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Girls imagineering: A cultural-historical study of preschool children's first experiences of engineering education in play-based settings

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Abstract

The focus of this chapter is on understanding how in play children's imagining in science and engineering becomes revealed as part of the STEM motivated actions of girls within a new activity setting in a preschool. Designed as an educational experiment (Hedegaard, 2008), thirty-one children and five teachers were followed during the first moments of introducing the new activity setting which was part of a subsequent 5.4 weeks of a program of science and civil engineering involving bridgebuilding to support the role-playing of the fairytale of the 3 Billy Goats Gruff. The overall study included digital observations (27.3hr) of the teachers and the children (aged 3.4 – 5.5 years; mean age of 4.4 years). The concepts of imagination and creativity (Vygotsky, 2002), motives and demands (Hedegaard, 2014), and a cultural-historical conception of play (Vygotsky, 1966) were used to analyse the data set. The findings show that during free play periods, a completely new activity setting for science and engineering was featured alongside of the traditional Froebelian learning areas, such as the block area, the drawing table and the home corner. Named as imagineering, the new activity setting and practices, gave new possibilities for STEM imagining and the building of theoretical knowledge of STEM. However, it was also found that when children enter into, participate and contribute to the new activity setting, gendered divergences in participation emerges. Moving beyond traditional binaries, the dialectical relations between the institutional practices and actions of the girls imagining and creating are discussed in relation to how they meet the new demands of imagineering in social play.

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

1 Introduction

In the process of the young preschool child growing into their culture, Davydov and Kudriavtsev (1998) drew attention to historically formed theoretical 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 at that" (p. 53, original emphasis). This means children do not just reproduce accumulated cultural knowledge, but rather imagine and create their own productions. 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). Play as the leading activity of the preschool child (Vygotsky, 1966) gives insights into how imagination in play and imagination in STEM come together and are made visible in social relations.

STEM is a broad interdisciplinary field. To limit the scope of this chapter, the study and theorisation will be centered on preschool engineering. Engineering as a profession encompasses the use of science concepts, features the design process, problem solving, and draws upon a range of technologies and project management competencies. In this chapter, preschool engineering acts as the practice context in which young children imagine, wonder and create. The term imagineering is introduced to capture this dynamic and dialectical complexity.

The aim of this chapter is to report on the results of a study into how girls enter into and engage, imagine and create engineering and science practices. In order to achieve the aim of this chapter, we begin with the central cultural-historical concepts that framed the research, followed by an overview of what is known about engineering education for girls, details of the study design, findings, and discussion.

The study reported in this chapter contributes to the literature by identifying how children imagine and create during unstructured play periods in the preschool where teachers create new conditions for engineering. The new engineering activity setting develops new practices and gives possibilities for new actions of all the children. The results show the blockage points for girls in preschools for access, participation and imagining of their full engagement in science and engineering education. Importantly, the findings reveal how in the beginning girls positively perceive and imagine themselves within the engineering practices, but over the course of unstructured play time in the preschool, girls appear to progressively experience invisibility and exclusion during their first encounters of engineering education. The chapter concludes by suggesting that preschool girls meet barriers in engineering education at the beginning of their education, and this mirrors the challenges reported in the literature (Grossman & Porche, 2014), but the results also show new possibilities for practice when new play and learning areas are introduced into the preschool that can positively or negatively shape agency and future identity and imagining in STEM education.

2 Imagination

In this chapter the dialectical concepts of imagination and creativity follows the theorisation first introduced by Vygotsky (2004) who 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. 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. In summary, a cultural-historical conception of imagination lies not in the person, but as a relation between person and environment and is developed through social relations.

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 playgroups 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. 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.

Imagination in play and imagination and creativity were topics theorised by Vygotsky and his conception of the latter in the context of how it develops, also guided the present study of engineering and science practices of children. In the article on *Imagination and creativity in childhood*, Vygotsky (2008) brings forth 4 key characteristics that are helpful for understanding the development of a child's imagination. First, imagination is based on the accumulation of a child's experience, and "the richer the experience, the richer the act of imagination" (Vygotsky, 2004, p 15). Second, constructing an image of either a real experience or one acquired vicariously takes on great importance in a cultural-historical conception of the development of imagination and creativity. 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).

