MONASH University

Conceptual PlayLab

Working paper number 68 –

https://www.monash.edu/education/research/projects/conceptual-playlab/publications

Submitted to: Adams, J.D and Siry, C (in press). Wondering science: Creativity, Imagining and Future Thinking in Science Education, Springer Publisher. Cultural Studies of Science Education Book Series.

Imaginating in preschools: A cultural-historical study of girls' first experiences of STEM education in play-based settings

Marilyn Fleer
Conceptual PlayLab, Monash University, Australia
marilyn.fleer@monash.edu

Abstract

The aim of this chapter is to report on the results of a study into how girls enter into engineering and science play practices in preschool settings. Designed as an educational experiment, 31 children and five teachers were followed during the first moments of introducing science and engineering involving bridgebuilding over 5.4 weeks. Data included digital observations (27.3hr) of teachers and children (3.4 – 5.5yrs; mean 4.4yrs). Cultural-historical conceptions of play, imagination and creativity framed the study. The findings show that during free play periods, a completely new activity setting for engineering and science was enabled alongside of the traditional Froebelian learning areas (eg., blocks, craft). The new activity setting gave new possibilities for girls. However, gendered divergences in participation emerged. The results suggest that there is an undervaluing of the impact of social relations on how girls imagine, wonder and create during engineering and science play. The findings have implications for professional development of educators working in preschool settings, where a recognition of the positive *imaginating* by girls is needed in engineering and science play.

Keywords: imagination, early childhood; science, engineering education; STEM, gender; preschool

1 Introduction

The aim of this chapter is to report on the results of a study where preschool children were introduced into new engineering play practices associated with science, alongside of the traditional learning areas of the home corner, craft areas, and outdoor play. The specific focus of the chapter is on how the girls were oriented to the new play practices and how they were positioned by both teachers and other children as they imagined and created block bridges.

The study is based on a conception that play is the leading activity of the preschool child (Vygotsky, 1966), and the new play practices associated with engineering and science can be better understood when imagination in play and imagination in science, technology, engineering and mathematics (STEM) come together in social relations between children and educators. The term STEM is often used by researchers to capture scientific and technically oriented activities in educational settings, and is used in this chapter to capture the engineering and science play practices of preschool children.

In keeping with the focus of this volume, imagination is key to both design in engineering and to wondering in science, but imagination is also needed for the creation of new imagined products through engineering processes. In this chapter, preschool engineering acts as the practice context in which young children imagine, wonder and create in their scientific and engineering play. Engineering as a professional term encompasses the use of science concepts, features the design process, problem solving, and draws upon a range of technologies and project management competencies – all features of STEM.

The chapter begins with an overview of what is known about girls in STEM related fields such as engineering and science, followed by a discussion of the cultural-historical conception of *imagination and creativity* (Vygotsky, 2004) as the theoretical framework for the study. This is followed by the details of the study design, the results, and a discussion of the findings. The chapter concludes with implications for teacher professional learning and practice associated with setting up engineering play environments in preschools for girls engineering and science learning.

2 Girls in STEM education

There is now an abundance of international statistics on the under representation of girls and women in STEM (Nguyen, Russo-Tait, Riegle-Crumb and Doerr, 2022). The concerns are for both the small number of women in the STEM professions (Régner et al., 2019), such an engineering, and the lack of interest by girls and young women in pursuing STEM careers (Kung, 2021). The STEM pathway or pipeline appears to be leaky and blocked to girls and women (Corrigan and Aikens, 2020). Further, when entering the STEM professions, problems with workplace culture (White, Miles and Frantell, 2020) and retention are evident (Kaspura, 2017). Preparation for future STEM careers appear to be difficult for girls and young women (Kim, Jin and Bian, 2024). This has also been noted in research where the focus has been on the racial/ethnic gap in STEM (Riegle-Crumb et al., 2019; Kim, Jin and Bian, 2024). Calls for action in staff diversity in STEM professions now proliferate in Government reports, suggesting some urgency for change (Nguyen, Russo-Tait, Riegle-Crumb and Doerr, 2022).

The argument for changing the current situation include drawing attention to the lack of representation of women and girls in STEM which involves 50% of the population (Croft, 2015), the need for diversity of the STEM profession for innovation and creativity (*Gender in research and innovation,* 2015), and the presentation of a business case for gender diversity featuring impact on economics, innovation, improved governance and a bigger talent pool (Belanger, 2015). However, there is also an increasing realisation that this challenge should be examined at the beginning of the pipeline (Carrasco Rueda, González-Gijón Martínez-Heredia, 2023; Hamel, 2021; Rueda, González-Gijón and Martínez-Heredia, 2023; Stephenson, Fleer and Fragkiadaki, 2022a) so that science and engineering are imagined as possible activities and future career pathways for girls (Chapman, 2023; Kung, 2021; Kim, Jin, and Bian, 2024). But there are challenges, as noted by Prioletta (2022) who found "early learning settings, such as kindergartens, are prime sites in which gender violence is enacted and normalised" (p. 973) and as noted by Kung (2021):

> The degree of gender-type play shown by preschoolers can predict their occupational interests 10 years later following transition into adolescence (p. 843).

What is known about gender differences in preschool engineering activities appear to be contested in the literature (Hamel, 2021). There are studies that show no gender differences in STEM activities of boys and girls in preschool settigs. For instance, Gold et al. (2015) concluded that no differences in gender were found in their study. They examined the engineering practices of 66 preschool children and found no difference in gender for physical, social and what he termed engineering play across three different study conditions. Through examining the behaviours of 29 girls and 37 boys in a traditional outdoor play area using loose parts (e.g., large light weight soft blocks) and the dramatic play area, no gender differences were found in the engineering play of the children. Only a small difference in boys' explanations of their engineering play was noted and this centered on a tendency to explain their activity in relation to how something worked.

Positive dimensions of engineering for girls have also been noted in educational programs designed specifically for preschool children in community based programs. For example, in a study related to girls in family based engineering programs, Pattison et al., (2022) studied the impact of an engineering program on 18 low-income Spanish and English-speaking parents with their preschool aged children and found that these programs were valued and created a strong sense of togetherness for the families. No gender differeces were reported.

In contrast, there is general literature and systematic reviews oriented to early childhood teacher perceptions and beliefs about STEM that are gendered (Hamel, 2021) and reviews and empirical studies that examine girls' motivations for STEM (Carrasco Rueda, González-Gijón Martínez-Heredia, 2023) where the negative impact of girls' early experiences of STEM are evident. Both longstanding and recent studies show girls' negative experiences of STEM. For instance in earlier research by Gold (2014) where pre-schoolers physical, social and engineering play behaviours in relation to gender and the play environments were examined, differences in girls and boys interactions with STEM were noted. From two preschool classrooms of children aged 3 to five years, a sample of 66 children were followed by two researchers across three play-based settings over 3.5 months. The spaces were an imagination playground which had large loose parts, the outdoor play area with a mix of fixed and moveable play equipment, and a dramatic play area which also included drawing materials. Going beyond a construction play context, Gold (2014) found that girls were engaged in more social play than boys, and boys engaged more in manipulative play than girls. But no gender differences in gross and fine motor play were found or any differences between boys and girls in relation to engineering thinking and play. However, Nguyen et al., (2022) who investigated precollege women's early experiences of engineering, found that while the primary motivator for them had been their teachers and parents, the boys had explicitly sought to socially exclude them from STEM activities. Their mixed method study found that the boys (and later the male engineers) ignored or avoided them or they took credit for their ideas in addition to undermining them. This is also consistent with Hallstrom et al. (2015) who undertook an ethnographic study in Sweden of free play across two centres which involved a range of construction technologies. Included in the study was how children played during free play time with blocks, Lego bricks, sandbox, and outdoor loose objects, such as pipes, ropes, sticks and cones. They found that boys engaged more often with each of the resources when the activity was set up in a way that involved some form of construction. Boys also used more technical language. Girls tended to position themselves in a helping role, such as passing blocks to boys for them to build, and therefore girls positioned themselves on the side lines in an auxiliary role – as this example from their data shows.

> A group of children are playing in the construction room. The room is equipped with different kinds of materials with the purpose of stimulating construction games. Two boys [five years old] are playing with blocks. They are talking with each other and decide to build a tower as high as possible. Amanda [five years old] is looking at the boys play but she does not touch or play with the blocks herself. After a while she starts to serve one of the boys with blocks. For several minutes the girl is watching the construction play. She never tries to build herself but gives blocks to the boys (field notes) (Hallstrom et al., 2015, p. 144).

When girls do enter the block area, teachers do not support the girls efforts to build. As noted by Prioletta (2022) in her study of spaces and objects in two Canadian preschools:

> Sofea goes to the Lego table and reaches over to the Legos. Happy covers the Legos with his arms and says, 'No! My blocks.' He pulls the Legos close to his body and hunches over the table. Aashni goes to the Lego table. Happy says, 'No! My blocks' and pulls more Legos into his pile under his body. Patricia (early childhood educator) walks by and instructs Happy to share. [he doesn't]. Sofea and Aashni leave the Lego table and go the dramatic play centre (p. 983).

