The Development of a STEM Literacy and Numeracy Program for the Foundation to Year 2 Years of Schooling

Tom Lowrie
University of Canberra
thomas.lowrie@canberra.edu.au

Ilyse Resnick
University of Canberra
ilyse.resnick@canberra.edu.au

Kevin Larkin
Griffith University
k.larkin@griffith.edu.au

This paper describes design and content decisions undertaken in the development of the Early Years STEM Australia (ELSA) Foundation-Year Two (F-2) school program. The ELSA F-2 program aims to foster critical STEM literacy and numeracy skills in young learners by providing an integrated approach to science, technology, engineering, and mathematics (STEM). The paper reviews the existing literature on the STEM Practices framework and the Experience-Represent-Apply (ERA) pedagogical approach that underpinned the design of learning activities and digital tools to ensure concentrated topic coverage of STEM related outcomes from the Australian Curriculum V9.

The Early Years STEM Australia (ELSA) program has received ongoing support from the Australian Government since 2016. The aim of the program is to enhance Science, Technology, Engineering, and Mathematics (STEM) engagement and numeracy learning from preschool (see Lowrie & Logan, 2019) through the early years of school (i.e., Foundation-Year 2). The school program will be the focus of this paper. Although STEM engagement has had a presence in schools for more than a decade, the term and its practice(s) have not been clearly defined (English, 2016). To some degree, this is because classroom teachers and educational leaders cannot reference a curriculum document to support the development of authentic learning activities. Instead, should they choose to follow a STEM approach, they must plan integrated STEM activities drawing from three different curriculum documents – Mathematics, Science and Digital Technologies, with the additional limitation that there are no curriculum documents supporting the integration of Engineering into STEM activities.

The conceptual framework underpinning ELSA is built on STEM practices, a departure from traditional, content-based approaches that dominate early years education. This framework provides a foundation for STEM literacy and numeracy that encourages active engagement with real-world problems, allowing young students to explore, apply, and represent their understandings in innovative ways. Instead of focusing solely on discipline-specific content, the ELSA framework nurtures skills and processes related to STEM thinking, which is crucial for building a more holistic understanding of the world.

This paper explores the conceptual framework of ELSA, drawing on existing research in STEM education and early childhood pedagogy, including the work of Larkin and Lowrie (2017), Lowrie et al. (2018), and Lowrie and Larkin (2020). In the following sections, we will outline the STEM practices framework, the Experience-Represent-Apply (ERA) pedagogical model, and report on how these theoretical and pedagogical constructs influenced the design of the ELSA F-2 program.

STEM Practices as a Design Brief

A practice is defined as an application or use of an idea, method or value (Lowrie et al., 2017). Such practices are enabled in situations when content is both contextualised and contested within the classroom—as students not only learn about discipline content but also understand how to use and apply knowledge and skills in various contexts. The focus on

