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# Engineering PlayWorld – supporting children to collectively design, imagine and think using engineering concepts

## Abstract

It is reported that preschool environments offer an abundance of opportunities for exploring the physical world where children can learn *engineering concepts* and *principles* (theories or laws). Yet how engineering thinking builds over time for the early childhood period has not been fully investigated. This is particularly surprising given the global trend towards fostering a culture of innovation within the context of future knowledge-based economies which harness STEM thinking. The study reported in this paper investigated how teachers and young children engaged in engineering principles over twelve months. Digital video observations (123 hours) captured the daily interactions of two teachers and 13 children across two classrooms during their engineering sessions. The participants were 8 preschool children aged 4.7-5.5 years and 5 school children aged 5.5-6.4 years. The new pedagogical practices of the teachers created new play practices and learning conditions for the children. The new practices, named as an *Engineering PlayWorld,* contribute to better understandings the nature of engineering education in play-based settings.

**Keywords**: PlayWorlds, play, Engineering, cultural-historical, early childhood

## Introduction

Concerns for not having a STEM qualified workforce are mounting in many countries, as "problems in the pipeline from schools and universities into the workforce" have become increasingly evident (Australian Industry Group 2017, p. 7). These societal values create new demands upon schools and early childhood settings for the development of new practice traditions for STEM learning. What appears to be new in Australia, is a societal expectation for the teaching of engineering principles in schools from the beginning of primary school (Australian Industry Group 2017) and increasingly in early childhood settings, as noted in the international literature (Bagiati and Evangelou 2016; Gold, Elicker, Choi, Anderson and Brophy 2015; Lippard, Lamm and Riley 2017).

This paper takes up the challenge of engineering appearing as a new societal value for schooling in Australia, and significantly as a potentially new institutional need for early childhood education. With calls for knowing more about what engineering education looks like at the beginning of the pipeline (Lippard et al. 2017), it is timely for a review of what is known and a study of what might be possible, to be undertaken. This paper seeks to find out how teachers can engage with engineering education in play-based settings. This is different to the existing literature (Bagiati and Evangelou 2016), which primarily looks at engineering affordances of preschool environments (Lippard et al. 2017).

To achieve the goal of this paper, a review of what is known about early childhood engineering is presented, followed by the theory informing the research, where details of the study design are given. The paper concludes with insights gained from studying how teachers design engineering education for young children.

**Engineering in preschool settings**

One of the central problems in researching engineering in preschool settings is what conception of engineering is drawn upon by both researchers and participants. At a fundamental level, it has been shown with children aged 6 to 10 years that when asked to draw an engineer doing engineering work as a basis for an interview of children's conceptions, that the results consistently show that children equate engineering primarily with engines or building, and an engineer as someone who fixes engines, builds or who is a technician or physical labourer (Capobianco, Diefes-Dux, Mena and Weller 2011). It is suggested in engineering curricula in the US, that significant educational gains are made and expanded conceptions of being an engineer result. In using an engineering curriculum, early studies have shown that children learn about engineering through stories and characters from different countries following an ask, imagine, plan, create, and improve, stepped process (Hester and Cunningham 2007, as cited in Cunningham, Lachapelle and Davis 2018). These studies introduce the idea of engineering, which could contribute positively to broadening conceptions of engineering as a profession. It is suggested in recent engineering reports from Australia (Australian Academy of Science 2019; Kaspura 2017), Canada (Engineering Success in STEM 2019), the UK (Lucas, Hanson, Bianchi and Chippindall 2017) and the US (National Academy of Engineering and National Research Council 2009) that the broader community does not yet fully understand the breadth of engineering disciplines within a broadly defined engineering profession. Consequently, it is not surprising that young children equate engineering with engines. Penuel (2016) argues that children can develop repertoires of participating in engineering that can transform the way they imagine and that this can expand their possibilities, or not, for engaging in engineering professions in the future.