Londstanding research and recent systematic reviews (Rueda, González-Gijón and Martínez-Heredia, 2023) capture the nature of the gender differences in STEM related to socialisation processes, suggesting little has changed in the experiences of girls and women in STEM, because "Girls are frequently socialized into a service role, providing for and tidying up after men, and they continue these tasks in the laboratory…" (Kelly, 1987a, p. 72) and boys occupy more of the preschool space and more of the construction areas than girls (Beat, 1991) giving less access to STEM related activities (Prioletta, 2022). The conclusion reached by Carrasco Rueda, González-Gijón Martínez-Heredia (2023), "With regard to the content analysis of the results of the selected documents [in systematic literature review is that] almost all of them show the presence of gender roles and/or stereotypes for boys and girls in preschool education" (p. 200).

Children's play actions and choices of toys/materials in the STEM areas within preschools have also been studied. For example, what girls and boys do with the construction materials in the different areas of the preschool has been closely examined by Hallström et al. (2015) who have argued that, 'Construction can be seen as the play itself; the boys are focused upon making the construction as solid as possible', which is why during play they negotiate about the best building methods (p. 143). They found that girls appear to negotiate and problem solve during design and play. It has also been shown that they "construct with another end in mind – the play (p. 143). The longstanding research of Beat (1991) has also shown differences where '…boys tended to make models that moved and were part of an imaginative scene they had created… Girls tended to make non-moving models such as houses or gardens and while making them they were usually talking about something quite different' (Beat, 1991, p. 79). In a more recent study, Cohen et al., (2021) examined the early STEM experiences of children at age 4 and again at age 10 years and noted that those who used STEM related toys or kits, watching STEM TV, playing STEM digital games were strong predictors of Year 4 children's attitude to science and their identity related to STEM fields. They also found that girls were more likely (1.5 times) than non-female children to be involved in "baking/cooking/kitchen chemistry, one of the two negative predictors of STEM identity" (Cohen et al., 2021; p.1143). Consistent with Carrasco Rueda, González-Gijón Martínez-Heredia (2023), they found:

> In all age groups, 9-17 months, 18-23 months and 24-32 months, there were stereotypical gender preferences for toys. Boys played more with toys considered masculine and girls with toys considered feminine. Girls used the toys that boys rejected. Toys were more stereotyped by boys and girls than other objects. Boys did not give trucks to girls, and girls did not give dolls to boys because they would not like them. Boys and girls chose warlike, sexist and competitive toys that generated gender differences (p 198).

Gendered ways of interacting with technological construction resources was evident, and this suggests that the 'pedagogical problem that girls and boys learn to approach and handle technology differently…confirming rather than dissolving gender boundaries' (Hallström et al., 2015, p. 147). How this is explained is that a 'masculine concern with things fits more easily with the dominant form of physical science than the feminine concern with people' (Kelly, 1987a, p. 73). Similarly, Little and de la Barra (2009) found expectations were centered on girls being 'more interested in issues to do with human health and well-being, whereas boys are more interested in things to do with technology and physics' (p. 440). Furthermore, Hallström et al. (2015) noted differences between girls' and boys' confidence in design and construction activities. Even though boys and girls performed equally on all tasks, in their play they found that 'boys were the most active while the girls distance themselves' (p. 144). However, this perspective positions the problem as related to girls' lack of engagement, rather than girls being socialised out of STEM activity in preschools. In research which examined girls and boys STEM activities in preschool before the age of three years, documented through video recordings over 7 weeks, Fleer (in press) noted that girls and boys showed equal interest before the age of 3 years in early childhood settings, but at age 3 the girls' in their study experienced disruptions to their engagement, motives, and development of competencies in STEM in childcare settings (31 children: 15 girls and 16 boys). The study concluded that girls entering preschool at age 4 already have experienced barriers to building competencies and self-efficacy in STEM – one year earlier than the general research literature has identified. Rather than suggesting that gender differences are related to the girls and boys interests, a better explaination for why girls in preschools are more oriented to people and boys to things, is that girls have different experiences of what they can and cannot do within free play settings before they enter preschool STEM programs (Fleer, 2019). This leads to different competencies early in life that impact on girls' future interests and thinking in STEM. The net effect on the course of children's education is accumulative. That is, by the time girls and boys enter secondary school they have established differences in their background in STEM, interests, thinking and expectations surrounding their future (Kelly, 1987a; Kung, 2021).

Researchers have named the socialisation away from STEM by girls as micro-agressions or as gender-based violence. Prioletta (2022) in her observational study of preschool children identified acts of agressions by the boys towards the girls during free play time. She said the girls experienced gender violence when they dared to participate in STEM related play activities. Lyttleton-Smith (2015, p.241) identified 'micro-spaces' in preschools where 'gendering takes place", such as "the playhouse, the scramble wall, the tree den, the hidey hole, the toilets, the sofa, behind the kitchen units' (p. 241). She found 'Many of these micro-spaces were primarily inhabited by girls… private and marginalised, while boys roamed more widely over the open, public spaces of the nursery, producing more scope for boisterous physical activity and domination' (p. 241).

Intervention studies have also confirmed girls distruptions to being involved in STEM as taking place through micro-agressions. For instance, in a study by Stephenson, Fleer and Fragkiadaki (2022b) who made video observations of preschool children's interactions and examined girls' STEM related experiences within and outside of an intervention program (two preschool teachers and 13 children aged 2.3–3.2 years) found that the girls experienced microaggressions in free-play settings that positioned them away from STEM activity. They noted that the microagressions were minimised inside the intervention play area due to the changed role of the teacher. They argued that the possibilities afforded by intervention positively shifted the interactional patterns to create more motivating conditions for girls in STEM, allowing both girls and boys the opportunity to have a strong engagement in STEM. These findings were confirmed by Stephenson, Fleer, Fragkiadaki and Rai (2021) when undertaking interviews of the teachers involved in the intervention. Stephenson, Fleer and Fragkiadaki (2022b) identified that the teachers were closely connected to the children's STEM experiences, rather than leaving children to explore STEM activities during free play. This had made a difference to the girls' experiences of STEM. Similar results have been reported when studying free play settings, where STEM related activities are made available to all children. However, girls consistently experience micro-agressions in free play settings (Fleer, 2019) and when teachers are less available to notice and intervene (Stephenson, Fleer and Fragkiadaki (2022b).

To better understand micro-agressions, Moroz (2015) explained how *microassaults* are aimed to attack a person's identity, and this raises the belief that the recipient of these assaults do not belong. It is argued that girls and women receive 'gestures [that] may seem harmless at first. However, dozens of glances quickly add up – over days, weeks months, years – and send a message to the recipient: you are different' (Moroz, 2015, p. 2). Captured as *microinsults*, these stereotypes, rudeness or insensitivity, are often based on assumptions about individuals, such as, how different it is for a girl to think about engineering as an activity and future profession. These, often unconscious assumptions can change the life trajectory of a person. Gullberg et al. (2017) in Sweden showed acceptance of gendered practices in preschools associated with STEM where, 'These small occasions [expectations of boys and girls] are internalized by the child and influence their identity formation. These reoccurring influences will be so integrated that the choices a person makes will be apprehended as innate, even later in life according to educational and professional norms' (p. 23). Moroz (2015) also noted *microinvalidations*, which were often unconscious, and could negate, exclude and deny the experiences and feelings of an individual who is subjected to these microaggressions. That is, the recipient often feels their response is possibly an overreaction. As noted by Moroz (2015), even if 'these microaggressions are unintentional', the net effect is "damaging" (p. 2).

Intervention studies in informal settings designed to increase girls interests and engagement in STEM have also focused on the materials themselves. For example, Mulvey, Miller and Rizzardi (2017) have examined if the colour preferences of engineering materials make a difference to children's engineering aptitude, and what their beliefs are about stereotypical (blue for boys, pink for girls) or counter stereotypical resources at age 5 are and again at age 9. By either assigning pastel or primary coloured construction materials to children (random assignment of both stereotypical and counter-stereotypical) in a museum context, or by inviting children to self-select the construction materials to solve an engineering problem, they noted that contrary to established practices of toy manufacturers to target girls' engagement by using pastel colours, their results demonstrated that engineering aptitude was not heightened when girls were assigned pastel-coloured building materials. Interestingly, when boys were assigned pastel materials the results showed they demonstrated lower engineering aptitude.

Mulvey et al. (2017) argued that boys appeared to have ‘more restrictions when choosing non-stereotypic activities” and in referencing the earlier work of Biernat and Manis (1994), state that in using pastel coloured materials this means boys are “engaging in lower-status activities associated with females’ (p. 124). They identified that “females have more barriers than males when challenging gender stereotypes” (p. 124). In contrast to many longstanding studies about gender and STEM that typically place the responsibility for social change associated with gender on teachers or on girls themselves (Harding, 1987; Walkerdine, 1987), they suggest that their results support the view that ‘more attention may need to be paid to boys when considering the impact of gender stereotypes’ (Mulvey et al., 2017, pp. 124-125). However, Mulvey et al. (2017) did note that although girls aged 5 and girls aged 9 equally liked primary and pastel colours, they also saw the injustice of and harmful effect of social exclusion from the resources, whilst this was not evident by the boys. ‘The current finding suggest that older girls are also more aware than boys that excluding someone from the opportunity to engage with their preferred materials is wrong’ and ‘simply marketing pastel-colored toys to girls might not be an effective way to enhance their engineering aptitude’ (Mulvey et al., 2017, p. 124).

In another intervention study designed as an ethnography over five years across four bush preschools, Speldewinde and Campbell (2023) regularly took groups of preschool children out of the preschool and created science experiences within natural enviorments through bush walks and play related bush experiences. They found that girls showed and engaged in as much science related activity as the boys. They said,

> Outdoors, in the bush kinder, the girl’s imagination acts to complement their STEM learning. Ice cream vendors and playhouse engineers take STEM concepts and apply them in nature (p. 282).