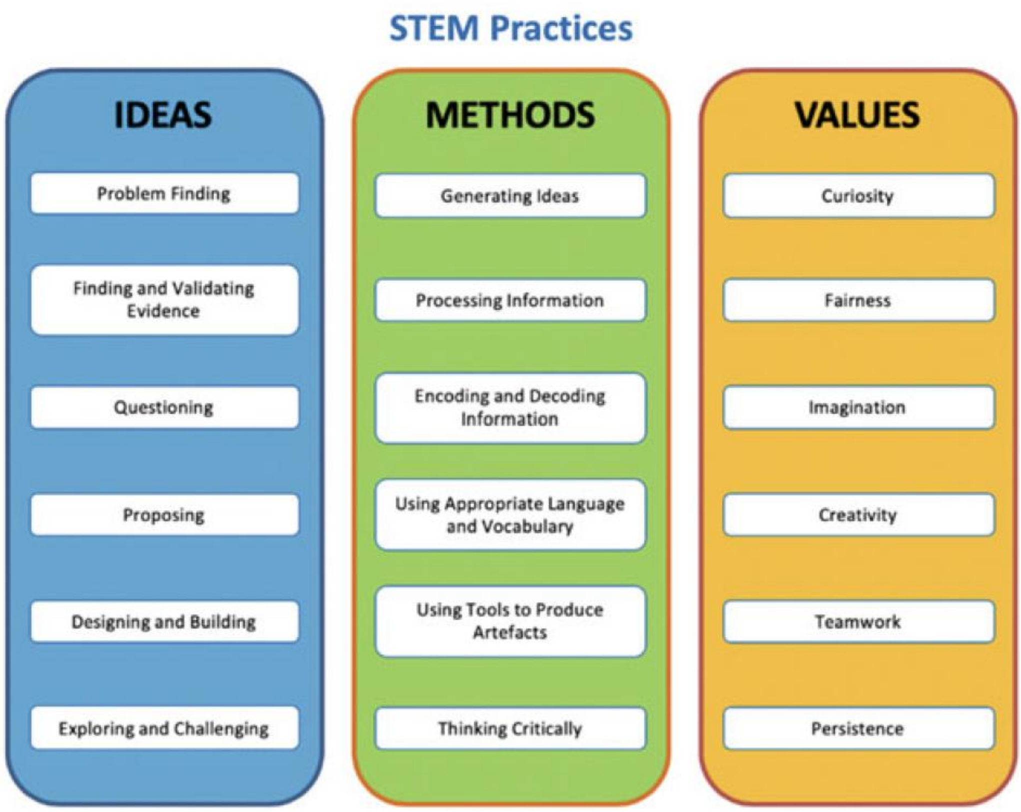
(2025). In S. M. Patahuddin, L. Gaunt, D. Harris & K. Tripet (Eds.), *Unlocking minds in mathematics education. Proceedings of the 47th annual conference of the Mathematics Education Research Group of Australasia* (pp. 269–276). Canberra: MERGA.

practices ensures that understandings are related to the real-world contexts that are enacted through participation and engagement (Kemmis, 2008). Larkin et. al., (2022) maintained that STEM education should go beyond simply teaching the content of science, technology, engineering, and mathematics. Instead, STEM should focus on the practices that are characteristic of these disciplines. This approach aligns with the idea that STEM is a way of thinking and doing, rather than a body of knowledge that can be compartmentalised into isolated subjects.

Lowrie et al. (2018) discuss how these practices involve concept development and formation, problem-solving, critical thinking, and collaboration. STEM practices also emphasise real-world applications, where students can engage with complex problems and come up with solutions that have tangible outcomes. This approach allows students to not only acquire content knowledge but to also understand how to apply it in various contexts. In working with educators in the ELSA program, the following 18 ideas, methods and values were established as important for early years STEM learning (see Figure 1).

Figure 1

STEM Practices Underpinning the ELSA Program (Note: Permission Granted by SPLAT-Maths to Use This Image).



By focusing on STEM practices, the ELSA program encourages young learners to engage with the core principles of STEM through hands-on activities that promote exploration and creativity. This aligns with research that suggests that early exposure to STEM practices supports the development of critical thinking skills and helps students become more confident and competent in their problem-solving abilities (Brenneman, et al., 2019).

The Experience-Represent-Apply (ERA) Pedagogical Framework

The Experience-Represent-Apply (ERA) framework, theorised by Lowrie and Larkin (2020), is the second key component of the ELSA program. The ERA framework emphasises three distinct phases that are integral to STEM learning: experience, represent, and apply. This framework builds on the understanding that learning is an active process that involves not only encountering new information but also making sense of it and applying it in meaningful ways.