A second pattern noted in the engineering education literature is the identification/analysis of everyday preschool practices that could be deemed to be engineering related. A number of related studies have examined how block building can contribute to engineering thinking. For example, Bagiati and Evangelou (2016) observed spontaneous activities of US preschool children when block building in order to determine if some of these actions might be related to engineering behaviours. In their naturalistic study of free play of 3-5 year old children using open, semi-structured and structured materials they examined if what happens in preschools could mirror what takes place within the engineering professions. Specifically, they studied if there were possibilities in the preschool for spontaneous engineering behaviours and related play-learning activities and concluded that preschools do afford engineering possibilities. This is consistent with Bairaktarova, Evangelou, Bagiati and Brophy (2011) and Gold et al. (2015). As with Bagiati and Evangelou's later study (2016), Gold et al. (2015) sought to examine the existence of early engineering thinking over 4 months and found goal setting questions, explanations of how things are built or work, actual behaviour of building or making things, problem solving and some form of evaluating. This was different to Lippard, Lamm, Tank and Choi (2018) who found that children rarely stated the problem or gave alternative solutions when solving problems. Gold et al. (2015) compared general free play time in the home corner with the play of large light weight blocks in both the indoor and outdoor play areas of 2 preschool rooms over 2 months. Results show that more design and construction took place in the play with the large blocks than within the dramatic area, and the least engineering activity was in the traditional playground. As with Lippard et al. (2018), they also found higher rates of behaviour for communicating goals. Taken together, the studies showed affordances for engineering thinking in free play time.

The third area to emerge related to the role of the teacher in supporting engineering thinking in preschools. Christenson and James (2015) identified specific pedagogical practices through a case study of a preschool teacher using blocks for engineering. The teacher used a stepped approach of, define problems, research solutions, build and test prototypes, and share results. In another study of block building, Lippard et al. (2018) found that teachers do not necessarily create or extend engineering thinking of the children in preschools. In their study of preschool practices of what they termed pre-engineering thinking, they noted a strong relationship between child-initiated problems and engineering habits of the mind. Only two instances of teacher initiated activities were observed. In line with most of the literature, they argue that teachers should expand children's pre-engineering thinking, suggesting, "Our results indicate that once teachers have experience and confidence in their ability to engage children in learning and managing children's behaviors, they are primed to encouraging children's development of engineering habits of mind" (Lippard et al. 2018, p. 10).

The studies reviewed focus on the important area of determining the resource affordances for engineering thinking and behaviours. The knowledge and behaviours appear to have come from the practices of the engineering profession and have been used to examine the resources' affordances and possibilities for models of practice in preschool. This is a first step. But this important work does not focus on how teachers design programs. Nor do we know what could be the best practices for designing engineering programs. There appears to be gaps in the literature that the present study seeks to address.

## A cultural-historical framing of everyday and scientific concept formation as a double move

The study reported in this paper is founded in a cultural-historical methodology, which allow researchers to study holistically how children learn concepts in the context of the practices of the teachers. In this theoretical framework, the researcher examines both the child's thinking (intrapsychological) and the social relations (interpsychological) in which that thinking is embedded. This is the essence of dialectical relation between inter and intra-psychologically functioning. Vygotsky (1993) argued that "…understanding, like all the higher psychological processes, develops in no other way than in the **process of collective actions by the child"**

(Vygotsky 1993, p. 205; my emphasis). In the preschool period that is the focus of this paper, play is conceptualised a key form of collective action of the preschool child. Specific to the goal of this paper are the dialectical concepts of everyday practices and engineering concept formation that develops in play-based settings. Vygotsky (1987) said that "the concept must be seen as part of the entire system of relationships of the fibers that tie it to the common fabric" (p 193). Everyday practices are viewed as experiences that Vygotsky called everyday concepts and they are important because they lay a conceptual pathway through which engineering concepts become consciously understood. "Scientific [and engineering] concepts are the gate through which conscious awareness enters the domain of the child's concepts" (Vygotsky 1987, p.193).

It is through the contemporary research of Hedegaard (2008) that the central theoretical foundations introduced by Vygotsky, become operationalised as a dynamic whole in practice, captured through the term *a double move*. Hedegaard (2002) explains this concept as a relationship between teaching practices and children's conceptual learning which support children "to plan and participate in research activities with the objective of creating a link between the pupils' own questions and the problems that are central for the subject being taught" (p. 81). The engineering "problems become the key between the child and subject area" (p. 81).

The Vygotskian conception of everyday and scientific concept formation and Hedegaard's concept of a double move are relevant to the goals of this study because they give an analytic frame from which to better understand how teachers introduce engineering practices and children engage with engineering principles as part of learning abstract engineering concepts. This is captured in Table 1. Column 1 shows the theoretical concepts within a double move, and Column 2 shows the practice contexts that were developed to create motivating conditions and which align with concepts in Column 1.