In contrast to earlier studies, they did not report any disruptions to the girls’ STEM experiences and suggested that changing the environment had enabled girls to positively experience science. They concluded that,

> …kinder settings in Australia provide young girls with opportunities to develop their STEM identities. Social interactions with teachers and peers and the unique bush kinder environment enabled STEM learning (p. 282).

They argued that when the STEM contexts are more gender neutral, such as going on nature walks, that girls had as many opportunities to participate in STEM related activities as the boys.

The challenges of disrupting gender stereotyping, captured through the concept of microagression in the preschool, still seem to have remained and does not appear to be contested by teachers (Stephenson, Fleer and Fragkiadaki, 2022b). For instance, Hallström et al. (2015) found that teachers did not give girls and boys equal opportunity to play with non-gender-stereotyped materials and toys. This can be better understood in the context of teacher beliefs, as noted by Gullberg et al. (2017) who studied of 47 preservice teachers in Sweden and identified a connection between pre-service teachers’ views of the child and whether gender stereotypes were reproduced or counteracted. If teacher believed in following the child and their interests, they did not intervene in children's play, despite gendered ways of playing being observed during activities in STEM. They noted in their review that 'Although teachers, when questioned, say that they have the same expectations for girls' and boys' achievements in science, their teaching practises do suggest the opposite…' (p. 7). Studies have also shown variations in teachers' beliefs and observations of children, with some teachers reporting that children approach the construction technology differently (Hallström et al., 2015), whilst others suggesting they did not see any differences (Gold et al. (2015). It was noted that teachers thought that conceptualising everything as construction technology, meant teachers believed girls and boys had equal opportunity (Hallström et al., 2015). This is consistent with longstanding research which has also shown teacher interactions vary in relation to gender (Kelly, 1987b) confirming little has changed.

Whyte (1986) in researching the effect of girl friendly programs designed to increase girls motivation for STEM activities 'found that teachers…remarked that though they had achieved a 50/50 interaction ratio, it *felt* as if the girls were being given too much time and attention' (p. 275; original emphasis). Hallstrom et al. (2015) noted that teachers were generally not active in supporting children's play during construction time, and this meant the children were not extended in their learning opportunities or positioned to take different roles in their construction play. Significantly, they found teachers 'encourage boys use of [construction] technology one way and girls use in another' (p. 147). Further, Hallström et al. (2015) noted that when the teachers did locate themselves within the block and other construction areas, the girls tended to gravitate more to these areas, and engaged more in construction play when compared with the times when the teachers were not in these play areas.

Longstanding arguments have blamed teachers for not taking action, as noted by Browne (1991, p. 21) 'By avoiding involvement in scientific investigations women teachers are not challenging the view that science is for boys and men' (Browne, 1991, p.21). English (2018) also commented on teachers' lack of preparedness in engineering education, suggesting that this contributes to their confidence in the implementation of an engineering curriculum. There is also a long trajectory of research in early childhood science education (Garbett, 2003) as well as primary education (Appleton, 1992) which consistently shows that the problem lies with the teacher, and their lack of confidence and competence is what causes them to not engage in the teaching of STEM or bring in the girls into the STEM areas within the preschool, such as the block area. Yet the arguments for the low levels of confidence and competence of teachers in science, were identified primarily through surveys and interviews, and they mostly do not appear to go beyond teachers' self-reports, and in preschool engineering are associated more with not capitalising on the engineering affordances of the construction areas within the preschool. The longstanding arguments suggest that, 'female teachers have had far less childhood experience of making things' and 'little opportunity to compensate for this lack of experience' (Siraj-Blatchford, 1991, pp. 126-127).

What tends to emerge in the literature, is that teachers are positioned as shouldering the responsibly for change (Fleer, 2019). Siraj-Blatchford (1991) has noted that even when early childhood teachers given opportunities to participate in STEM courses, they are not female friendly and delivered by those from outside of early childhood, with what 'appears to be "watered down" junior science' and 'are often given no specific guidance on early years science at all' (p. 30).

In summary, it seems that the longstanding and recent research shows that the experiences of boys and girls are different on entering preschool, that social exclusion of STEM by girls often happens unconsciously by teachers, and that early childhood teachers who are primarily female, generally have less experience and confidence in STEM teaching. The literature suggests that there is an acculative negative impact on girls engagement and motivation for STEM activity. Therefore more needs to be known about what happens in the first moments of girls experiences of STEM to better understand the conditions created for engineering and science play. This chapter takes up this challenge by presenting the outcomes of a cultural-historical study of children's first moments of engineering and science play in a preschool setting. The goal is to contribute to a better understanding of children's social intereactions and how girls enter into engineering and science play practices in preschool settings.

3 A cultural-historical conception of *imagination and creativity* as foundational for informing the study design

Inspired by sociology to name and explain concepts of micro-agressions (Moroz, 2015), this chapter also draws on a cultural-historical perspective to theorise the study and findings. Specifically, in this chapter social action is culturally framed and children's orientations and motivations in STEM are culturally constructed as lived experiences and interactions with others. In the process of the young preschool child growing into their culture, Davydov and Kudriavtsev (1998) drew attention to historically formed knowledge, such as STEM, and wrote, "growing into its problem-oriented field, does not represent a simple independent rediscovery of something that has already become part of the cumulative experience (on the order of the "rediscovery of America" or "reinvention of the wheel"). It does not represent an imitation of creative acts but rather genuine creativity-and *cultural* creativity" (p. 53, original emphasis). This means children do not just reproduce accumulated cultural knowledge, but rather imagine and create their own productions in their everyday lives. Realised as a dialectic, imagination and creativity are fundamentally human activities (Vygotsky, 2004) that can only be understood in the process of their development (Vygotsky, 1997) and in social relations with others.

In this chapter the dialectical concept of imagination and creativity is used to explain how children come to imagine if STEM is for them or not, following the theorisation first introduced by L.S. Vygotsky. Vygotsky (2004) argued that imagination is not something within the person, but rather it is seen as a cultural process that 'depends on experience, on needs, and the interests in which these needs are expressed' (p. 29). This means that imagination is developed through the dialectical relations between person and the social-concrete environment. A child is born into pre-existing cultural practices developed over generations (Davydov and Kudriavtsev, 1998). Specific to this chapter, STEM knowledges are but one of the many knowledge forms that were culturally developed over time to serve particular human needs. STEM is currently seen in Australia and elsewhere as a valued form of knowledge and therefore societal expectations are for children to learn and use STEM concepts for engaging in the world. But many STEM concepts are cultural inventions, such as force, and when used for instance with bridgebuilding with blocks, need to be imagined. Engaging in STEM activities, designing bridges in play, and playing productively with others to realise designed goals, also brings forward the development of imagination as a psychological function (Vygotsky, 1966). Vygotsky (2004) wrote that,

> …imagination takes on a very important function in human behaviour and human development. It becomes the means by which a person's experience is broadened, because he [sic] can imagine what he has not seen, can conceptualize something from

> another person's narration and description of what he himself has never directly experienced (p. 17).

In this chapter, the Vygotskian characteristics of the development of imagination – direct and vicarious experience – as seen as important for wondering and imagining in the first moments of instruction associated with science and engineering play and where girls come to experience and imagine if STEM is for them. Vygotsky (2004) suggested that,

> …there is a double, mutual dependence between imagination and experience. If, in the first case, imagination is based on experience, in the second case experience is based on imagination (p. 17).

The doubleness of experience and imagination through instruction is an agentic and dynamic process. In this dynamic, children experience science and engineering instruction as early forms of engineering and science when for instance, working with blocks. When children *experience* block building with blocks falling down, and with *instruction of the scientific concept of force*, they begin to *imagine* how the forces are acting when a structure is stable and when it is not. They use their imagination to understand their subsequent experiences of block building. But this mutual experience as a dynamic through instruction also informs how they imagine their place within STEM activity. If they are encouraged to act as an engineer or scientist in their play, they are more likely to positively imagine themselves in STEM. But if they are discouraged or ignored and experiece microaggressions or gender related unconscious bias or violence, they are less likely to imagine themselves as being agentic in STEM activity. The importance of emotions (how I feel about my place in STEM) is foregrounded as part of the act of imagining and creating. That is, "the intellectual and the emotional – are equally necessary for an act of creation. Feelings as well as thought drives human creativity" (Vygotsky, 2004, p. 21). All forms of creativity influence emotions, but also how one feels affects the act of imagining and creating. Relevant for the aim of this chapter, is how a child feels and imagines themselves as being a part of this scientific and engineering play community or imagines themselves as either active participants or peripheral to a new engineering activity setting.

Play is the leading activity of the preschool child (Vygotsky, 1966) and is used as an activity for supporting early education. Like imagination, play is not a biologically determined process, but rather it is a cultural practice supported in many Western communities through the institution of preschools and through families giving time and resources to their children to play. A cultural-historical conception of play suggests that children create imaginary situations, where they change the meaning of the objects they see and give them a new sense (Vygotsky, 1966), such as when a block becomes the span on a bridge being imagined and a pier is added for structural stability. Imaginary situations are also realised with others, such as when children act 'as if' engineers designing and building bridges towards an end goal. In imaginary situations, objects, actions or words can act as placeholders of the new meanings ascribed to the visual field. This reading of play informed the study and acts as the basis of the new engineering activity setting in the preschool that is presented in this chapter.

