, to ensure the big mathematics and science ideas were connected to the relevant curriculum descriptions for the chosen year level.

The approach for the second sequence differed in that rather than focus on a big idea, the planning process commenced with the Australian curriculum. The group collaborated to discuss key content and skills in the curriculum that presented clear opportunities for connecting the two subjects through a sequence of lessons that would be engaging for students.

Planning of the first sequence spanned three sessions (approximately five hours), while the second sequence was planned over two sessions (approximately four hours). Factors such as initial building of relationships between the group members and facilitating planning online also contributed to the timeframe, although the time invested in establishing this community of practice is difficult to quantify without a comparable counterfactual.

**The Lesson Sequences: Conceptual Understandings**

Two interdisciplinary lesson sequences materialised from the collaborative planning process: *Keeping your finger on the pulse* and *Journey through space – you plan it!* Overviews of the lesson sequences and descriptions of the integrated learning activities are presented in Tables 1 and 2.

The conceptual understandings of the first sequence, *Keeping your finger on the pulse,* aimed to develop multiplicative thinking and proportional reasoning by measuring heart beats per minute to calculate heart rate. To engage students with the mathematics and science, this learning sequence adopted the context of variation in heart rate as an adaptation of human survival. The learning tasks involve students in collecting a variety of data through manipulating demands placed on the body, that is, increasing or decreasing physical movement and applying the mathematical concepts of rate, proportional reasoning and percentage including percentage increase and percentage decrease, estimation and error. In the science curriculum, collecting and representing data and designing an experiment to collect data are key characteristics of the process of scientific inquiry.

The sequence *Journey through space – you plan it!* wasbased on the context of space exploration. It encompassed three big mathematical ideas in number: extending place value to explore large numbers, multiplicative thinking and early proportional reasoning which involves extending multiplication and division concepts to include rate, ratio, and percent (Siemon, Bleckly, & Neal, 2012). One common mathematical difficulty for students is distinguishing between the relative magnitude of large numbers and knowing how to read the numbers, for example, reading the number 250, 000, 000, 000. A common misunderstanding is for students to think additively rather than multiplicatively when comparing quantities. In the context of the lesson sequence, this was framed in terms of travel time and distance between planets: Planet A is 30 million kilometres away and takes 5 days to fly there and Planet B is 50 million kilometres away. An additive thinking approach might assume that it takes 25 days to fly to Planet B. In the lesson sequence, students also engage with concepts of rate and use proportional reasoning. In relation to scientific understandings, the abstract nature of space can create difficulties for students to comprehend the size of the planets and the large distances between them. The design of the sequence was also intended to provide a context for students to learn about some of the features of the planets in earth’s solar system, for example that some planets are solid and others are gaseous, and the differences between planets and other astronomical objects in the solar system (e.g., earth’s moon and the sun).

**Table 1. Keeping your finger on the pulse. Overview of the lesson sequence and learning focus of integrated activities**