Table 1

*A double move of concepts and practices in the educational experiment*

| **Development of theoretical concepts – Double move (Hedegaard, 2008)** | **Motivating practices** |
|---|---|
| Children formulate goals about the thematic relationships that compromise the main problem – initial relations to be researched. | *Group time:* Story of Robin Hood creates motivating conditions for solving a social problem |
| Formulation and expansion of the initial relations into a core model of the problem area being investigated. | *In place of table top activities:* Children enter into imaginary PlayWorld of Robin Hood to embody the everyday problem |
| Children take a critical position on the conceptual relationship being investigated. | *In place of table top activities:* Children engage in research related to the central engineering problem |
| Children draw upon conceptual knowledge to build theoretical models as their research | *In place of table top activities:* Children design and prototype models |
| Children evaluate the outcomes | *Group time:* Children test their model |
| Children use their theoretical knowledge in child-initiated play during free play periods | *Free play period:* Children initiate the collective building and construction work in the free play area |

The approach is particularly pertinent to the study of engineering education because abstract engineering concepts are grounded in everyday engineering practices which become the core principles of the different engineering professions.

Participants:

In this study two degree-qualified teachers (Ruth and Olivia) from two classrooms brought their children together to team teach. A third staff member (Adrian) was involved in the program from time to time, taking a role in the imaginary play that was developed, and supporting the technical dimensions of the program. A total of 13 children consented to participate in the study. Five children were aged 5.9 years with a range of 5.5-6.4 years and 8 children were aged 5.1 years with an age range of 4.7-5.5 years.

*Data collection:*

Digital observations: The period of data collection for the overall study was two years. The data from the second year of study forms the basis of this paper. Digital observations were made over a total of 35 data gathering sessions, with a total of 52 sessions recorded. These are referenced as periods in the analysis. A total of 123 hours of video data were collected. Two cameras captured the digital observations. One camera was hand held and followed the children and teachers, and the second camera was on a tripod capturing the main teaching area. In addition, some photographs and digital phone recordings were made by the teachers when the researchers were not present.

*Analysis:*

We used the relational concepts of everyday and scientific concept formation (Vygotsky, 1987) within the analytical frame of a double move (Hedegaard 2002) as shown in Table 1. This formed the theoretical analysis of the data after it had been digitally logged for conceptual development over time, iteratively organised, and digitally tagged in relation to patterns of engineering practices and patterns of learning engineering concepts.

## Findings and discussion

In contrast to previous studies of engineering in play-based settings, where the environmental affordances for the learning of engineering concepts was central, this study sought to find out what conceptual learning might be possible when teachers were charged with teaching engineering through the imaginary play of the story of Robin Hood. As the focus is both the teaching and the learning of engineering concepts and practices, the findings will be reported primarily from the perspective of the teachers.

**New pedagogical practice for early childhood engineering**

In keeping with a cultural-historical approach the dynamic teaching and learning context is captured. The teachers begin the program by considering the planning documents in relation to preparing an engineering program for children aged 3 to 8 years. Olivia during the interview said she found the curriculum documents available to her were not specifically focussed on engineering as an outcome. Rather, the documents were more generic, and this meant she needed to determine what might be the concepts associated with engineering that were appropriate for young children to learn:

> I have tried to make links with the Victorian Curriculum and some questions that relate to PYP, such as "What do we want the children to know/learn?" The PYP goes into things like specific skills, dispositions for learning, broad concepts, transdisciplinary themes that are in some way overarching and keep the inquiry/project together if you like. There is always a big ideas question that drives the inquiry/project and supports educators to think about the enduring understandings that we want children to take away from this endeavour that both children and teachers come away with together. …The children are always at the centre of it all… (Olivia, 29 August; Planning documentation).

Although challenging, Olivia prepared a detailed program where she recorded STEM learning. She also included a section on role play and on technologies, as the extracts from her program show:

> Objectives - The children will:
>
> [Engineering and science concepts]

Explore how **forces** can be used to create light, sound, heat, movement, control or support in systems. Students develop an understanding of how forces and the **properties of materials** affect the behaviour and performance of designed engineering solutions [Oliva's emphasis].

Role play:

Different kinds of engineering teams.

Create with and ask the children who will be robin hood, other possible characters? Will they be in the castle or in the forest?

Technologies:

Keywords: systems, pullies, gears, cogs and bellows…

Invention. Castle as a defence system. …We use the science concepts to ask why is it so and then invent.