4 Study design

The overall study examined the engineering and science practices of children and teachers over 5.4 weeks as they implemented a civil engineering program. Engineering education is new to preschools in Australia, and therefore, it is possible to have more confidence that the teachers and children had not experienced this form of education before. Only the data from the introduction and arrangement of the new activity setting is presented in this chapter.

In this study the teachers designed a program on civil engineering that featured bridge building in the context of the popular fairytale of the 3 Billy Goats Gruff where they also made a digital movie of this fairytale and looked at force. The digital practices and the overall delivery of the program are not discussed in this chapter. This chapter builds on previous research (Fleer, 2019) where future imaginings of being and becoming an engineer were discussed, but where the first moments of the new activity setting were not the focus. Specifically, the study reported in this chapter answers the research question of: How do educators create and children (particularly girls) experience an engineering and science activity setting during the first moments of its introduction within the traditional areas of a preschool?

4.1 Participants

The participants of the engineering play program were 5 teachers and their 31 children (aged 3.4 – 5.5 years; mean age of 4.4 years). 18 girls and 13 boys regularly attend the centre. The teachers were Indian Australian (3), Sri Lankan Australia, and European Australian backgrounds. The children were from a range of cultural heritage backgrounds. Mostly European/Australian and some with Asian, African and Middle East heritage. Data were collected in the centre on different days, with different numbers of children attending. All the vignettes presented in this chapter describe how many children were in the particular activity setting for the example presented.

4.2 Data gathering

Digital observations (27.3hours) and interviews of teachers were undertaken. Two cameras were used to digitally observe and capture the engineering practices. One camera was placed on a tripod near the specific activity setting of the bridge building and role-play area, and the other hand-held camera followed the children in order to enable close-up observations of the children's and teachers' interactions to be made. Digital observations took place for a period of 2-5 hours at a time and were gathered over 8 data collection visits. The overall data set constituted a total of 27.3 hours of digital observations and a total of 336 digital photos, with only data from the first observation period featured in this chapter.

Teachers were interviewed in situ about their program or at the end of the session where key moments were referenced as part of the interview. Teachers were also interviewed at a pre-arranged time. A total of 2.5 hours of interview data were digitally recorded.

4.3 Analysis

This cultural-historical study drew upon Hedegaard's (2014) holistic analytical framework for studying young children. Her conception of society, the institutional practices and person within the activity setting drove the analysis process. In this cultural-historical dynamic it is possible to conceptualise the values of a particular society, such as the need for more girls to be involved in STEM, whilst also examining how a girl and a boy enter into the new engineering practices within a preschool, where the engineering activity setting put demands upon children, whilst at the same time each child makes demands on the activity setting and those within it. The demands of the activity setting, such as making a bridge to re-tell the story of the 3 billy goats, create developmental conditions which Hedegaard (2012) has conceptualised to support and develop motivated actions of the child.

The categories that were formulated were drawn from the literature and from cultural-historical theory and were used to focus the analysis on the interactions between children. Figure 1 below is a screen shot of the first step in the process.

In this first step, specifically tagged moments of gendered interactions were made. As part of this first analytical step, data were digitally copied from the raw data set and made into clips of single situated practices. Digital data allows for continuous revisiting of the data set, and thereby viewing the data many times for additional coding and nuancing of the interpretations. Vygotsky (1997) conceptualised this kind of analysis using the metaphor of skipping. It is during this process of skipping within a raw data set (full video recordings), that additional digital editing takes place (digital clips). This allows for the cutting of single situated practices (e.g., free play time) into a series of interrelated clips (e.g., whole group instruction periods; bridge building activity setting at different time points), but these are always tagged in relation to the raw data (i.e., holistic interpretation). This process of analysis has been termed by Hedegaard (2012) as a commonsense interpretation. Each of the segments can be analysed and placed into additional folders under one heading, such as gender oriented data (e.g., working together, numbering children as engineers).

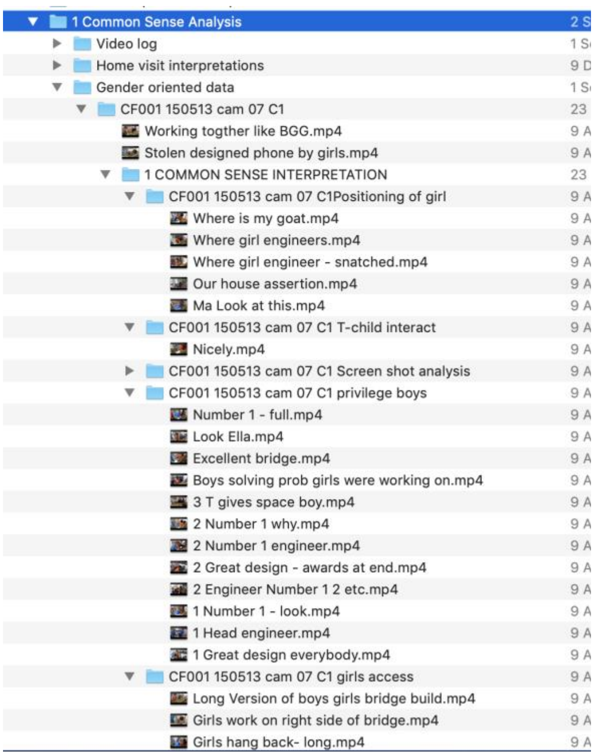

Figure 1. Commonsense interpretation of digital data – skipping within a raw data set for digital editing of gendered interactions.

The second step involved examining the data folders of gendered interactions in order to gain a sense of density of emerging patterns related to the gender categories, such as access to engineering resources or gendered positioning of girls, and the activity settings in the preschool, such as whole group time, tables, free play. For example, copying and then clustering all of the related video clips into sub-folders, such as teacher interactions with children that are related to gendered positioning of girls (e.g., Folder called Teacher interactions). This second step in the analysis allowed for new categories of interactions to be digitally organised into a gender folder on gendered interactions. Figure 2 shows a screen shot of folders which contain multiple digital clips of gendered practices, but also the activity settings common within preschools. This process of analysis has been termed as a situated practice interpretation.

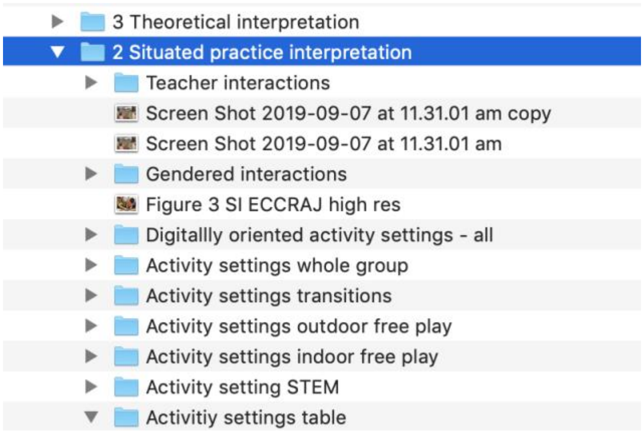

Figure 2. Situated practice interpretation

The third step in the analysis process involved a conceptual synthesis and theorisation of the data categorisations. The gendered practices were digitally copied and then organised in relation to the categories that were identified in the literature, such as microinsults (e.g., taking a block out of a girl's hand) or motives for engineering (teacher not noticing or ignoring a child's suggestions/ideas for block building). Figure 3 shows a screen shot of folders which contain multiple digital clips of gendered practices clustered around particular categories.

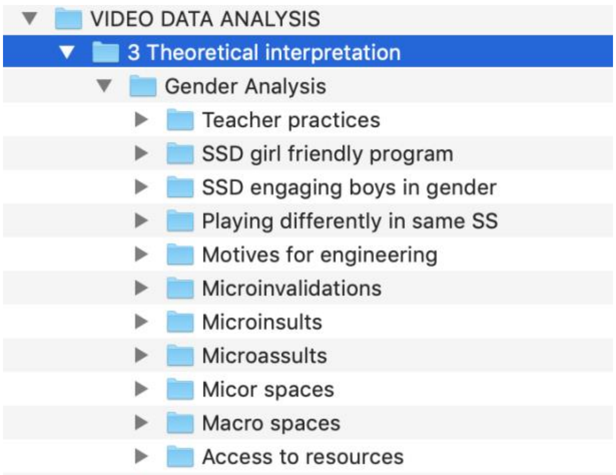

Figure 3. Theoretical and thematic interpretation

The synthesis and theorising are always in relation to the research question driving the study, but also the system of concepts and the literature related to the focus of the research. In this study, this meant examining the patterns of gendered interactions within the folders in relation to the models of practice in STEM that support girls in engineering and related science concepts, such as girl friendly engineering and science practices or access to resources. The Vygotskian concepts of imagination and creativity, and play, and the Hedegaardian concepts of demands and motives within the societal values, institutional practices and the engineering activity settings were used to understand the patterns of interpretations that emerged during steps 1 and 2. For example, when examining the activity settings of group time and free play time (common-sense interpretation) in relation to bridge building and girls access to the resources (situated practice interpretation) patterns of gendering were tagged and clustered into folders for further study (theoretical and thematic interpretation). Important for a cultural-historical study, is the interconnections between the 3 analytical steps so that a holistic interpretation is possible. For example, were there patterns of mico-aggressions that could be observed in relation to play and girls seeking to act 'as if' an engineer or when exploring the forces acting on the different components of the bridge. Identifying if and how the experiences were collectively contributing or negating girls access and motivation to STEM learning were also determined at this point (e.g., imagining if STEM was for them or not). The iterative processes are interrelated, and together the interpretations support the answering of the research question of this study.