- Experience: In the first phase, students engage with real-world problems or scenarios that stimulate curiosity and inquiry. They are encouraged to explore concepts through hands-on, experiential learning activities that connect abstract ideas to tangible experiences.
- Represent: In the second phase, students use various tools and strategies to represent their understanding of the concepts they have explored. This may include using visual representations, mathematical models, diagrams, or digital technologies to express their ideas.
- Apply: The final phase involves students applying their knowledge to solve problems or create solutions in real-world contexts. This phase encourages students to think critically and make connections between their learning and the world around them.

The ERA framework supports the idea that learning is an iterative process that involves not just absorbing content but also actively engaging with and applying that knowledge. By incorporating this framework into the ELSA program, students are guided through a structured process of engagement that encourages them to think critically, make connections, and develop practical solutions to problems.

Scope of the School Program

In conceptualising the scope of the program, we were especially mindful that in many rural and remote areas across Australia children are learning in classrooms with peers from different year levels. Consequently, we envisaged developing ‘content bundles’, which could be accessed by children across various learning arrangements in the early years of schooling (e.g., single year level classes, combined year level classes, home schooling, distance learning). Such an approach fits with our conception of STEM practices and provides teachers with flexibility in the delivery of contextually relevant content. The content bundles address learning outcomes from the discipline areas (mathematics, science, digital technologies) in ways that promoted the STEM practices. Within each of the units (a four-week block of activities explained below), relevant STEM practices were outlined for the teachers. For example, in the Foundation Unit on Location and Transformation, student learning was underpinned by the following STEM Practices: *Ideas* - Exploring and Challenging; *Methods* – Processing Information and Appropriate Language and Vocabulary; *Values* – Teamwork.

Our main vehicle for ensuring contextual, community based, and culturally appropriate learning experiences was to ensure that theme-based content had some form of authenticity and connectivity to children of this age, irrespective of their geographical location. The Program Advisory Group, established by the Department of Education, was especially helpful in providing advice on this aspect of the program scope. The STEM-practice themes included:

- Foundation: Local store and local garden
- Year 1: Fire and ambulance emergency services
- Year 2: Community radio station

To make learning more accessible to children in rural and remote areas, themes were not aligned to traditional or commonly perceived STEM professions such as engineers or mathematicians or scientists. Rather the themes supported an understanding that STEM is present in much of the daily lived experiences of students, such as a local garden or the emergency services in their town or community radio. These broader themes also provided teachers with opportunities to tailor the learning to suit the learning context they were in.

The Design Process

Using the ERA Framework as our guide, we developed four integrated STEM units for each year level – Foundation, Year One and Year Two. Within each of these 12 units there were four topics, giving a total of 48 topics across F-2. Some examples of the topics covered in the program include *sorting objects based on spatial and numerical attributes; aligning numbers to spatial patterns;* and *give and follow directions using landmarks* (Foundation); *measure and estimate distance with informal units*; *decoding representations using maps;* and *sorting and ordering visual data* (Year 1); and *graphing using and X- and Y- axis*; *Fraction Families – Wholes, halves, quarters and eights;* and *transformations and rotations* (Year 2).

Using the ERA framework as a scaffold, each topic included experience, represent and apply activities that would comprise approximately 1 to 1.5 hours of learning (this included time spent using the digital devices – approximately 12-15 minutes per topic). It was recommended to the teachers that they deliver one topic per week and that at the end of the four weeks they take an additional week to consolidate learning within the unit. The units were mapped to STEM Outcomes from the Australian Mathematics, Science and Digital Technologies Curriculums V9 and included learning outcomes and success criteria, digital and non-digital resources, and skills progressions via the digital games. The teachers also had access to a digital dashboard that provided learning analytics (updated daily) on each student's learning journey as they interacted with the digital games.

Digital Learning Experiences

The ELSA programs uses both digital and non-digital learning materials as part of the ERA learning experience outlined above. Here we focus on the design of the digital learning materials created in the program, as they played an important role in our vision for flexible learning experiences for children and teachers participating in the Program. The place of digital tools in children's learning has been well established in the research literature (Hirsh-Pasek et al., 2015; Moyer-Packenham et al., 2019).