Introduce the concept of design:

Design-make-appraise…engineering design process…Adam role paying the castle architect [later he is the castle engineer back in the time of Robin Hood]

Draw/design a time machine to travel back in time.

> Problem: We need to go back in time…because we need to see the castle…there's a lot things we don't know…. Thinking of perspective in being able to look at things from a bird's eye view etc.

Early on it the implementation of the program it seemed that the teachers began their planning and teaching by fitting the concepts to be learnt into the existing frame of the program, as noted in the field notes: "*Olivia has made plans that fit with her curriculum and the project, and on Thursday she will look at perspective, 3D shapes. Next week they will create an obstacle course and give Friar Tuck simple directions, positioning, location, space, in the context of a* *castle wall*" (Field notes, 24th August). This is consistent with the literature which suggests that one approach to teaching engineering concepts is to integrate engineering within the regular curriculum (Moore, Tank and English 2018). Later the teachers became increasingly creative about how to deepen the conceptual learning through setting up additional problems that expanded the play and deepened the learning. As the field notes show:

1. Olivia to visit in role as Friar Tuck bearing a letter from the dragon asking the children to help rescue her. Designing a "grabby hand" complex machine to rescue the dragon and treasure. Making a list of materials needed (Field notes, 10th October).
2. Travel back in time through time machine to the castle to have a look at the treasure room. Children take photos on iPads –from dragon's eye and wolf's eye view – of the pullies and other equipment in Bob's workshop – they can use these photos to help in designing complex machine. Ruth notices a pipe in the treasure room. How will we design the grabby hand machine to fit through? (Links to Robin's escape plan). Robin Hood play outside. Use GoPro in the time machine – both ways (Field notes, 11th October).

Olivia and Ruth in their practices go beyond existing integration and introduced key engineering concepts to the children that were planned, and which were consistent with, and showed more advanced practices than recent recommendations for "STEM integration" (Moore et al. 2018). However, the level of sophistication of the engineering is consistent with the view of Moore, Tank and English (2018) who claim that STEM "needs to be "intentional and "specific" with consideration given to both content and context" (p. 14). This was also discussed as a key need in studies of the affordances of the preschool environment for learning engineering concepts (Bagiati and Evangelou 2016) or for developing engineering habits of the mind (Lippard et al. 2018).

Analysis of the digital data indicated that the teachers were amplifying the play and engineering in ways that supported the engineering concepts to be personally meaningful for the children. For instance, scenarios also arose during children's play in the imaginary context of Sherwood Forest and the Castle from the story of Robin Hood:

> … Olivia and the children discuss going outside to play the story - they choose the part where Robin Hood escapes down the toilet pipes and imagine how that would be. … Millie and Catherine had planned and played rescuing Robin Hood with a rope around his waist and Ruth emphasised the pulling to get him out of the water… (Video observation PR006).

The teachers also focused the children's attention on key engineering concepts in their play, as the following planning example shows:

> The children make pulleys in the castle block area today. The planning is to collectively engage in role-playing being pulleys/complex pulley systems to make the science of push and pull more conscious, and also the components of a pulley system, or different kinds/complexities of pulley systems. Also investigating the materials that we would use to make the pulley – is a chain stronger than a rope? – as part of the planning process, the children could make a list of what is needed, and what needs to be tested" (Field notes, 31st August).

The children's study of *"Is a chain stronger than a rope?"* was also evident in the drawings that formed an important part of the children's research, as shown in Figures 1 and 2 below.

Figure 1. *Studying the structure and strength of different materials - chains*

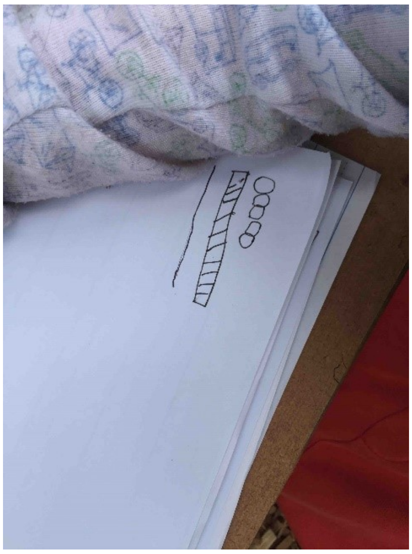

Figure 2. *Documenting the details of different materials in order to understand their strength – ropes and chains*