5. Findings

The research results are reported in relation to 1) the introduction of a new engineering and science activity setting in the preschool, 2) how the children enter into the new activity setting for the first time, where new institutional practices support imagining and creating, but where girls and boys meet these new demands in different ways.

5.1 Engineering as a new activity setting in preschool

The "Bridge building" activity setting was a new area within the preschool. It was designed specifically for introducing civil engineering and associated scientific concepts to preschool children. This area involved the building of a bridge for the 3 Billy Goats Gruff to walk across, and this same activity setting was also used for role-playing the fairytale of the 3 Billy Goats Gruff. Figure 4 is a floor plan of the centre. The location of the civil engineering with related science concepts as an activity setting is shown in relation to the other areas within the preschool.

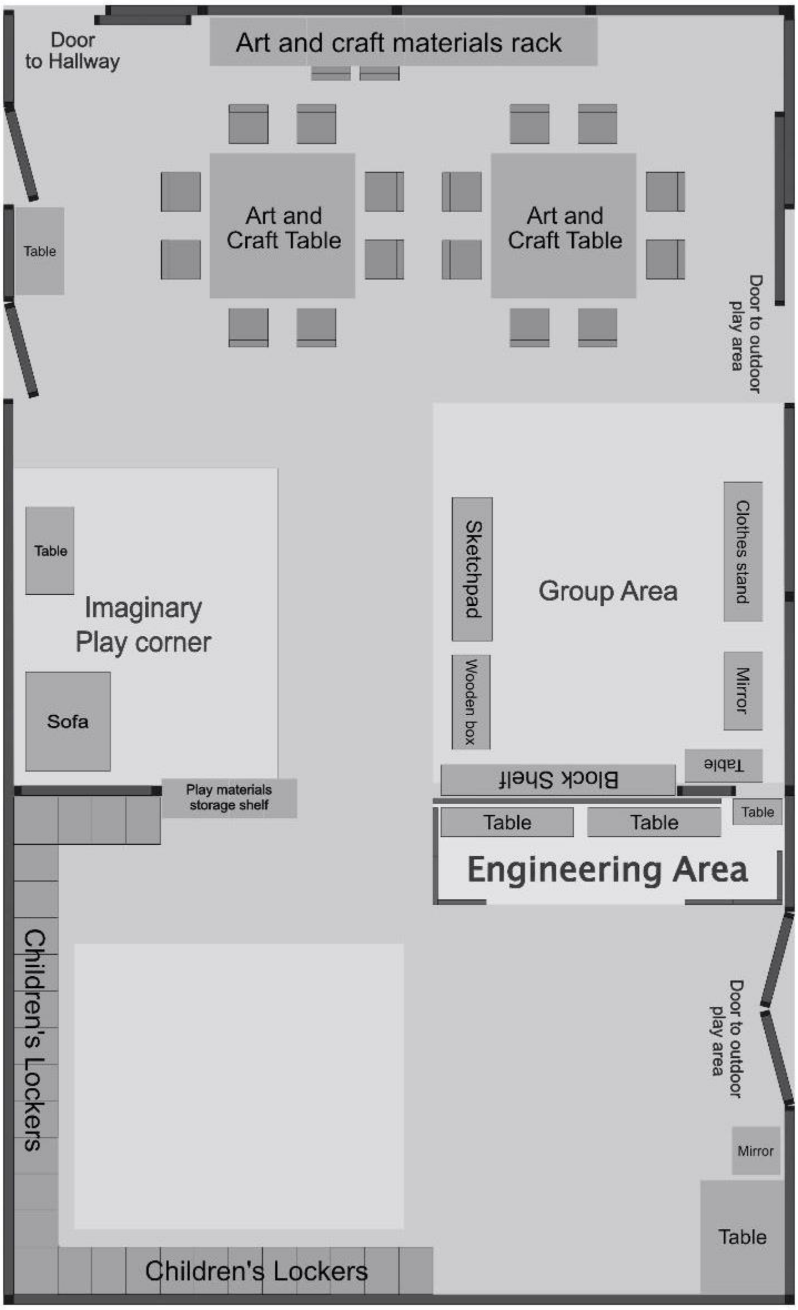

Figure 4. Centre activity settings

Two important findings emerged in relation to creating an engineering and science space in the preschool. First, having an area that was completely different to the existing play areas in the preschool gave new possibilities for both the teachers and the children. Different to previous research which looked for affordances of engineering activity within the exiting areas, such as the block area (Bagiati & Evangelou, 2016), the civil engineering and science space in this study was a completely new space dedicated to engineering practice and science related experiences of force.

Second, the study found that not only was a new space within the centre created, the activity setting was introduced in the context of a social purpose for building a bridge for role-playing a popular narrative. This meant that when the children were read the fairytale of the 3 Billy

Goats Gruff at group time and were invited to join the teacher in the engineering and science space to build bridges and to role-play the fairytale, a motive for participation in civil engineering practice and science concept of force was created. This acted as a lived experience of STEM, as Vignette 1 shows:

> Vignette 1: *Collective engineering and science at circle time*
>
> The teacher is seated on the mat with all the preschool children seated in front of her. They have just heard the fairytale of the Three Billy Goats Gruff. Still holding the book, the teacher says, “This is a very special circle time. We are going to create. Do you know what the word create means?” The teacher pauses, and boy calls “No”. She then continues, saying, “Make. We are going to make, create together our Billy Goats Gruff scene”. Behind the teacher is the engineering area, that she has called Philip Island. She continues, “On Philip Island. Do you know why we are going to do it on Philip Island?”. A chorus of “No” is mostly heard from the boys, then a chorus of girls, say “Why?”. The teacher responds, “Because we found some rocks, remember (referencing a recent visit to Philip Island), Granite rocks… we have Granite rocks to put on Philip Island. And we have lots of dead grass”. These are props that she has placed on a table outside of the engineering space. The teacher holds up the book of the 3 Billy Goats Gruff and says, “Oh no there is dead grass, all dead grass on this side [of the bridge]. And then we are going to make the bridge and then we are going to see if we can create our green grass on the other side [of the bridge] and get our Billy Goats Gruff and the only thing that is missing at the moment is the troll… Can I have all of my Philip Island Billy Goats Gruff people. Let’s go” (CF001 150153 cam 7).

Evidence of the possibilities for girls when creating a new space with a social purpose was evident when equal numbers of boys and girls showed interest in being involved in the engineering and science activity setting as Vignette 2 shows where the children transitioned from group time to the engineering and science space.

> Vignette 2: *Transition into the engineering and science activity setting*
>
> Fourteen children follow the teacher as she walks between the circle time activity setting and the new engineering activity setting. As they near the Engineering activity setting, one boy says he does not wish to participate, and the teacher responds by stopping and offering other suggestions for all the children to consider, such as table activities and the book corner. The teacher is standing at the entrance of the engineering activity setting that is now crowded with children. Seeking to reduce the number of children, she says, “I only want the children who really want to be on Philip Island”. Immediately 3 girls and then 3 boys enter into the engineering space, and others peel away to the activities close by (CF001 150153 cam 7).

Consistent with previous research, this study showed that when there is a social purpose for construction work (Fleer, 2020), that girls do enter into the area ready to contribute to bridgebuilding. In contrast to previous studies that show girls not becoming involved in construction areas as much as boys, this study identified that the dedicated and purposeful civil engineering and science activity setting was motivating, and this meant that as many girls as boys were initially drawn into block building. The study found that the educators created an engineering and science space and narrative that seemed to appeal to the girls and was inviting enough for them to self-select to become involved in building with blocks - different to what the literature suggests for engineering with blocks where girls drop away or do not enter the block area.

The study also found that the proximity of the new engineering area to the tabletop-based craft materials, the home corner, and the block area was important (Figure 4). Because the new engineering and science activity setting was nestled between other spaces which were resource rich, the children could easily access what they needed from a broad range of materials to support their engineering.

Having a different space for the use of blocks appeared to initially disrupt the gendered belief surrounding playing with blocks, as noted in previous studies of block play (Hallstrom et al., 2015) or the self-creation of micro-spaces by girls (Lyttleton-Smith, 2015). Having equal numbers of girls to boys initially go into the new activity setting of engineering suggests that girls imagine the area was also a space for them to play in, construct in, and to legitimately be in. In summary, it would seem that by creating a new space within the preschool for civil engineering and science, and providing a narrative around its purpose, gave new possibilities for girls' involvement in engineering and science. Even though the number of children reduced when the teacher insisted on only having those wishing to go to Philip Island, the equal number of girls and boys does suggest that the social narrative was important for the children.

These findings contribute to the existing literature because they show that when a new activity setting is established in a preschool which is dedicated to engineering and science (see Speldewinde and Campbell, 2023), it does not seem to bring with it, pre-existing gendered assumptions of how the space should be populated and used. This is an important outcome of the study because it gives concrete practice directions to teachers for how to engage girls in engineering and science. It is also consistent with the general practice tradition of the Froebelian kindergartens which is made up of learning areas and corners. However, what is different to previous research is that the engineering and science activity setting was not set up in an existing area, such as the block corner/area. Rather, the new engineering and science activity setting has the possibility of being one turning point in changing opportunities for girls in STEM (see Fleer, 2019). More research is needed across different preschools to determine if a dedicated engineering and science activity setting can attract equal numbers of boys and girls to engineering and science.