This cultural-historical reading is critical for the focus of this chapter. A young child does not directly experience all STEM concepts, such as the Earth being a sphere, but has to imagine many conceptions that are often seem counter intuitive, such as the Earth being flat. Many STEM concepts are imagined and only later, with the development of new technologies, such as powerful telescopes and space travel, these imagined STEM concepts become confirmed in scientific communities.

In this chapter, we consider both these 2 Vygotskian characteristics of the development of imagination – direct and vicarious experience – as being important for wondering and imagining in the first moments of science and engineering play. 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).

This is an agentic and dynamic process. Children experience science and engineering, but at the same time this experience informs how they imagine their place within STEM.

The third characteristic outlined by Vygotsky (2004) suggests that the development of imagination and creativity are conceptualised as a dialectic in a cultural-historical theorisation. Vygotsky (2004) thought that this dialectic takes place through the unification of imagining dissociated and altered images in new ways to create something that does not yet exist. He said,

> …imagination is the combination of individual images, their unification into a system, the construction of a complex picture. [but] …creative imagination does not stop here. …the full cycle of this process will be competed only when imagination is embodied or crystalized in external images (p. 28).

This means that the crystalisation of imagination takes place through the act of creation. Creativity is realised in practice, but it needs imagination. For example, this can be seen when children imagine a bridge design based on dissociated and altered images and then build their imagined bridge into reality. That is, 'imagination becomes reality' (Vygotsky, 2004, p. 20). Further, when the bridge exists in reality it can furnish a child's imaginary play, for example, when used with props in the role-playing of the fairytale of the 3 Billy Goats Gruff. Whilst Vygotsky (2004) references artefacts as part of his definition of creativity, such as machines to effect the world in new ways, a bridge made from blocks by children also effects their imaginary play practices.

Finally, emotion is the fourth characteristic noted by Vygotsky (2004) when considering the association between the functioning of imagination and reality. The importance of emotions 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" (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 community or imagines themselves as either active participants or peripheral to a new engineering activity setting.

3 Gender and engineering in preschools

There is now an abundance of international statistics on the under representation of girls and women in STEM (Science, Technology, Engineering and Maths (Gibney, 2016). 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 (Reuben et al., 2014). The STEM pathway or pipeline appears to be leaky and blocked to girls and women (Blickenstaff, 2005). Further, when entering the STEM professions, problems with workplace culture (Male & MacNish, 2015) and retention are evident (Kaspura, 2017). Preparation for future STEM careers appear to be difficult for girls and young women (Grossman & Porche, 2014). This has also been noted in research where the focus has been on the racial/ethnic gap in STEM (Riegle-Crumb et al., 2019). Calls for action in staff diversity in STEM professions now proliferate in Government reports, suggesting some urgency for change.

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 so that science and engineering are imagined as possible activities and future career paths for girls (Fleer, 2019).

But what is known about gender differences in preschool engineering activities appear to be contested in the literature. 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. This was different to an earlier study of Gold (2014) where he examined pre-schoolers physical, social and engineering play behaviours in relation to gender and the play environments created. 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. No other recent studies could be found that specifically examined gender and engineering in preschool settings that showed differences in boys and girls engineering play and learning.

In contrast to these two studies, Hallstrom et al. (2015) 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).

These findings are in line with longstanding research where "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). This gendered socialisation continues to be mirrored within early childhood settings, as noted more recently by Lyttleton-Smith (2015) in her study of 3-and 4-year old children attending a nursery school.

What children do with the construction materials in the different areas of the preschool has been closely studied 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). Collectively these studies have shown that when girls do build, they construct with imaginary play in mind.

Studies have also shown variations in teachers' observations of children, with some teachers reporting that children approach the construction technology differently, whilst others suggesting they did not see any differences. Interestingly, teachers thought that conceptualising everything as construction technology, meant teachers believed girls and boys had equal opportunity. 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). What emerges in both the longstanding and the more recent literature is 'The masculine concern with things fits more easily with the dominant form of physical science than the feminine concern with people' (Kelly, 1987a, p. 73).

Evidence from longstanding research also points to how boys occupy more of the preschool space and more of the construction areas than girls. For instance,

> There was a general tendency for boys to gravitate towards the construction activities, once there, to stay for almost the entire session excluding any girls who made attempts to join the group. Also throughout the hours the construction activities, which were usually on the carpeted area, would steadily spread to the surrounding areas as more boys joined in. Meanwhile the girls were generally involved in drawing, colouring and cutting-type activities and in one particular case they were 'huddled' in one small area of the classroom while the boys dominated the rest of the space, sprawling along the floor and over tables (Beat, 1991, p. 78).