What is interesting to note in the planning and practices of the engineering program designed by Olivia and Ruth, is that both the concepts and principles of engineering were originally written as explicit objectives. So too was the planning by them for a holistic program that was personally meaningful to the children. For instance, *Ruth notices a pipe in the treasure* *room. How will we design the grabby hand machine to fit through?* The problems were social and the solutions were technical and conceptual, giving the children new ways of thinking and new ways of playing. For instance, *Children take photos on iPads –from dragon's eye and wolf's eye view – of the pullies and other equipment in Bob's workshop.* This is different to the broader literature on preschool engineering, where the affordances of the play-based environment are the focus (Bagiati, Yoon, Evangelou and Ngambeki 2019), and the engineering concepts appear to be primarily about stating goals/problem solving/questioning/evaluating designs with the existing resources (Bairaktarova et al. 2011), as isolated experiences of individuals or small groups of children. For example, observing a child using a circle block as though it is a steering wheel instead of building one and using that, and stating that this creative and innovative idea can be described as "Child tries different, not common approach when playing with materials and/or building object in regard to shapes or functionality" (Gold et al. 2015, p. 3). Yet engineering practice across the various engineering professions is primarily about teams, is about a need for finding a solution to a social problem which needs a broadly framed team approach for its successful resolution – as was the evident in this study: *How to help the villagers; How to get the treasure back and re-distribute the wealth.* Figure 3 is the mind map of the children that was documented. Questions arose and actions needed to be taken, such as "Where is the treasure room?", "What materials are needed?" and "What kinds of tools need to be made?". With these questions, children needed to draw, make models and test out their solutions to the engineering problems they were seeking to solve.