5.2 *How children enter into the new activity setting for the first time*

The study was also interested to examine what happened within the new engineering and science activity setting when engineering eduation was first introduced. A close study of the micro-genetic transitions within the activity setting, gives a new perspective on girls' opportunities for engineering activity in particular. In examining the movements of the children within the activity setting during unstructured play time, the results show 3 specific turning points when studying the micro-genetic movements of children.

First, girls' access within the space to the bridge building begins to emerge as problematic as the imaginary play and bridge building evolves. Details of this are shown in Vignette 3 below and shown in Figure 5.

> *Vignette 3: Access to space:* Initially 3 boys and 3 girls entered into the activity setting. The boys position themselves to the left of the teacher where the

bridgebuilding takes place, and the girls to the right side. The teacher fixes her body and gaze to the boys. Four more boys return to the activity setting and enter the space and the three girls are pushed back, remaining behind the teacher (Figure 5). Oliva and Bryce each have a block in their hands, and position these in place. Oliva removes some blue tac from the back of some paper graphics that are on a block. The block had previously been made into a mobile phone by two girls.

Figure 5. Boys in the front row of bridge building with the teacher

Oliva uses the blue tac to try and join 2 blocks together to create the support for the right end of the bridge. But because only one side of the bridge support is being constructed (pier), the children work with a 45 degree angle rather than a 90 degree angle (Figure 6). Bryce says, “No not like that” suggesting the technique of joining the blocks will not work. The teacher passes over a small piece of blue tac and says, “There’s plenty of blue tac. Here”. Oliva places three blocks together, leaning them at 45 degrees to the long wooden board that acts as the bridge span. The boys spend a long time trying to solve the problem of how to build one end of the bridge with various attempts at attaching the span to the one side of the bridge.

Figure 6. Bridge block building – the children struggle with how to build a bridge span

Three girls remain in the background watching now from a distance. They have sticky tape in their hands ready to build, but there are 2 layers of boys now densely packed directly in front of the bridge building space. No progress appears to be being made to the bridge building. Eventually, Rita moves around the back of the boys (See Figure 7), and then with her hands behind her back (possibly signalling she won't touch the blocks) slowly moves into the field of view of the bridge when a space opens up, and she inspects what is happening with the bridgebuilding. The moment is lost, as the back row of boys push forward moving her further to the left. She steps back and then moves out of the engineering area.

Figure 7. Rita moves from the back of the boys to the side of the bridge building

The teacher positioned herself as facing towards the boys, where she set up the bridge building problem that they were to solve as engineers. Although equal access within the space was afforded to both boys and girls, the teacher's positioning could have been interpreted by the girls as exclusionary as her actions limited their involvement.

Overall, this first engineering encounter for the children showed that some boys position themselves directly in front of the action, claiming the prime engineering space. Consistent with the literature, the girls had difficulties with entering the prime space (Stephenson, Fleer and Fragkiadaki, 2022b; Hallström et al., 2015; Prioletta, 2022). The resolution was to either give up waiting and move on, or persist and stay primarily in the background observing, waiting for spaces to become available when the boys moved on when the space was free of boys.

The second challenge that emerged was in relation to invisibility of girls engineering prowess, imagining and solving the engineering problem. As is shown below in Vignette 4, Rita moves to the left side of the bridge span and begins to build a pillar in anticipation of joining it to the construction after inspecting the bridge building (Vignette 2), it seems she has imagined a solution to the problem and begins work on stabalising the other end of the bridge. As Vignette 4 shows below, her imagining through problem-solving and her created solution were invisible to the teacher, who intervened in the boys' construction work and coached them into noticing what was the problem. However, the teacher does not reference Rita's engineering solution as a model example to follow.

> *Vignette 4: Invisible engineers:* Bryce suggests 'sticky tape' to solve the problem and the teacher provides each child who asks for this with a 10cm strip of masking tape. The activity continues with different suggestions being made about how to solve the problem, and many meters of masking tape become applied to the blocks by the boys at only one end of the bridge. Eventually, Rita who has been observing the problem from a distance, moves across to the left and begins to build a support for the other end of the bridge (pier). However, she does this not next to the boys, but 30 cm away (See Figure 8). She uses the masking tape to secure the blocks together and to achieve this, she has to move out of the space back to the teacher and ask for more tape.

> *Figure 8.* Rita begins to build a support (pier) for the other end of the bridge with this solution in mind

> The teacher does not notice Rita's construction work on the left with her pier as a support for the bridge, but rather is focused on the group of boys who are struggling with how to sort out the problem of the 45 degree angle when the support blocks are assembled with the bridge span. The teacher steps in and invites the boys to consider the problem by thinking about the other end of the bridge. After her subtle intervention, 3 boys pay attention to the other end of the bridge. Oliva, Bryce and Grey rush out of the area and collect blocks from the block corner, and at this moment Rita asks for another strip of masking tape so she can continue her construction work. A space is left by the boys rushing to collect more blocks but is quickly taken up by the second row of boys, who have now moved in and are also trying to work on the problem of creating a support on the other side of the bridge. Later the boys leave, creating a further opportunity for Rita to work again on the support for the bridge.

As can be seen, Rita was actively engaged in the engineering and science activity setting, but her actions and achievements appeared to be primarily invisible. Over the course of the unstructured play period, Rita was in the activity setting and actively trying to contribute to bridge building. In conclusion, Rita appeared to identify the structural problem shown in Vignette 3 and imagine a solution. The teacher did not draw attention to what Rita had done as a solution to the problem and thereby did not position her actively into the bridge building or position her as someone who had worked out the solution to the problem. Rather her engineering and related scientific work were invisible.

The third challenge identified in the study relates to the children's access to resources. The study found that over the play period Rita consistently had difficulty with gaining access to the bridge as a whole, and her engineering problem solving and joining of blocks to provide a strong and secure pier were consistently foiled. Despite the consistent barrage of exclusion, Rita persisted in her efforts to secure resources and have access to the space. She appeared in the imaginary play over the duration of the unstructured play period. During this time, she seemed to be positively oriented towards the engineering activity. However, taking resources out of the hands of girls was observed within the engineering activity setting. But it was not always girls who experienced this. Boys did take resources from each other. But it was primarily the girls who encountered these microassaults from the boys.

In summary, it was found that this first introduction of engineering and related science within a dedicated activity setting in the preschool held equal numbers of girls and boys on first entering the space. But how children subsequently interact within the civil engineering and science activity setting appears to be in keeping with the literature, where access to resources and active participation in engineering were problematic for the girls in this study (Stephenson, Fleer and Fragkiadaki, 2022b; Hallström et al., 2015; Prioletta, 2022).

6. Discussion

A cultural-historical interpretation goes beyond this individual internalisation and foregrounds the interrelations between children's imagining of engineering solutions and the social context of the imagined building of a bridge for the imaginary play framed through the storytelling of 3 Billy Goats Gruff. If we consider Rita's constant persistence and her demonstrated interest in STEM an additional reading of the results is possible. In the social practices of imaginary play, acting 'as if' engineers, we found that Rita was clearly positioned as invisible. The context for building a bridge through the story of the 3 billy goats gruff gave motivating condition through the social purpose for play. It seems that Rita found a way to continue to engineer. She used the materials 'on-the-side' to build a stable structure (see Figure 8). She found a way to continue to bridge build so that the children could later role-play the 3 billy goats crossing the bridge. This suggests a strong motivation for STEM in the context of imaginary play. Even though her solution at the time of bridge building was not valued and her identity as an engineer who had developed a solution was not supported, she persisted. The motivated conditions for STEM through the social practices of imaginary play appear to give new directions for teachers when introducing engineering play.

The engineering area was designed as a space where boys and girls could imagine bridgebuilding using wooden blocks. It was not the traditional block area in the preschool, but rather a green field for new actions and imaginary play possibilities. This is consistent with Speldewinde and Campbell (2023) who show that giving children new play spaces that are different to the traditional play areas in preschools gives girls opportunities for STEM. But different to their ethnographic study, the research showed that the greenfield of engineering practices on their own were not enough for the continued engagement of the girls in the STEM related activity of bridge building. Teacher intervention of the violence against the girls, as suggested by Prioletta (2022), was also needed.

Another positive outcome of the study related to the positioning of the new activity setting between other areas in the preschool that were resource rich. Children were able to bring to the engineering activity setting a range of resources that included role-playing with craft materials, blocks, and a range of adhesive for joining materials. It could be argued that the combination of materials and a social purpose for engineering in a newly created space, has the potential to disrupt stereotypical views surrounding a masculine view of engineering education. There are longstanding arguments for creating girl only times when in the new play areas so that girls do not have to compete with boys when accessing resources (Whyte, 1986), but this does not change the nature of the interactions between boys and girls in STEM when teachers are not present (Hallström et al., 2015; Prioletta, 2022).

Although the children did not have previous experience of engineering as a profession or what an engineer does, the practices within the engineering space nevertheless became colonised with gendered interactions. In line with the earlier work of Mulvey et al., (2017) and Prioletta (2022) access to the materials was difficult for the girls, as the boys did monopolise the prime engineering construction space and resources. Rather than negotiating for scarce pieces, some of the boys simply took the materials away from the girls. The boys also pushed and clambered over each other to be close to the engineering area, whilst the girls consistently stayed on the periphery, with the net effect of only one of the original girls who entered into the engineering space staying. These results confirm earlier studies and show that the problem of boys dominating STEM resources remains (Prioletta, 2022).