In the development of the ELSA Program, the ERA Framework was also used to guide the design of the digital components of the ELSA Program. It is necessary to indicate here that, although digital design and coding experts (professional app developers) were employed to code the 48 learning games in the program, they worked under the close and very explicit pedagogical direction of the ELSA pedagogical team. This ensured that the digital games were explicitly linked to the weekly ERA learning activities that we created for students in F-2. This design process regularly resulted in very robust discussions between educators and app developers to ensure that the apps were philosophically aligned to a play-based approach to learning (Arnott et al., 2018) and pedagogically aligned to the EYLF and intentional teaching (Lowrie & Larkin, 2020).

Thus, the digital games were designed to reinforce the learning from each ERA topic cycle and were also designed to be played by children without teacher support. Each game increases in complexity as the children experience success in the game with scaffolding provided in game. Below we provide an example of one digital task from each year level.

Foundation

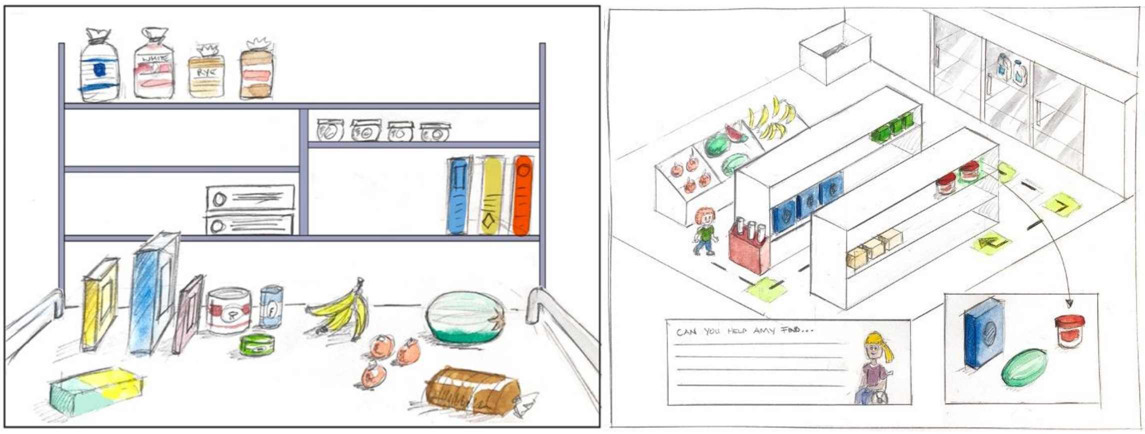
The first set of tasks is for students *to order objects (groceries) based on a specified attribute (e.g., height, width, number).* Children are in a local store and are looking at a set of shelves. There are groceries that need to be packed onto the shelves. Students place the grocery items onto the shelves according to specified attributes. For example, in the first task, the height of the items varied, but all other attributes remained the same. Students ordered different sized groceries onto shelves (See Figure 2A) based on the following levels using language such as tall/short:

- Copy the ordered sequence
- Extend the ordered sequence
- Identify missing item in ordered sequence
- Create an ordered sequence

In a subsequent task, students follow directions using positional language and landmarks (see Figure 2B). Students move down an aisle in the local store. There are 3-4 aisles with 2-4 items on each side of the aisle, depending on the complexity of the challenge. Students first identify items they see on the shelves and then follow/provide directions to find these items in the store. By way of example, students find a grocery item in the store (where they have already labelled the products in the previous challenge) by following directions using positional language to move around store (e.g., move towards the fruit section, or walk past the apples, or collect the item next to the plums). The instructions become more complex each turn, that is, to attain the goal, students correctly follow two or more instructions, for example, go past the apples, between the frozen food and the bread and collect the item next to the plums.