|  |  |
| --- | --- |
| **Rationale:**  This integrated mathematics and science learning sequence uses the context of ‘heart rate’ as an adaptation for human survival to engage students with important mathematical and scientific ideas, in particular, proportional reasoning and scientific inquiry skills. Heart rate can be measured indirectly via the pulse and can be manipulated with exercise and breathing. The sequence offers the opportunity to collect a variety of data around heart rate, through manipulating demands placed on the body (i.e. increasing or decreasing physical movement). Data can be recorded and analysed, applying the concepts of percentage (i.e. percentage, percentage increase and percentage decrease), estimation and error. Collecting and representing data and designing an experiment to collect data are key characteristics of scientific endeavour.  The sequence also offers the opportunity to understand why the beating heart and broad concept of a ‘circulatory system’ (without going into specific detail) is an adaptation for survival, particularly for animals that move around. | |
| **Overview of learning tasks** | **Learning focus** |
| Lesson 1   * Finding and measuring heart rate (HR) * Experimenting with measuring HR over 1 min * Calculating HR over time and noticing changes due to increased activity | *Science focus*: Measure pulse rate over one minute and describe effects of increasing heart rate on the body, specifically, adaptations that can be observed when the heart rate changes.  *Mathematics focus*: Measure, calculate and compare during an elapsed time (recording data over one minute). Explore meaning of rate per minute (proportional reasoning). |
| Lesson 2   * Defining resting HR and looking at the range observed in the class * Explore strategies for lowering HR, * Designing experiment to increase HR by certain percentage | *Mathematics focus*: Calculate a percentage and compare frequencies across experiments.  *Science focus:* Define resting HR. Investigate HR as being measured as a range (which varies between people), strategies for lowering heart rate, influence of metabolism on heart rate, consider ideas of experimental design, accuracy for data collection i.e., the same person measuring, recording data accurately, notion of variables - not changing too many variables each time. |
| Lesson 3   * Investigating how to raise HR by 50%: students engage with physical fitness activities | *Science focus*: Adaptations for survival. The body needs oxygen and energy for survival. The heart is responsible for pumping blood around the body and the blood contains oxygen and chemical energy. Heart rate increases when the body needs more of these things. Everybody has a different resting heart rate (hence why it is a range not a fixed figure). Heart rate changes when we exercise and when we are anxious. We can reduce our heart rate through purposeful means, such as mindful breathing and reduced activity.  *Mathematics focus*: Calculate percentage increase in HR. |

**Table 2. Journey through space: You plan it. Overview of the lesson sequence and learning focus of integrated activities**

|  |  |
| --- | --- |
| **Rationale:**  This lesson sequence uses the Year 5 Australian Curriculum: Science, Earth and Space Science focus of the Earth as part of a system of orbiting planets within our solar system. As we are unable to easily travel around the globe or leave the confines of Earth, it can be difficult to appreciate how big Earth is and how far away it is from the Moon and planets. Using the solar system as a rich context, this lesson sequence encourages students to explore the solar system, in particular focusing on distances and times it would take to travel between planets and bodies within the solar system. In so doing, students are also supported to work with large numbers and consider the nature of relative values and proportional mathematical relationships. Starting with familiar units of measure (i.e. distance and travel speeds) between familiar locations, the sequence encourages students to compare these distances and travel times to unknown and abstract locations, such as the speed of a space probe travelling to Mars or beyond. Time is used as a tangible way of making comparisons. A dynamic mural of the solar system is created and used throughout the lesson sequence to support students to consider relative size and relative distance. Student ownership and development of this mural encourages engagement. | |
| **Overview of learning tasks** | **Learning focus** |
| Lesson 1   * Name and rank the order of the planets of our solar system. * Recognise the relative size of each planet by assigning diameter values to each planet in words, rather than numbers. | *Mathematics focus*: Relative size and distance of the planets and making sense of large numbers.  *Science focus*: The Earth is part of a system of planets orbiting around a star. |
| Lesson 2   * Calculate relative speeds of different modes of transport, in particular: walking, driving, flying in an airplane or a space probe between Sydney and Melbourne | *Mathematics focus***:** Estimating, proportional reasoning e.g., speed can be measured in km/hour and metres/seconds, comparing units.  *Science focus:* Using concrete experiences to act as a spring board to more abstract ideas |
| Lesson 3   * Review estimates of travelling to the moon * Estimate the distance and speed it would take in a plane and probe to travel to your chosen place. * Calculate the distance and speed of the probe between Melbourne and Sydney and Earth and the moon. * Create timeline to compare distance between earth and moon. | *Mathematics focus:* Working with big numbers to develop an appreciation for differences in magnitude e.g., the moon is 384 million metres from the Earth  *Science focus:* Relative distances between the planets. The relative distances between planets is a different scale to the relative diameters of the planets. Order of the planets. Size of the solar system in terms of distances or how long it takes to travel across it. |

**Guidelines for planning interdisciplinary learning sequences**

Based on the individual and collaborative reflections of the team members during the planning process, and insights from subsequent discussions on the completed lesson sequences, we have developed a set of six guidelines for designing an interdisciplinary mathematics and science learning sequence.