Unlike Hallström et al. (2015), the girls didn't position themselves in helping roles, but rather when they did have access to the resources, the remaining girl, Rita, appeared to build in parallel – almost keeping herself at a safe distance from the boys. The findings do not support the view that the girls played differently to the boys, as argued by Little and de la Barra (2009), but rather the girls were as engaged as the boys on the problem of building a bridge for the 3 Billy Goats Gruff. There did not appear to be any difference in technical language, as the boys and girls equally did not discuss the problem, but rather worked on building solutions through their actions. That is, their engineering primarily featured problem solving with the materials, with an imagined end goal in mind to add a pier to the left side of the bridge to stablise it.

The findings of this study do, however, support recent conceptualization of girls' experiences in STEM through the lens of microaggressions (Prioletta, 2022). The data consistently showed that boys and even the teachers, interacted with the girls in ways that invalidated the girls' potential imagining of acting as an engineer. The boys regularly made *microassaults* on the girls, by taking resources and by pushing them out of the way. The net effect was an attack on the girls' agency and imagining as someone who rightfully can inhabit the space and use the engineering resources, and this potentially raises the belief in girls that as recipient of these assaults, they do not belong. This is an imagined social position that STEM is not for girls. This study showed that all the girls, except one, left the engineering activity setting. As argued by Moroz (2015), when girls receive these microassults, the gestures might seem harmless at first, but after continued snatches and pushing, over days, weeks, months, or the full year, girls receive a strong message of not belonging in certain areas of the preschool and thereby not *imagining STEM as being for them*.

The term *imaginating* is introduced to capture these social practices (be they positive or negative) between children when building with blocks and between children and teachers' in a context of a social purpose for engineering and science play. It is through naming the wondering and imagining of the girls about *if STEM is for them*, that we can begin to make visible the impact of the negative socialisation and gendering that this study has shown, and which has been reported more broadly in the literature on preschool STEM education for girls.

7. Conclusion

This chapter reports on the results of a study into how girls enter into engineering and science play practices in preschool settings. The study found important gender-based differences. That is, while the results suggests a new practice tradition and structural organisation that together support engineering and science education, the social purpose of building a bridge on its own did not support the boys to be able to successfully build a bridge or the girls to stay participating. The results show blockage points for girls in preschools for access, participation and imagining of their full engagement in science and engineering education. This is consistent with earlier research (Carrasco Rueda, González-Gijón Martínez-Heredia, 2023; Prioletta, 2022).

Even though the findings reveal through the actions of the children that in the beginning girls appear to positively perceive themselves within the engineering and science play practices, it was also shown that over the course of unstructured play time in the preschool, the girls progressively withdrew from the activity setting, and the teachers struggled to change the ways the boys interacted with the materials or used the space.

Although the teachers planned and implemented a socially motivating and meaningful engineering and science program, where engineering and science were undertaken for a social purpose, the girls appeared to be unconsciously positioned as invisible within the new activity setting. As Gullberg et al. (2017) explains, when gendered interactions become accepted in preschools in relation to STEM, this influences a child's identity formation and could change their life trajectory as a person. That is, the often unintended and unconscious oversight associated with not noticing the girls' successful engineering solutions, could negate, exclude and deny them the possibility of imagining themselves as engineers of worth. As Hamel (2021) suggests:

> A continuous emphasis on gender categorization by a teacher may signal to children that this is an important bases for classifying people. This is significant in relation to science because children are forming ideas about their own gender and others gender which may unintentionally serve as a foundation for science-related stereotypes regarding who does and does not do science and who belongs in scientific fields. (p. 268)

The findings suggest that there is an undervaluing of the impact of negative interactions on how girls imagine, wonder and create during engineering and science play. The term *imaginating* was identified through the research and is introduced in this chapter as a key term to capture the complexity of girls imagining, wondering and creating in engineering and science play with others in preschool settings. It is through naming specific gendered practices in STEM play that teachers and researchers are enabled to actively consider girls current and future imagined aspirations in science.

The results show important directions for engineering education at a time when societies are worried about the under representation of woman and girls in STEM (Régner et al., 2019). The findings contribute to better understanding the key role educators have in how they perceive and position girls in engineering and science play (Wang, 2023). This has implications not only for practices in preschools, but also for professional development of early childhood teachers to be more aware of their unconscious biais towards boys and girls in STEM. Although an indepth study of the micro movements of the children in their first moments of engineering and science related play was presented, more research across a broader range of centres is needed if we are to understand the complex dynamics of girls and boys participating in engineering and science education practices.

8 References

Appleton, K. (1992). Discipline knowledge and confidence to teach science: self-perceptions of primary teacher education students. *Research in Science Education, 22*, 11–19.

Bagiati, A., & Evangelou, D. (2016). Practicing engineering while building with blocks: Identifying engineering thinking. *European Early Childhood Education Research Journal, 24*, 67-85. https://doi.org/10.1080/1350293X.2015.1120521

Beat, K. (1991). Design it, build it, use it: Girls and construction kits, In N. Browne, (ed). *Science and technology in the early years. An equality opportunities approach* (pp. 77-90). Open University Press.

Belanger, M. (2015). The business case for gender diversity. Increasing Canada's competitiveness. In R. Parker, J. Pelletier, and E. Croft (Eds.), *WWEST's gender diversity in STEM. A briefing on women in science and engineering* (pp. 6-9). UBC Press.

Biernat, M., & Manis, M. (1994). Shifting standards and stereotype-based judgments. *Journal of Personality and Social Psychology, 66*, 5–20.

Blickenstaff, J. C. (2005). Women and science careers: Leaky pipeline of gender filters? *Gender and education, 17*(4), 369-386. https://doi.org/10.1080/09540250500145072

Browne, N. (1991). (ed.). *Science and technology in the early years. An equal opportunity approach*. Open University Press.

Chapman, R., (2023). *Gender expansion in early childhood education. Building and supporting pro-diversity spaces*, Palgrave McMillan, Cham, Switzerland.

Cohen S.M., Hazari, Z., Mahadeo, J., Sonnert, G., & Sadler, P.M. (2021) Examining the effect of early STEM experiences as a form of STEM capital and identity capital on STEM identity: A gender study. *Science Education, 105*(6), 1126–1150. https://doi.org/10.1002/sce.21670

Corrigan, S., & Aikens, K. (2020). *Barriers to participation in engineering and the value of interventions to improve diversity*. Monash University.

Croft, E. (2015). Foreword. In R. Parker, J. Pelletier, and E. Croft (Eds.). *WWEST's gender diversity in STEM. A briefing on women in science and engineering* (pp. iii-iv): UBC Press.

Davydov, V.V. and Kudriavtsev, V.T. (1998). Developmental Education, Russian Education & Society, 40:7, 37-64, DOI: 10.2753/RES1060-9393400737

Education Services Australia (2018). *Optimising STEM Industry-School Partnerships:*

Inspiring Australia's Next Generation Final Report. Carlton, Victoria, Australia: Education Council.

European Union (2016). *She figures 2015—Gender in research and innovation. Statistics and Indicators.* https://ec.europa.eu/research/swafs/pdf/pub_gender_equality/she_figures_2015-leaflet-web.pdf

English, L. (2018). Engineering Education in Early Childhood: Reflections and Future Directions. In L. English, and T. Moore (Eds.), *Early engineering learning* (pp. 273-284). Springer Nature, Springer Singapore.

Fleer, M. (2019). When preschool girls engineer: Future imaginings of being and becoming an engineer. Learning Culture and Social Interaction. *30*, DOI: 10.1016/j.lcsi.2019.100372

Fleer, M. (2020). Studying the relations between motives and motivation – How young children develop a motive orientation for collective engineering play, *Learning, Culture and Social Interaction, 24*. https://doi.org/10.1016/j.lcsi.2019.100355

Fleer, M. (2021). Re-imagining play spaces in early childhood education: Supporting girls' motive orientation to STEM in times of COVID-19. *Journal of Early Childhood Research: ECR*, *19*(1), 3–20. https://doi.org/10.1177/1476718X20969848

Fleer, M. (in press). A cultural-historical study of the genesis and disruption to girls' motives and competencies in STEM. In Helen Watt, Erin Mackenzie, Rebecca Lazarides *Research Handbook on Gender and STEM*, within the Edward Elgar Press International Handbooks on Gender Series

Garbett, D. (2003). Science education in early childhood teacher education: putting forward a case to enhance student teachers' confidence and competence. *Research in Science Education, 33*(4), 467–481.

Gibney, E. (2016). Women under-represented in world's science academies. *Nature News*. http://www.nature.com/news/women-under-represented-in-world-s-science-academies-1.19465 (29 February 2016).

Gold, Z. S. (2014). *Preschoolers' physical, social, and engineering play behaviors: Differences in gender and play environment.* (Master thesis), Purdue University, Ann Arbor. https://search.proquest.com/docview/1651208002?accountid=12528

Gold, Z. S., Elicker, J., Choi, J. Y., Anderson, T., & Brophy, S. P. (2015). Preschoolers' engineering play behaviors: Differences in gender and play context. *Children, Youth and Environments, 25*, 1-21. https://doi.org/10.7721/chilyoutenvi.25.3.0001

Grossman, J.M., &Porche, M.V (2014). Perceived gender and racial/ethnic barriers to STEM success. *Urban Education, 49*(6), 698-727. https://doi.org/10.1177/0042085913481364

Gullberg., A., Andersson, K., Danielsson, A., Scantlebury, K., & Hussénius, A. (2017). Pre-Service Teachers' Views of the Child—Reproducing or Challenging Gender Stereotypes in Science in Preschool. *Research in Science Education*. https://doi.org/10.1007/s11165-016-9593-z

Hallström, J., Elvstrand, H. & Hellberg, K. (2015). Gender and technology in free play in Swedish early childhood education. *International Journal of Technology and Design Education, 25*,137–149. https://doi.org/10.1007/s10798-014-9274-z

Hamel, E. E. (2021). Science starts early: A literature review examining the influence of early childhood teachers' perceptions of gender on teaching practices. *Journal of Childhood, Education & Society (Online)*, *2*(3), 267–286. https://doi.org/10.37291/2717638X.202123118
Harding, S. (1987). (Ed.) *Feminism and methodology. Social science issues*. Open University Press.