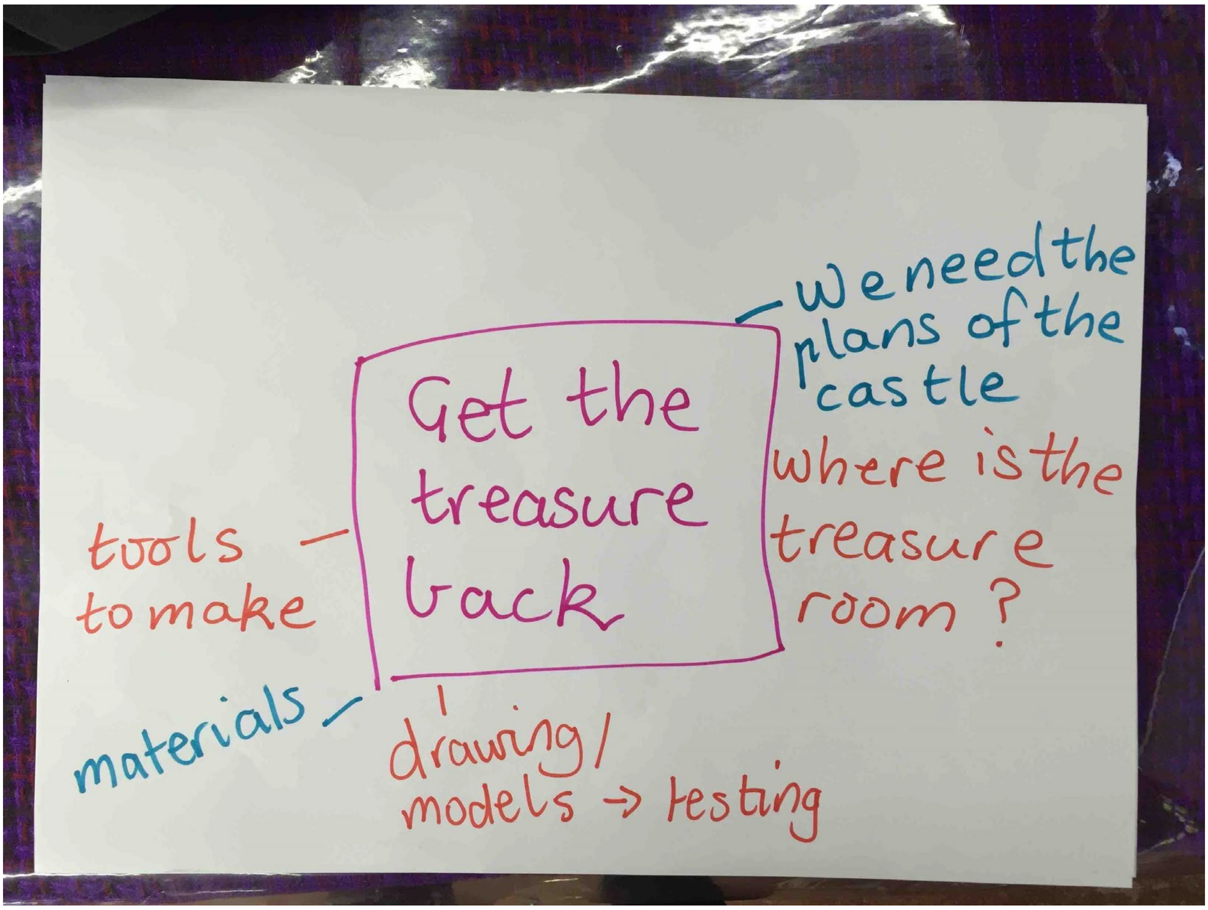


Figure 3. *A mind map of the problems that arise after reading the story of Robin Hood*>

In Figure 3 it is possible to see a range of engineering practices that will need to draw upon engineering concepts in order to solve the social problem that has arisen through the story reading of Robin Hood. The engineering practices and principles position the children as a collective solving the social problem, and this motive orientation to engineering (Author 2019) creates a holistic engineering context for the children and teachers. It seemed that the engineering practice was supporting the children's thinking and acting in ways that were in the service of their imaginary play. This is different to what is in the literature, as the categories of engineering behaviours applied to free play with construction materials have mostly identified and used discrete categories to analyse existing practices, such as, communication of goals, design and construction, problem solving, creative/innovative ideas, solution testing, evaluating design, explanation of how things are built, following patterns and prototypes, logical mathematical thinking, technical vocabulary (see Gold, Elicker et al. 2015).

**Collective Engineering play – Being an engineering team**

It was found that the engineering play was collective and the problems and their solutions were collectively engineered. For instance, the teachers planned "*Different kinds of engineering teams"*. The teachers regularly worked on the engineering problems and solutions in teams. They regularly referred to the group as 'a team' and they regularly positioned and named the children as 'engineers', as shown in the first example of exploring engineering principles in Period 26 and in the second example of investigating pulleys and booms within the preschool environment in Period 46, where two engineering teams are formed:

> *Circle discussion about inventing a complex machine to go back (a "grabby hand" machine - Catherine's name for it) and rescue Robin Hood and the treasure. Travelled back in time in the time machine. Bob sent the children to play while he rigged up the first, single, pulley to lift a heavy bucket of water.* ***Teachers called the engineers (children) to come and try the pulley, which was too heavy to lift.*** *Bob showed them the double pulley (fixed and moving pulley system) and they went to play again while he rigged that up. (see cam 10 for different angle and position of girls).*
>
> Children still playing. The engineers (children) are called over and they pulled on the pulley and were able to lift the bucket [see Figure 4]. (Video observation PR026).


Figure 4. Exploring engineering principles for lifting the treasure out of the castle

*It is group time and Ruth showed the photos (of models) from Thursday …* ***Harrison explained his concerns about the group design - it looked like the counterweights were just hanging there, unsupported - several children were curious about this.*** *The children broke into* ***two teams of engineers*** *to investigate the major problems on the group mind map:* ***Team Boom*** *to go around the school with Ruth and investigate properties of materials suitable for boom; and* ***Team Pulley*** *with Olivia to continue to refine the pulley designs. Both teams need each other to make the complex machine. Both to report back through recording a video on the iPad. Stopped for recess before breaking into teams*. (Video observation PRO46).

The regular positioning of the children as engineers was most evident in how the children collectively designed their complex machine. Children drew individually to explore different dimensions of systems of cogs and gears they were exploring, as well as their investigations back in time to study the ropes and chains used in the drawbridge of the castle. This is more than "open-ended challenges…fostering problem-finding and creative problem-solving" where it is claimed "that play in engineering can foster all of the engineering habits of mind" and where "early engineering can help young learners by supporting the development of natural ways of thinking into productive problem-solving" (Moore et al. 2018, pp. 15-16). By default, the latter is individually oriented, but the former is deliberately collective. How young children become a team of engineers has not been previously studied.