Figure 2

Spatial Ordering of Objects (A) and Spatial Transformation in Following Directions (B)

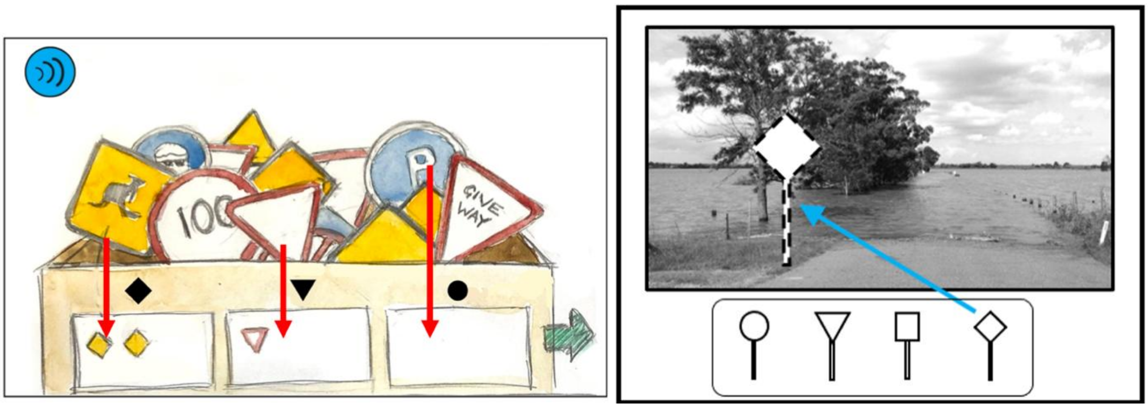


Year 1

Students are working in an Emergency Services (e.g., Fire/Ambulance) Station. In one scenario, a delivery of new signs has arrived, but they have all been mixed up. Students need to sort and organise these signs so they can be used by the emergency services. The students are encouraged to initially sort signs using simple categories, that is, by colour and shape (see Figure 3A). Firstly, one shape (e.g. a triangle) is orientated a particular way and then is presented in various orientations. As the task progresses it increases in complexity as students undertake two-way sorts (i.e., colour and shape by a second level of shape orientation). As the students progress through the challenges, they also engage in more complex decoding skills, such as applying signs to a simple scenario based on interpretation of the sign and the scenario (see Figure 3B). Initially students are scaffolded with their decoding, progressing to select the correct sign (based on attributes of shape and colour) by encoding the problem scene only.

Figure 3

Decoding Data (A) and Encoding Data (B)



Year 2

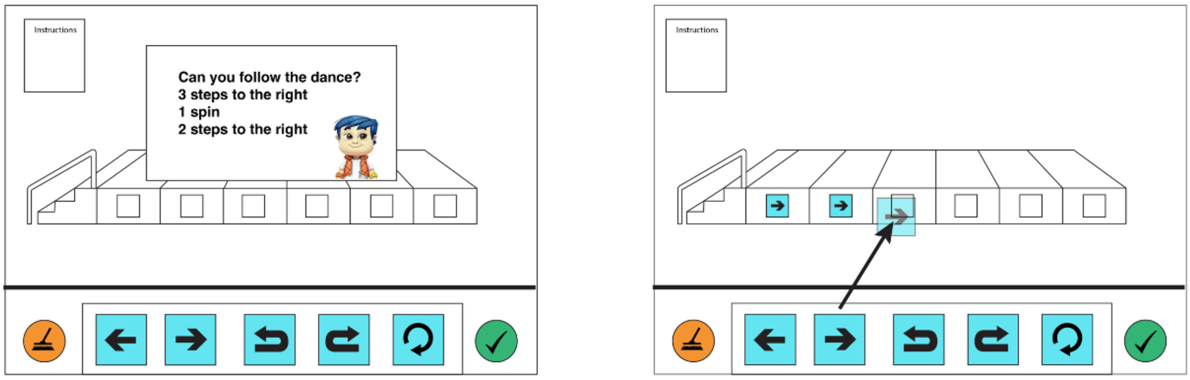
At this grade level, students complete tasks related to the functionality of a community radio station. Students will transition from computational thinking activities in the radio station (e.g., debugging errors in how a sound mixer is set up by moving sliders and turning dials and designing simple musical devices using coding blueprints they have chosen) to a dance studio where they will teach an ELSA character to dance. The series of dances incorporate, with increasing complexity, translations, internal rotations, external rotations, and combinations of translations and rotations. The increasing complexity will be achieved by modifying the number of moves to be choreographed, by changes to the representations of the moves (from pictorial through to symbolic), and by including numerical instructions whereby the character can perform loops of instructions. The children move the character into the position they would be at the end of the instructions and then hit submit (see Figure 4). The levels of complexity include:

