Sue Dale Tunnicliffe
Teresa J. Kennedy *Editors*

Play and STEM Education in the Early Years

International Policies and Practices

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Part I
Play as the Foundation of STEM Experiences During a Child's Learning Journey

Chapter 1
Introduction: The Role of Play and STEM in the Early Years

Teresa J. Kennedy and Sue Dale Tunnicliffe

Abstract This introductory chapter provides an overview of the entire content of the book, *Play and STEM Education in the Early Years: International Policies and Practices,* providing various viewpoints representing 47 STEM experts from 16 countries defining developmental milestones during the early years and the importance of play during this critical developmental period. As the book is divided into four sections: (1) Play as the foundation of STEM experiences during a child's learning journey; (2) Policies and training for formal education environments; (3) Early years experiences in kindergarten and formal schools for 5–8-year-olds; and (4) Informal settings and family involvement in play, this chapter provides preliminary information and definitions as related to educational development in the early years. The chapter maintains that with a greater understanding of what constitutes play and why it is important, an appreciation and acceptance of the beneficial roles for the child, as well as the adult's role within the development of play, will emerge. It is posited that sharing international policies and practices promoting STEM subjects in the early years, through unstructured and structured play, will provide exemplary models that parents, citizen scientists, daycare practitioners, primary school teachers and preservice teachers, as well as researchers and policy makers, can employ to design the best learning experiences for the children in their care.

Keywords Early years · Heuristic play · STEM · Structured play · Unstructured play · Early childhood care and education (ECCE)

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1.1 Play and the Early Years

Early childhood is generally marked by achievements in specific developmental milestones over various life stages. The United Nations Educational, Scientific and Cultural Organization (UNESCO) defines early childhood as the period from birth to eight years of age (UNESCO, 2019a), affirming that early childhood care and education (ECCE) is "one of the best investments a country can make to promote human resource development, gender equality and social cohesion, and to reduce costs for later remedial programmes" (para. 3). It is increasingly recognized that the first 1001 days from conception to a child's second birthday are the most critical time for the developing brain since during this pivotal stage in a child's life they are shaped and influenced by the environment and people around them, particularly by their family members (Cupp et al., 2018; Pramling Samuelsson & Kaga, 2007, p. 13). Studies of this age group reveal the importance of holistic development in terms of a child's social, emotional, cognitive, and physical needs to build a solid and broad foundation for lifelong learning and well-being.

"Play has been at the center of early childhood curriculum from the beginning of our history in early childhood education to present-day models—from Pestalozzi and Froebel's kindergartens to Montessori's method, and Rudolf Steiner's Waldorf schools to Reggio Emilia curriculum" (Wisneski & Reifel, 2012, p. 175). According to Pramling Samuelsson and Kaga (2007, p. 12), "It is in the early childhood period that children develop their basic values, attitudes, skills, behaviours and habits, which may be long lasting." In addition, many researchers define the end of early childhood at the age of eight because it reflects "a critical year for mastery of the reading skills upon which further learning will build and a reliable predictor for future educational success" (Center for High Impact Philanthropy, 2021, para. 1). We believe that children also form the beginning of their understanding of science and engineering before age eight.

The early years (EY), however, represents different age ranges to different audiences. There is a clear divide between the types of experiences encountered before entering school and once in formal school, and our particular interest lies in pre-formal educational experiences. Further, the age when a child begins formal schooling also varies by country. For example, in Mauritius, formal schooling previously began at 7 years of age, however in 2015 the government, at the instigation of their education minister, a former teacher, changed this age to 5. The new program is contained in the *Nine Years Continuous Basic Education* plan developed by the Mauritius Institute of Education (n.d.), which will be discussed in detail in Chapters 13 and 20. In Germany, formal school begins at 6 years of age, while in the United States, it typically begins at age 5, with entry into a formal early childhood program occurring when children are between 3–5 years of age (Workman & Jessen-Howard, 2018). However, in England, early years education describes a child's progression from "nursery" to the Early Years Foundation Stage (EYFS). Therefore, the distinction between formal education is not the key, since the EYFS covers children from birth to five years for registered providers and covers the following areas through play and games: communication and language, physical development, personal, social, and emotional development, literacy, mathematics, understanding the world, expressive arts, and design (Department of Education, n.d.). Additional examples are provided throughout the forthcoming chapters, as the examples above represent only four of the 16 countries addressed in this book.