In line with Beat (1991), 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).

It is not just space, but access to resources that has been identified in the literature. Kelly in reviewing the literature back in 1987 noted that,

> Boys frequently make a dash for the apparatus and end up with the lion's share, or at least the bits in better condition. Although this could be seen merely as an indication of boys' great enthusiasm, it can also be interpreted in terms of male dominance. …how boys push into queues ahead of girls, 'persuade' them to give up scarce pieces of apparatus and monopolize the classroom space (Kelly, 1987a, p.70).

Access means that different kinds of participation between girls and boys result, influencing their experience of STEM and how they are positioned in preschool settings. The net effect is that early experiences in preschool also build over the course of children's education, having an accumulative effect on both boys and girls. That is,

> By the time they reach secondary school, girls and boys differ in many ways. They have different interests and hobbies, different background experiences and they envisage different futures for themselves. Girls' interest centre around people, boys' around control… Based on their toys and childhood hobbies boys have much greater experience than girls of tinkering activities (Kelly, 1987a, p. 67).

Differences in boys' and girls' interests has also been noted in the more recent literature. 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).

Parker et al. (2015) suggest that when the research is brought together on gender diversity in STEM that there is a lifetime of microaggressions that have been experienced which collectively contribute to girls and women not thinking engineering is for them. For instance, Moroz (2015) explains 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) suggested as a result of more recent research in Sweden which showed acceptance of gendered practices in preschools associated with STEM, that, '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).

Contemporary research into early childhood engineering has examined interventions for increasing the participation and interests of girls towards engineering**.** For instance, 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) argue that boys appear 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 identify 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).

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. 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). This is consistent with longstanding research which has also shown teacher interactions vary in relation to gender. For instance,

> Many researchers have found that teachers, both male and female, tend to spend more time talking to boys than to girls in class. In our society, males are considered more important and interesting than females (Kelly, 1987b, p. 13).

Whyte (1986) in researching the effect of girl friendly programs '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). More recently, English (2018) has 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. In summary, the 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. Siraj-Blatchford (1991) has noted that even when 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 preschool boys and girls are already different. But none of the recent studies reviewed looked at the first moments of how boys and girls engaged in a preschool engineering program. This study seeks to contribute to filling this gap. By following children's first preschool experiences of engineering we can better understand girls' imagining, creating and participation in science and engineering education.

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 bridgebuilding 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 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). 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.

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 bridgebuilding 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, that additional digital editing takes place. This allows for the cutting of single situated practices into a series of interrelated clips, 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.

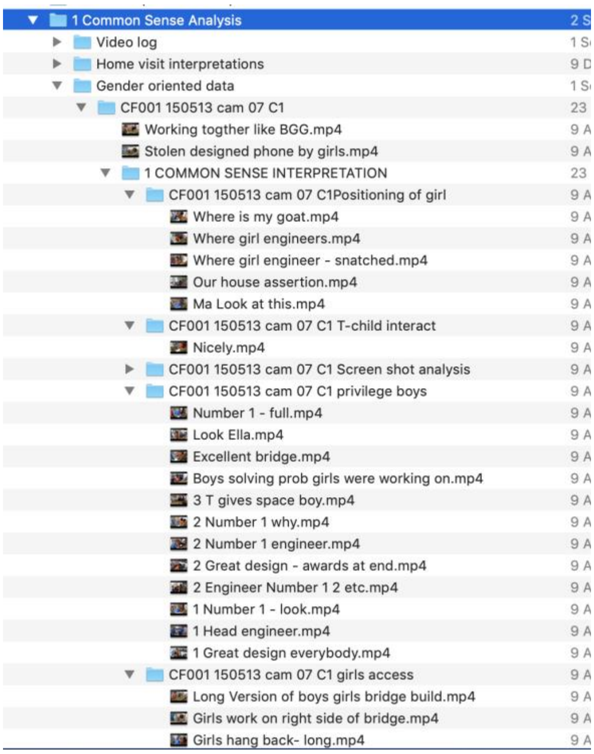

Figure 1. Commonsense interpretation of digital data – skipping within a raw data set for digital editing of gendered interactions.

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. This second step in the analysis also 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.