Hedegaard, M. (2008). The educational experiment. In Hedegaard, M., & Fleer, M. (Eds.), *Studying children: A cultural historical perspective* (pp. 181–201). New York, NY: Open University Press.

Hedegaard, M. (2012). Analyzing children's learning and development in everyday settings from a cultural-historical wholeness approach. *Mind Culture and Activity, 19*, 127-138.

Hedegaard, M. (2014). The significance of demands and motives across practices in children's learning and development: An analysis of learning in home and school. *Learning, Social Interaction and Culture, 3,* 188-194.

Innovation and Science Australia (2017). *Australia 2030: prosperity through innovation*. Canberra: Australian Government.

Kaspura, A. (2017). The Engineering Profession: A Statistical Overview. Barton ACT, Australia: Institution of Engineers Australia.

Kelly, A. (1987a). Why girls don't do science. In A. Kelly (ed). *Science for girls* (pp. 12-17). Open University Press.

Kelly, A. (1987b). The construction of masculine science. In A. Kelly (ed). *Science for girls* (pp. 68-77). Open University Press.

Kim, S., Jin, K., & Bian, L. (2024). Gender brilliance stereotype emerges early and predicts children's motivation in South Korea. *Child Development*, *95*(3), 913–928. https://doi.org/10.1111/cdev.14043

Kung, K. T. F. (2021). Preschool Gender-Typed Play Behavior Predicts Adolescent Gender-Typed Occupational Interests: A 10-Year Longitudinal Study. *Archives of Sexual Behavior*, *50*(3), 843–851. https://doi.org/10.1007/s10508-021-01976-z

Little A. J., & León de la Barra, B. A. (2009). Attracting girls to science, engineering and technology: an Australian perspective, *European Journal of Engineering Education, 34*(5), 439-445. https://doi.org/10.1080/03043790903137585

Lyttleton-Smith, J. (2015). *Becoming gendered bodies: A posthuman analysis of how gender is produced in an early childhood classroom* (PhD thesis). Cardiff University, UK.

Male, S.A., & MacNish, C. (2015). Pilot exploration of gender inclusivity of engineering students' exposure to engineering practice in an Australian university. *Australasian Journal of Engineering Education, 20*(2), 135-144. https://doi.org/10.1080/22054952.2015.1116176

Moroz, S. (2015). Microaggressions. Gender and Microaggressions, In R. Parker, J.Pelletier, and E. Croft (Eds.), *WWEST's gender diversity in STEM. A briefing on women in science and engineering* (pp. 2-5). UBC Publisher.

Mulvey, K.L. Miller, B., & Rizzardi, V. (2017). Gender and engineering aptitude: Is the color of science, technology, engineering, and math materials related to children's performance? *Journal of Experimental Child Psychology, 160*, 119-126. https://doi.org/10.1016/j.jecp.2017.03.006

National Academies of Sciences, Engineering, and Medicine (2019). *Science and Engineering for Grades 6-12: Investigation and Design at the Center*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25216.

Nguyen, U., Russo-Tait, T., Riegle-Crumb, C., & Doerr, K. (2022). Changing the gendered status quo in engineering? The encouraging and discouraging experiences of young women with engineering aspirations, *Science Education*, 106(6), 1442-1468, https://doi.org/10.1002/sce.21748

Parker, R., Pelletier, J. & Croft, E. (2015). (Eds.). *WWEST's gender diversity in STEM. A briefing on women in science and engineering*. UBC Publisher.

Prinsley, R. & Johnston, E. (2015). *Transforming STEM teaching in Australian primary schools: Everybody's business. Position Statement.* Australian Government. Office of the Chief Scientist. https://www.chiefscientist.gov.au/wp-content/uploads/Transforming-STEM-teaching_FINAL.pdf

Prioletta, J. (2022). Unearthing gender violence with/ in kindergarten play environments, Gender and Education, 34:8, 973-990, DOI: 10.1080/09540253.2022.2118441

Régner, I., Thinus-Blanc, C., Netter, N., Schmader, T., & Huguet, P. (2019). Committees with implicit biases promote fewer women when they do not believe gender bias exists. *Nature Human Behaviour*. https://doi.org/10.1038/s41562-019-0686-3

Reuben, E., Sapienza, P. & Zingales, L. (2014). How stereotypes impair women's careers in science. *Proc. Natl Acad. Sci. USA* **111**, 4403–4408.

Riegle-Crumb, C., King, B., & Irizarry, Y. (2019). Does STEM stand out? Examining racial/ethnic gaps in persistence across postsecondary fields. *Educational Researcher, 48*(3), 133-144. https://doi.org/ 13.3102/0013189X19831006

Rueda, A. B. C., González-Gijón, G., & Martínez-Heredia, N. (2023). Systematic review on gender socialisation in pre-school education. [Revisión sistemática sobre la socialización de género en la etapa de educación infantil Revisão sistemática na socialização do género na fase de educação da primeira infância] *Pedagogia Social,* (43), 191-204. doi:https://doi.org/10.7179/PSRI_2023.43.13
Shwe Hadani, H., & Rood, E. (2018). The roots of STEM success: Changing early learning experiences to build lifelong thinking skills. San Diego, US: Centre for Childhood Creativity, Bay Area Discovery Museum.

Siraj-Blatchford, I. (1991). Achieving equality in the science education of early-years teachers in initial teacher education, In N. Browne, (ed). *Science and technology in the early* *years. An equality opportunities approach* (pp. 24-36). Open University Press.

Speldewinde, C. & Campbell, C. (2023) Bush kinders: enabling girls' STEM identities in early childhood, Journal of Adventure Education and Outdoor Learning, 23:3, 270-285, DOI: 10.1080/14729679.2021.2011337

Stephenson, T., Fleer, M., Fragkiadaki, G., & Rai, P. (2021). Teaching STEM through play: conditions created by the conceptual PlayWorld model for early childhood teachers. Early Years, 43(4–5), 811–827. https://doi.org/10.1080/09575146.2021.2019198

Stephenson, T., Fleer, M., Fragkiadaki, G. & Rai, P., (2022a) "You Can be Whatever You Want to be!": Transforming Teacher Practices to Support Girls' STEM Engagement, Early Childhood Education Journal, 50, 1317–1328 https://doi.org/10.1007/s10643-021-01262-6

Stephenson, T., Fleer, M., & Fragkiadaki, G. (2022b). Increasing Girls' STEM Engagement in Early Childhood : Conditions Created by the Conceptual PlayWorld Model. *Research in Science Education (Australasian Science Education Research Association)*, *52*(4), 1243–1260. https://doi.org/10.1007/s11165-021-10003-z

Vygotsky, L. S. (1966). Play and its role in the mental development of the child. *Voprosy Psikhologii, 12*(6), 62–76.

Vygotsky, L.S. (1994). The problem of the environment. In J. Valsiner & R. vander Veer (Eds.), *The Vygotsky reader* (pp. 347-348). Oxford: Blackwell

Vygotsky, L.S. (1997). *The collected works of L.S. Vygotsky. The history of the development of higher mental functions*. Vol 4. Tran. M.J. Hall. Editor of English Translation, R.W. Rieber. Kluwer Academic and Plenum Publishers.

Vygotsky, L.S. (2004). Imagination and creativity in childhood. *Journal of Russian and East European Psychology*, 42(1), 7–97.

Walkerdine, V. (1987). Some issues in the historical construction of the scientific truth about girls, In A. Kelly (ed). *Science for girls* (pp. 37-44). Open University Press.

Wang, S. (2023). Exploring Early Childhood Educators' Perceptions and Practices Towards Gender Differences in STEM Play: A Multiple-Case Study in China. *Early Childhood Education Journal*, 1–14. https://doi.org/10.1007/s10643-023-01499-3

White, B., Miles, J., & Frantell, K., (2020). Intergroup Dialogue: A Justice-Centered Pedagogy to Address Gender Inequity in STEM. *Science Education*. 105(2), 232-254. 10.1002/sce.21599.

Whyte, J. B. (1986). Starting Early: girls and engineering. *European Journal of Engineering Education, 11*(3), 271-279, https://doi.org/10.1080/03043798608939308

9 Acknowledgements

Australian Research Council supported data collection (DP130101438 and DP140101131) and subsequent analysis (FL180100161). Thanks to Shukla Sikder (field leader), Sue March, Selena (Yijun) Hao, Anamika Devi, Omar Sulaymani, Kulsum Chishti Yonzon and Ainslie Holland (data organisation).

10 Biography

Laureate Professor Marilyn Fleer is an Emeritus Sir John Monash Distinguished Professor Monash University, Australia, who was awarded the 2018 Kathleen Fitzpatrick Laureate Fellowship by the Australian Research and holds the positions of an honorary Research Fellow in the Department of Education, University of Oxford, and the KINDKNOW Centre, Western Norway University of Applied Sciences.