**An Engineering PlayWorld**

A synthesis of the practices of the teachers and the corresponding engineering experiences of the children are brought together in Table 2 below. In contrast to Lippard et al. (2018) who claimed that teachers do not necessarily create or extend engineering thinking of the children in preschools, in this study the teachers appeared to develop motivating conditions for engineering. It was through the practice of the collective engineering play that engineering concepts were systematically introduced in a holistic way as shown in Table 2.

The children's motive to play was used to create the motivating conditions for learning engineering concepts (Column 1). How children entered into the new practice conditions was studied and captured in Column 2 as a collective engineering motive that is personally meaningful. Examples from the overall study are shown in Column 3. In Column 4 the pedagogical outcome is captured. The double move of concepts and practices in the educational experiment uniquely supported the ongoing analysis of everyday concept formation as an engineering practice and the conceptual formation of what were identified as uniquely engineering concepts for children 3 to 8 years.

Table 2

*Engineering PlayWorld*

| **Motivating practices for engineering education in play-based settings** | **Personally meaningful engineering** | **Data example** | **Pedagogical characteristic** |
|---|---|---|---|
| *The story creates motivating and emotionally charged conditions* for solving a social problem that needs engineering solutions. Both children and teachers are engaged in the narrative. | The story of Robin Hood raises concerns for fairness for the children and they wish to help the villagers. Solving the social problem by rescuing the treasure box. | *"If they steal money then all of the people won't have money to be able to buy food. We have to get the treasure out".* | **Using an engaging story with a social problem that needs to be solved with engineering solutions.** |
| *Teachers create an imaginary engineering situation of Sherwood forest*. A story with a structure that allows the children and teachers to collectively go on adventures. Being inside the imaginary play, taking a role. | Children are in an imaginary PlayWorld of Robin Hood where they embody the everyday practice problem within an imaginary play situation. | Children *imagine being dragons, Maid Marian, a Castle Engineer in* the story of *Robin Hood.* *Children want to design a grabby hand machine to lift the treasure out of the dungeon.* | **Designing an imaginary Engineering PlayWorld.** |
| *The teacher together with the children change the meaning of the wooden fort in the outdoor area from a climbing frame into a time machine.* The teacher makes beeping sounds and the children count down from 10 and imagine traveling back in time. The fort is the cultural device that marks the entry and exist into the imaginary PlayWorld of Robin Hood. | The children imagine that the climbing frame is a time machine, and they imagine themselves in role entering the imaginary PlayWorld of Robin Hood. The time machine takes them back in time to Sherwood forest. | *Thomas and Ross return to the group and are joined by other children and Ruth who line up and discuss what character they will be today in Sherwood Forest. The four children at the front are different kinds of wolves and go on all fours to transition to the 5s area.* | **Planning the entry and exit into the Engineering PlayWorld by using a cultural device to support transition.** |

| | | | |
|---|---|---|---|
| *The teachers use the children's interest in getting the treasure to introduce the idea of being an engineer to solve the problem situation.*<br><br>Collectively building engineering narratives, scenarios or problem situations. | Children research related to the central engineering problem, by interviewing the Castle engineer, taking photographs of engineering structures, and by watching YouTubes | *Circle discussion about inventing a complex machine to go back (a "grabby hand" machine - Catherine's name for it) and rescue Robin Hood and the treasure.* | **Planning the engineering problem to be encountered and solved inside of the Engineering PlayWorld.** |
| *Teachers take an active role by being play partners and co-researcher with the children investigating engineering solutions.* | Team Boom go around the school with Ruth and investigate properties of materials suitable for a boom (Figure 5) | *Design-make-appraise…engineering design process…Teacher role playing the castle architect [later is the castle engineer back in the time of Robin Hood]* | **Planning teacher interactions to deepen the engineering learning in support of the children's play.** |
| *Children build conceptual knowledge as part of the research process.* | *Back in the classroom Olivia read from a book about simple machines, watch video about cranes in Roman times.* | *Children take photos on iPads –from dragon's eye and wolf's eye view – of the pullies and other equipment in Bob's workshop* | **Researching in teams.** |
| *Children evaluate the outcomes of their research and consciously consider engineering concepts in their models/prototypes/designs.* | Children test their model/design – to help solve the problem in the play situation. | *Olivia asks Harrison to show the drawing he has done of the inside of the grabby hand machine and how it will work.* | **Engineering modelling in teams.** |
| *Children use their theoretical knowledge in child-initiated play during free play periods in the preschool.* | Olivia and the children discuss going outside to play the story - they choose the part where Robin Hood escapes down the toilet pipes and imagine how that would be. | *During free play in castle, Ruth notices a pipe in the treasure room. How will we design the grabby hand machine to fit through?* | **Developing the engineering play motive of the children.** |