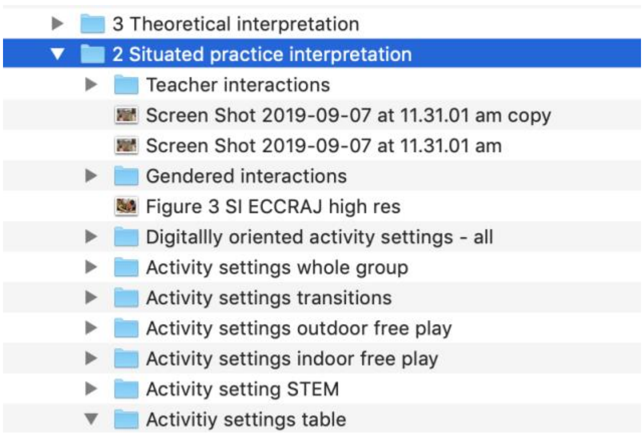

Figure 2. Situated practice interpretation

The third step in the analysis process involved a conceptual synthesis and theorisation of the data categorisations. The gendered practices were organised in the data set in relation to the categories that were identified in the literature. Figure 3 shows a screen shot of folders which contain multiple digital clips of gendered practices clustered around particular categories.

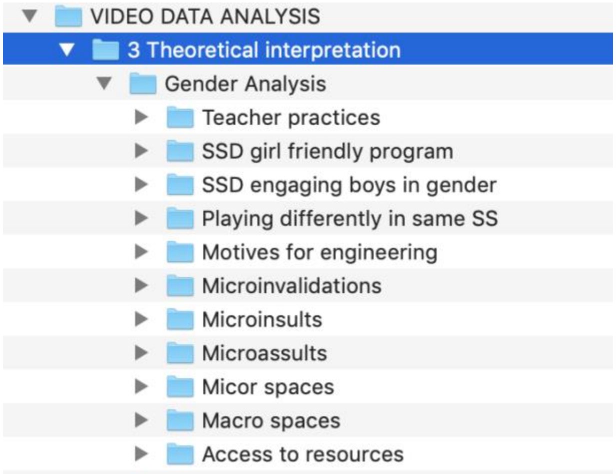

Figure 3. Theoretical and thematic interpretation

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, such as girl friendly engineering practices or access to resources. The Vygotskian concepts of imagination, 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. Important for a cultural-historical study, is the interconnections between the 3 analytical steps so that a holistic interpretation is possible. 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 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 “Bridgebuilding” activity setting was a new area within the preschool. It was designed specifically for introducing civil engineering 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 activity setting is shown in relation to the other areas within the preschool.