a) Movements left and right and right to left using various numbers of steps (e.g., three right, two left and two right).
b) Movements forwards and backwards and backwards and forwards using various numbers of steps (e.g., three forwards, two backwards and one forward).
c) Combinations of a and b above.
d) Combinations of a, b and c above, with numerical symbols indicating loops of actions to be taken.
e) Combinations of all of the above, but with abstract representation (e.g., dance shoeprint style).

Built into the game design is an important element of spatial reasoning as the children will have the option, later in the game, to change the perspective from which they see the dance performed. In this change of perspective scenario the students will code the dance, as per the instructions above, but will then have the option to choose to watch the ELSA character dance the instructions either from the perspective of the crowd (the perspective they will see as they learn to code the dance throughout the early levels), or from the perspective of the ELSA character performing the dance. In the later scenario, this means that instructions to move left or turn clockwise from the view of the crowd are, from the ELSA character's perspective an instruction to move right or turn anticlockwise. Research has indicated that perspective taking predicts mathematics achievement, and is especially important for girls (Harris et al., 2025) and those from rural/regional communities (Harris et al., 2022).

Figure 4

Encoding and Decoding Translations to Develop a Dance Sequence



Remy introduces the dance stage and gives first instructions

Drag and drop the moves to stage

Conclusion

The Early Years STEM Australia (ELSA F-2) program represents an innovative approach to STEM education in the early years of school. By focusing on STEM practices as a theoretical stance, and the Experience-Represent-Apply (ERA) as a pedagogical model, the program supports teachers in providing an integrated STEM experience in authentic contexts that can be modified to suit the needs of their students, whilst at the same time fostering essential STEM literacy and numeracy skills in young learners that are mapped to the Australian Curriculum. The program has also been designed based on a robust evidence base, highlighted by a national-wide randomised control trial (RCT), which assessed the efficacy of the preschool program under experimental conditions (Resnick & Lowrie, 2024). The RCT revealed that engagement with a play-based spatial program led to better overall spatial reasoning and transferred to better numeracy understanding for students compared with a business-as-usual control. The results underscore the importance of embedding spatial learning within strong pedagogy and authentic learning contexts, supported by the use of engaging digital games that can be played independently by the students with their learning automatically reported back to teachers, via a digital dashboard, at individual and cohort levels.

The continued development and implementation of the ELSA program will contribute to the broader goal of enhancing STEM education in Australia and beyond. In the next phase of research, we intend to report on a randomised control trial that was conducted during the 2024 school year. We hope to report of these findings at a forthcoming MERGA conference.

Acknowledgements

We acknowledge the support of the Australian Government Department of Education in its funding of the ELSA programs and research projects since 2016. We also acknowledge the support of all of the state and territory jurisdictions, and many catholic dioceses, for their willingness to engage with our programs.