When the practice examples are analysed in relation to the engineering concepts that children were actively exploring, it becomes evident that the play narrative acts as a glue to keep the children and the problem situation together as a collective engineering team enterprise. The practices that emerged can be conceptualised as a particular form of play practice, captured through the term *Engineering PlayWorld*. The Engineering PlayWorld encompasses (from Table 2):

1. Using an engaging story with a social problem that needs to be solved with engineering solutions;
2. Designing an imaginary Engineering PlayWorld;
3. Planning the entry and exit into the Engineering PlayWorld by using a

cultural device to support transition;

4. Planning the engineering problem to be encountered and solved inside of the Engineering PlayWorld
5. Planning teacher interactions to deepen the engineering learning in support of the children's play;
6. Researching in teams;
7. Engineering modelling in teams; and
8. Developing the engineering play motive of the children.

A synthesis of the findings shows that as children experienced this Engineering PlayWorld (Table 2), they formulated goals about the thematic relationships that compromised the main problem of designing a grabby hand machine. The initial relations between the engineering components were researched and documented in their drawings, photographs, and later in role-playing. The goals were expanded from the initial relation and were shown over time through producing their collective design. Importantly, it was found that the drawings and modelling, alongside of the regular visits into the imaginary Engineering Playworld of Robin Hood, supported the ongoing development of a theoretical model to capture what they were learning through solving the engineering problem. In line with Hedegaard's (2008) conception of a double move, the process of drawing not only supported the development of the core model realised as a grabby hand machine, but also it acted as a tool for evaluating their own and the collective thinking of how to design, make and use a grabby hand machine in their play of rescuing the treasure to help the villagers.

**Conclusion**

In contrast to previous research into the engineering thinking of young children in play-based settings where the naturalistic affordances for engineering were the focus (Bagiati and Evangelou 2016), or the study of pedagogical practices to promote engineering activity was only considered (Bagiati et al. 2019), this study looked at both, as a dialectical relation between the practices of the teachers and the engineering experiences of the children. In line with arguments of Lippard et al. (2017) who systematically reviewed the literature into preschool engineering, bringing together practices and outcomes is important for better understanding engineering education in play-based settings.

As a double move (Hedegaard 2002) it was important in the research to both explore engineering through the imaginary play of the story of Robin Hood, whilst at the same time supporting the children in building a conceptual model through drawing emerging engineering thinking. The latter was brought together through the design and embodying of a grabby hand machine to get the treasure out and to save the villagers from starvation (Table 2). This is an important finding that emerged because it shows how the problem situation motivated the children – saving the villagers (social problem set by the teacher). Engineering concepts and practices were introduced through a personally meaningful problem for the children.

The synthesis of engineering concepts and engineering practice of being an engineering team was realised through the play and the narrative of the storyline of Robin Hood. Engineering concepts and practices were consciously explored through collective play of the children in the imaginary situation of Sherwood forest. Lippard et al. (2017) theorised, “we suggest that children benefit from experiences with engineering because those experiences provide social opportunities to put into practice abstract academic concepts…” (pp. 464-465). The study findings support this theoretical proposition, but like all studies which use dialectically framed empirical data, the findings of this study show how this happens.

Different to the conclusions of other studies found in the literature, is the focus on the collective engineering play and storying context where social problems arise. Mostly what has been discussed has related to discrete concepts, such as, identify a need, set up a construction specific goal, and execute the goal through design and implementation (Bagiati and Evangelou 2016). In this study, the need arose within a motivating context of the story and the children identified the problem situation, which the teachers deepened in the imaginary play situations.

In summary, an Engineering PlayWorld emerged as the model of practice from this study of teachers and children over twelve months engaged in engineering education. An Engineering PlayWorld as a model of teaching engineering in play-based settings appears to provide a motivating context for teachers and children alike. Play is central for raising the consciousness of engineering concepts. Engineering PlayWorlds supports engineering concepts to become personally meaningful to children, and the children’s engineering competence in turn deepens their play. However, more research is needed to see if an Engineering PlayWorld can support the new practice need for teaching engineering more broadly across different play-based settings.

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