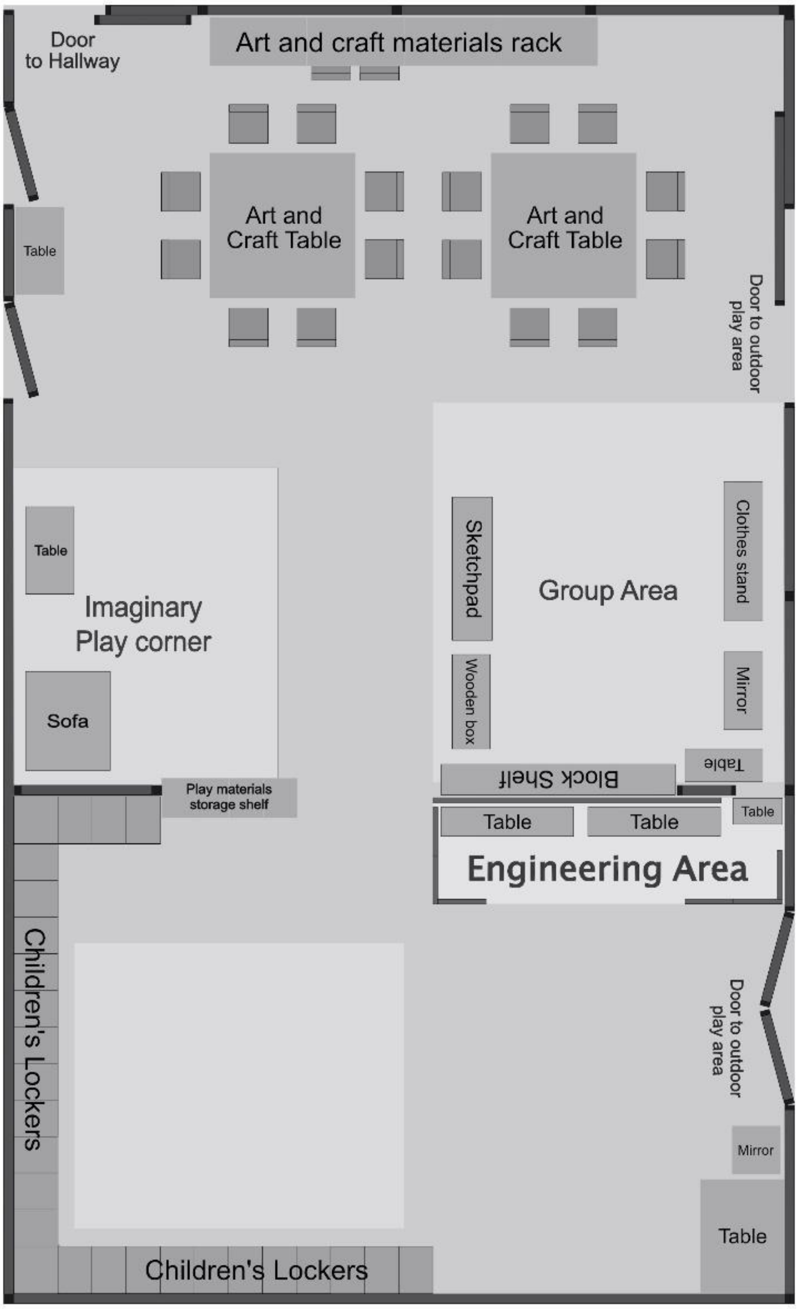

Figure 4. Centre activity settings

Two important findings emerged in relation to creating an engineering 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 space in this study was a completely new space dedicated to engineering.

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 space to build bridges and to role-play the fairytale, a motive for participation in civil engineering practice was created, as Vignette 1 shows:

Vignette 1: *Collective engineering 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 activity setting as Vignette 2 shows where the children transitioned from group time to the engineering space.

Vignette 2: *Transition into the engineering 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. She says, at this moment, "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 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 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.

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 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 providing a narrative around its purpose, gave new possibilities for girls' involvement in engineering.

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, 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. 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 activity setting was not set up in an existing area, such as the block corner/area. Rather, the new engineering activity setting has the possibility of being one turning point in changing opportunities for girls in STEM. More research is needed across different preschools to determine if a dedicated engineering activity setting can attract equal numbers of boys and girls to engineering.

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 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 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-movements of children.

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

> *Vignette 3: Access to space:* 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 right where the boys are standing. 4 more boys enter the space. Oliva and Bryce are directly in front of the bridgebuilding area, and behind them are the other boys. They 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. 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, the children work with a 45 degree angle rather than a 90 degree angle. 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.

At the same time, the 3 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 densely packed directly in front of the bridgebuilding space. No progress appears to be being made to the bridgebuilding. Eventually, Rita moves around the back of the boys and the teacher and on to the left side of the bridgebuilding, 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.

The teacher positioned herself as facing the left side, towards the boys, where she set up the bridgebuilding 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 or their involvement was less imagined as important than the boys.

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 longstanding literature, the girls had difficulties with entering the prime space (Beat, 1991). 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 bridgebuilding (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 the problem. However, the teacher does not reference Rita’s engineering solution as 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. However, she does this not next to the boys, but 30 cm away (possible bridge span). 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.

The teacher does not notice Rita's construction work on the left 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.

As can be seen, Rita was actively engaged in the engineering activity setting, but her actions and achievements appeared to be primarily invisible. Over the course of unstructured play period, Rita was in the activity setting and actively trying to contribute to bridgebuilding. 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 bridgebuilding or position her as someone who had worked out the solution to the problem. Rather her engineering work was 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 pillar 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 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 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.

6. Discussion

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 positive outcomes of this cultural-historical study are that preschools can create a new activity setting for engineering education and the new space appears to initially attract equal numbers of boys and girls. The social purpose of the activity setting seemed to engage both the boys and the girls. The engineering area was imagined as a space where boys and girls could imagine bridgebuilding with blocks. It was not the traditional block area in the preschool, but rather a green field for new actions and imaginary play possibilities.

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 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. However, in this study this potential was not realised.

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 Kelly (1987a), 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.

Unlike Hallström et al. (2015), the girls didn't position themselves in helping roles, but rather when they did have access to the resources, they appeared to build in parallel – almost keeping themselves 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.