References

Arnott, A., Palaiologou, I. & Gray, C. (2018). Digital devices, internet-enabled toys and digital games: The changing nature of young children's learning ecologies, experiences and pedagogies. *British Journal of Educational Technology, 49(*5), 803–806. https://doi.org/10.1111/bjet.12676

Australian Curriculum, Assessment and Reporting Authority (ACARA). (2023). *Australian Curriculum: Mathematics*. Retrieved from https://www.australiancurriculum.edu.au/

Brenneman, K., Lange, A. & Nayfeld, I. (2019). Integrating STEM into preschool education: Designing a professional development model in diverse settings. *Early Childhood Education Journal*, *47*, 15-28.

English, L. (2016). STEM education K-12: Perspectives on integration. *International Journal of STEM Education, 3*(1). http://dx.dio.org/10.1186/s40594-016-0036-1.

Harris, D., Logan, T. & Lowrie, T. (2022). Authentic perspective-taking: Looking beyond abstract spatial skills to the influence of culture and environment. *Learning, Culture, and Social Interaction, 33*. https://doi.org/10.1016/j.lcsi.2022.100611

Harris, D., Resnick, I., Logan, T. & Lowrie, T. (2025). Pathways From Spatial Skills to Mathematics: The Roles of Gender and Fluid Reasoning. *Developmental Science*, *28*(2), e13602.

Hirsh-Pasek, K., Zosh, J. M., Michnick Golinkoff, R., Gray, J. H., Robb, M. B. & Kaufman, J. (2015). Putting education in "educational" apps: Lessons from the science of learning. *Psychological Science in the Public Interest, 16*(1), 3–34. https://doi.org/10.1177/152910061 5569721

Kemmis, S. (2008). Critical theory and participatory action research. *The SAGE Handbook of Action Research: Participative Inquiry and Practice, 2* 121-38.

Larkin, K. & Lowrie, T. (2019). The Role and Nature of Digital Technology use in Preschool STEM. In G. Hine, S. Blackley, & A. Cooke (Eds.). *Mathematics Education Research: Impacting Practice* (Proceedings of the 42nd annual conference of the Mathematics Education Research Group of Australasia). https://eric.ed.gov/?id=ED604741.

Larkin, K., Lommatsch, C., Resnick, I. & Lowrie, T. (2022). The design and use of a digital tool to support the development of preschool children's logical reasoning. *Journal of Research on Technology in Education. 10*.1080/15391523.2022.2107590.

Lowrie, T. & Larkin, K. (2020). The Experience-Represent-Apply (ERA) framework: A new paradigm for teaching STEM. British Journal of Educational Technology, 51(1), 131-147. https://bera-journals.onlinelibrary.wiley.com/doi/abs/10.1111/bjet.12789

Lowrie, T. & Logan, T. (2019). STEM and Digital Technologies in Play Based Environments; A New Approach. In G. Hine, S. Blackley, & A. Cooke (Eds.). *Mathematics Education Research: Impacting Practice* (Proceedings of the 42nd annual conference of the Mathematics Education Research Group of Australasia). https://eric.ed.gov/?id=ED604741.

Lowrie, T., Leonard, J. & Fitzgerald, A. (2018). STEM literacy in early years: Developing the practices and processes of science, technology, engineering, and mathematics. *Education and Development in Early Childhood, 2*(1), 1243-1260. https://doi.org/10.15460/eder.2.1.1243

Moyer-Packenham, P., Lommatsch, C., Litster, K., Ashby, J., Bullock, E., Roxburgh, A., Shumway, J., Speed, E., Covington, B., Hartmann, C., Clarke-Midura, J., Skaria, J., Westenskow, A., MacDonald, B., Symanzik, J. & Jordan, K. (2019). How design features in digital math games support learning and mathematics connections. *Computers in Human Behavior, 91*, 316–332. https://doi.org/10.1016/j.chb.2018.09.036

Resnick, I. & Lowrie, T. (2024). Spatial reasoning supports preschool numeracy: Findings from a large-scale nationally representative randomized control trial. *Journal for Research in Mathematics Education, 54*, 295-316. https://doi.org/10.5951/jresematheduc-2022-0051