1. Prepare for the planning process: Design a planning framework
2. Use the curriculum as a guide for planning and thinking creatively
3. Connect concepts and skills using an iterative process
4. Use instructional processes to guide integration
5. Develop a collaborative culture
6. Enable flexibility to allow the content and process to evolve.

Each guideline is explained below, acknowledging that although this is a list, some overlap exists between items.

1. **Prepare for the planning process: Design a planning framework**

Prior to the first planning session with the teachers, the mathematics and science education researchers met to devise a planning framework that could support multiple purposes including our pedagogical approach, an inquiry and problem-based approach to learning, and the teaching of both disciplines (see Appendix 1, Supplementary Material, for Planning Framework template). We found that a three-phase cycle: Launch, Explore, Summarise for each lesson supported these purposes. Critical to the planning process was collaboration amongst team members in identifying key questions that is, prompting questions to support student learning of the key content and process skills for each subject. These prompting questions were recorded in a section of the planning document for each phase of the lesson. Further features of the planning document included support structures for student learning, such as an inbuilt review or reflection at the beginning of each lesson which we referred to as ‘looking back to retune’ student thinking. This was an important aspect in terms of maintaining continuity with inquiry thinking over the three-lesson sequence.

Maintaining a record of our thinking in a way that was accessible to other team members whose content knowledge and expertise was outside one of the subject areas was also critical. We did this through including a section on the ‘big ideas’, skills and common misunderstandings for student learning in the particular mathematics and science topics that we were focusing on.

1. **Use the curriculum as a guide for planning and thinking creatively**

A challenge encountered with the first approach which involved starting with a ‘big idea’ was that the mathematics and science curriculum links were not immediately obvious. We had chosen a ‘big idea’ about exercise and heart rate but the mathematics content for the primary science concepts in the curriculum seemed beyond that of the primary years. Initially it appeared that investigating the effect of exercise on heart rate would involve calculating an increase in heart rate to 70% or 80% or its theoretical maximum (220 minus age), which the mathematics curriculum indicated was more appropriate for Year 7-8 students. Although proportional reasoning is introduced in the Australian mathematics curriculum in the context of fractions for Year 6, percentage increase is not explicitly mentioned until Year 8 (percentage decrease in the context of money is introduced in the Year 6 curriculum). Through in-depth discussion centred around the instructional process, we realised that all students could engage with proportional reasoning if the focus was on the concept of ‘beats per minute’ (BPM) as the core manifesting of the central mathematical idea (proportional reasoning). Rather than treating BPM as a heuristic for measuring how hard the heart was working, this ‘big idea’ was unpacked. For example, we considered different ways of recording BPM by asking students to calculate their maximum BPM when engaging in various activities. Considering this proportional relationship - for example, counting beats for 15 seconds and multiplying by 4 - opened up a means of measuring BPM that was simultaneously more efficient and accurate. Moreover, BPM had the additional benefit of providing a context for exploring proportional relationships that students were highly familiar with; that is, understanding that time involves proportional relationships (e.g., when asked how many seconds are in a minute or how many minutes are in an hour). From this perspective, asking students to consider efficient and accurate ways to record BPM could be considered as building on Year 4 content (converting between units of time). Our deep discussions around the central mathematics idea highlighted the potential of the sequence of lessons to engage students through multiple year levels in proportional reasoning. Our initial challenge was dispensed with as a pseudo-problem because by the end of the process we had produced a learning sequence that was educationally worthwhile from both a mathematics and science perspective. The primary teacher members of our team considered the content sufficiently interesting and engaging for their students.

With regard to the science ideas, there was also no clear alignment between the notion of heart rate and the science curriculum. The curriculum description for level 5/6 related to adaptations of living things and was based on observable features of living things which enable them to survive. Although pulse rate is an observable and measurable thing, it was not suggested as an elaboration for this curriculum description. Creative thinking about how to make an authentic connection to the science curriculum description for this year level was required.