The findings of this study do, however, support recent conceptualization of girls' experiences in STEM through the lens of microaggressions. 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 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 being for them.

Gullberg et al. (2017) explains that 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 imagining of engineering solutions, could negate, exclude and deny them the possibility of imagining themselves as engineers of worth. However, 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 role-play of the 3 Billy Goats Gruff. A cultural-historical theorisation can give other insights into explaining the results. If we consider Rita's persistence and interest in STEM by her constant presence in the engineering activity setting, an additional reading is possible. Her invisibility as someone who had imagined a solution and who actively builds to solve the engineering problem, shows the significance of the motive orientation for bridgebuilding for a social purpose. This supports the finding in the longstanding literature that girls build with a social purpose in mind, and the teachers of this study created these conditions for the motivated actions of the girls for imagining in STEM.

7. Conclusion

This chapter sought to understand children's first preschool experiences of engineering. Specifically, the new engineering area within the preschool was studied to determine how girls and boys imagine, build and engage with engineering practices designed by teachers. Overall, it was found that the new engineering activity setting developed new practices and gave new possibilities for collective imagining, but with some important differences.

First, the new area in the Froebelian kindergarten did not have established ways of playing or an expected imagined practice tradition to follow. Rather, what drove the actions in the activity setting was the social purpose of building a bridge to support the role-play of the 3 Billy Goats Gruff. The social purpose created motivating conditions for all the children, and this was met with equal interest from the boys and girls in the preschool. This was different to studies of girls' and boys' play where gendered selection of areas to play in have been found (Hallström, Elvstrand and Hellberg, 2015).

Second, the imagined social purpose supported the children's leading activity to play and in so doing, foregrounded the motive for children to imagine solutions to problems when engineering their block bridge so they could play with the results. Imagination was the key psychological function being deployed. With the exception of Rita, who already had imagined a successful design solution for building the bridge, the other children needed support with imagining and then testing out solutions for the engineering problem that had arisen. That is, many of the boys focused on constructing only one side of the bridge and could not imagine a solution to the problem of the 45 degree angle that resulted (rather than a 90 degree angle if both ends of the bridge had been built simultaneously).

Third, the motivated conditions generated through the narrative of the fairytale created a collective imagining for bridgebuilding. The teachers appeared to support actions that coalesced around collective bridgebuilding. Rather than being conceptualised as individuals constructing individual creations in the block area, the motivating conditions supported the collective imaginings of bridgebuilding for the role-playing of the 3 Billy Goats Gruff. The storying and the new area for engineering, together supported imagining designs, imagining solutions to the engineering problems that arose, and imagining using the bridge for role-play. This suggests a new practice tradition and structural organisation that together support the psychological development of children's imagination. This can be conceptualised as a form of imagineering. Imagineering captures the collective imagining and engineering actions of the children and adds to the literature.

However, the social purpose of building a bridge on its own did not support the boys to be able to successfully build a bridge. Consistent with cultural-historical theory, it was in social relations that the teachers sought to support the children's engineering capabilities. But the majority of the children were not able to imagine the solution to the problem. Only Rita had imagined an engineering design solution and her imagined design seen through her actions could have been used to support the collective build, but this opportunity was missed. Here the Vygotskian idea of the doubleness in imagining is helpful for understanding this finding. That is, the mutual dependence between imagination and experience was not attended to, as the children had no models or experience with bridgebuilding to successfully imagine and use when constructing a bridge to support their role-playing of the 3 Billy Goats Gruff crossing the bridge. This suggests that engineering education in preschools needs to include experiences (both direct and vicarious) with engineering principles and models.

Finally, the study shows new possibilities when new play and learning areas are introduced into the preschool that both positively and negatively shape agency and future identity and imagining in STEM. The negative outcomes show the blockage points for girls in preschools for access, participation and imagining of their full engagement in science and engineering education. Even though the findings reveal how in the beginning girls positively perceive and imagine themselves within the engineering 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 program, where engineering was undertaken for a social purpose, the girls appeared to be unconsciously positioned as invisible within the new activity setting. This finding contributes to better understanding the key role educators have in what they imagine for girls and boys in engineering play. However, more research across a broader range of centres and engineering practices is needed, if we are to understand the complex dynamics of girls and boys successfully participating and imagineering together in engineering education.

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9 Biography

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