Following the challenges encountered with planning the first lesson sequence, the process for the second lesson sequence focused on first identifying curriculum content in both subjects to complement and support conceptual learning (Furner & Kumar, 2007). While this approach was found to be slightly more time efficient, it also involved continuous refining of ideas and clarifying of the learning focus, specifically the intended outcome for student learning. The problematic aspect during the *Journey through space – you plan it* sequence was more around how the sequence would culminate in an authentic and worthwhile task (in the third lesson) that required students to bring together skills and knowledge that had been previously developed and activated (across the two prior lessons). Through our post-planning reflections, it was apparent that this more fragmented, curriculum-oriented planning approach resulted in a narrow focus that initially relegated the student learning experience to a secondary consideration. It was only after we collectively pondered (and answered) the question: “What might the students be doing, saying, and displaying at the end of the three lessons that will reflect and represent their learning?” that we were able to develop a common vision for what the final rich task might comprise. Both planning experiences highlighted the importance of identifying one big idea centred on complementary science and mathematics content, unpacking both the content and related process skills and the implications for teaching the concepts within a timeframe. Both approaches also reinforced the importance of spending time clarifying through discussion the different mathematics and science ideas we wanted students to learn, why they were important to learn, and how they connected through the lesson sequence.

1. **Connect concepts and skills using an iterative process**

Drawing upon the literature on integrating mathematics and science, there is various advice concerning the process for integrating subjects. Furner and Kumar (2007) suggest three possible approaches: mathematics is taught entirely as part of science, mathematics is used as the language and tools for science teaching, or science is taught solely as part of mathematics. In contrast, Beane (1992) suggests first identifying a big idea or theme, then considering how each subject contributes to the learning of the idea. Our experience highlighted that planning for deep connections between the two subjects involves switching between disciplinary lenses so that the process is iterative rather than simultaneous. Each iteration allowed opportunities to connect concepts and skills across disciplines and to refine the plan with the core learning focus in mind. We found it was necessary to systematically vary our disciplinary lens and adopt an iterative process to deepen the connections between the big ideas for both mathematics and science and the learning activities.

Related to adopting a disciplinary lens during the planning process, is the need for the teachers to emphasise the key mathematical or scientific idea when teaching. Although the aim of an interdisciplinary approach is for concepts and skills to become “interconnected and interdependent” (Vasquez, 2015, n.p.), for example students can create a mathematical model to solve a scientific problem, our planning experiences highlighted the need for the teacher to emphasise the relevant science or mathematical idea when teaching rather than focus on both simultaneously. This meant that when we planned the lesson sequences, we included post-task reflections that focused on either the big ideas for mathematics or science.

1. **Use instructional processes to guide integration**

At the beginning of the planning process we were determined to think deeply about the mathematical connections so that the mathematics was not perceived as being in service of science i.e., a conscious effort was made to steer the mathematics away from the curriculum sub-strand of data representation and interpretation. However, our planning experience refuted our initial thoughts that integrating the data aspect of the mathematics curriculum would provide a superficial link. We came to realise that the connections between the data interpretation aspect of the mathematics curriculum and science inquiry skills (as opposed to science content) were inextricably linked and important to deepen student learning. Upon reflection, we discovered it was possible to map the data aspect of the mathematics curriculum to stages of science inquiry processes, thus emphasising the importance of integrating data representation and interpretation.

Our planning experience highlighted that the mathematics requires a context, or perhaps more accurately, the mathematics benefits from being taught through a rich context that makes it relevant and provides a real-life application. We found that for both sequences, the science provided the foundation on which to build the mathematics and in effect ‘bookended’ the process by providing the initial ‘hook’ and final ‘take-away’. Beginning and ending with the science learning, and adopting an iterative process to planning, meant that the ‘science was acting in the service of mathematics’ and vice versa. Essentially the relationship between the science and mathematics could be seen as symbiotic, rather than a dichotomous choice about which subject would dictate the planning decisions and processes. Furthermore, we found that integrating the subjects through an inquiry or problem-solving instructional approach helped to bridge the gap between abstract ideas and real-life experiences thus making the learning tangible, as well as strengthening the integration of scientific process skills (Furner & Kumar, 2007).

1. **Develop a Collaborative Culture**

Collaboration between teachers within a professional learning community is considered particularly powerful for integrating subjects because it provides opportunities to share content knowledge and expertise across fields; considered “a prerequisite of successful integration” (Johnston et al., 2020, p. 1401). Our project involved practising teachers, each specialised in one of the disciplines, and education researchers collaborating to design integrated lesson sequences. In our reflections on the process, it was notable that we were drawing upon the expertise and knowledge of each member in the group, which is recognised as being particularly important for planning across two subjects (Putnam & Borko, 2000) and emphasises our truly “joint enterprise” (Lave & Wenger, 1991).

When planning the first sequence, *Google Jamboard* provided us with a useful tool to share and access content knowledge across both disciplines. We collaborated to co-construct knowledge and develop a shared understanding of how science and mathematics concepts could be taught, by posing questions to clarify ideas and negotiate how best to integrate the teaching of the concepts for the two disciplines. The sharing of different perspectives by group members helped to refine planning and stimulate new thinking. These are behaviours that have been recognised as being important to teacher professional learning and the development of a well-functioning community of practice (Butler, Lauscher, Jarvis-Selinger, & Beckingham, 2004; Berry, Loughran, Smith, & Lindsay, 2009; Johnston et al., 2020).

1. **Enable flexibility to allow the content and process to evolve**

As we progressed with the lesson sequence design, we became aware that flexibility, creativity and risk-taking are useful dispositions and qualities for this type of curriculum planning. Such a process requires participants to develop relationships of trust through collaboration. We realised the importance of clarity in explicating what we were trying to achieve (keeping an end product in mind), while at the same time maintaining a sense of flexibility to allow the content and process to evolve. We took time at the beginning of each meeting to ‘check-in’ with each other about any issues or questions and to reflect on our purposes and progress. We encouraged each other to ask questions and reminded each other not to feel too tightly bound to the curriculum as we were developing the ideas together. Developing a culture of risk taking also meant that group members could put forward a discipline based idea, not necessarily knowing how it aligned with the other discipline, and trust that other group members with expertise in that discipline, or in classroom teaching, would be willing to offer ideas about potential connections and alignments.

**Conclusion**

For upper primary teachers interested in experimenting with an integrated approach to teaching mathematics and science, these sequences and our guidelines can provide a springboard for collaborative planning discussions and an opportunity to develop and/or adapt a learning trajectory depending on the prior learning experiences of students.

There was strong consensus amongst group members that planning the lesson sequences was a valuable learning experience on three levels: learning about the process of integrating the two subjects, deepening learning about the mathematics and science content, and learning to work in cross-disciplinary teams. The planning process involved a team of professionals collaborating, learning from each other, constructing knowledge, debating ideas and refining them. Although the planning process was valued by all participants, it comes with the caveat that it was also a deceptively time-consuming process. While we allocated two, three hour sessions for the lesson sequence design, in reality we did a lot of thinking and processing of ideas between sessions, and further reflection and refinement after the sequence was developed. Perhaps initially for us, because relationships and development of trust between education researchers and teachers had to be developed (we hardly knew each other before starting), our process took a little longer than might in a school where teachers already know each other well. Also, our situation was potentially compounded because of the need to conduct the planning online rather than face-to-face due to COVID-19. Finally, although we produced the two lesson sequences and a set of guidelines, there was a shared feeling among the group that our end product does not capture the fullness and extent of our professional learning discussions and decision-making processes. The experience was a significant and worthwhile opportunity to connect mathematics and science curricula in a meaningful way for the upper primary years, to tackle big ideas in mathematics, and important content knowledge and process skills in both subject areas, as well as bringing together teachers and researchers into a co-design process.

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**Ethics**

The research has been approved by Monash University Human Ethics Committee #22773

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