As previously stated, ECCE is increasingly reconsidered as key in the development of the child's social, emotional, cognitive, and physical needs, and may establish a firm holistic foundation for lifelong learning and well-being. ECCE has the possibility to nurture caring, capable, and responsible future citizens. However, in the everyday activities occurring around them, children gradually become involved or investigate phenomena by themselves. In "playing" a child often uses toys, everyday items at home, or manipulates artefacts found in their surrounding environment. It is through these actions which we seek to encourage recognizing their activities as foundational "STEM in action."

The United Nations 2030 Agenda for Sustainable Development, adopted in 2015, established 17 Sustainable Development Goals (SGDs). Goal 4, Quality Education, aims to "ensure inclusive and equitable quality education and promote lifelong learning opportunities for all," further specifying through SDG target 4.2 that "by 2030, all girls and boys will have access to quality early childhood development, care and pre-primary education so that they are ready for primary education" (United Nations, 2015). While SDG 4 acknowledges that "prior knowledge stems from various formal and informal contexts including everyday-life observations" (Osman et al., 2017, p. 28), "quality" is not specifically defined. The SDGs are similar to the Commonwealth Development Goals (Pisupati, 2018), which are also limited in their description of the nature and scope of the term "quality." Clarification regarding the definition of "quality early childhood development, care and pre-primary education" would strengthen these goals and subsequently provide guidance promoting adult–child interactions that support higher-order thinking. For example, some researchers have attempted to quantify the "quality" of play in early childhood through investigating play as a means of self-expression, as well as the use of play as a channel of achieving social sense, specifically examining beliefs, perspectives and theories related to the effects of culture, media, and technology on play (Johnson et al., 2005).

Throughout this book, we hope to illuminate potential factors contributing to "quality" educational experiences from various international perspectives. Young children are natural scientists. Beginning at an early age, children eagerly observe, explore, and discover the world around them. Technology also plays a role in science discovery through photography, recording and listening to sounds of insects and animals, and virtual play on educational websites and games (Lan, 2019).

Causal knowledge is a key element of understanding the world since it determines which aspects of specific concepts become more important than others to the learner. The question remains as to whether children come to understands by their own active exploration of their world. Piaget (1930) believed so, originally proposing three levels of play coinciding with early childhood during the Preoperational Stage (occurring from the age of 2 to 7 years): functional play (using body movements such as running and jumping), symbolic/fantasy play (using symbols to represent ideas, images, and words), and games with rules (strategy games such as checkers or chess). A fourth level of play, constructive play, was added by Smilansky, known for her work in the area of developmental psychology related to children and play, and for her research collaborations with Piaget. According to Smilansky, each type of play emerges at different ages and stages of cognitive development in an attempt to achieve social sense, noting that the level of play changes with maturation (Klugman & Smilansky, 1990; Smilansky & Shefatya, 1990). Through constructive play, children explore science in action, use mathematics through counting and comparing sizes and shapes, apply their imagination and curiosity by creatively exploring the world around them, and cooperate and communicate their understandings of their own environment.

Scholars such as Spelke et al. (1992) explained that children actually know and understand much more than that. According to Spelke (1994, p. 431), "Early developing knowledge appears to be both domain-specific and task-specific, it appears to capture fundamental constraints on ecologically important classes of entities in the child's environment, and it appears to remain central to the common-sense knowledge system of adults." Many believe that children's learning and usual level of understanding is conservative yet flexible; integrating what they see, experience, and evidence with their prior beliefs and competing causal hypotheses within their exploration, explanation, and learning (Bonawitz et al., 2011; Schulz & Bonawitz, 2007). Their inquiring approach to learning is inspired through their personal self-directed play, forming the major purpose for their actions to explore and build a scientific basis of evidence from inquiry.

Play typically occupies much of the time for many children and is considered by most to be one of the keys to their future development and learning (Lillard, 1993; Lillard et al., 2013). Much research has explored the development of symbolic play (Pellis & Pellis, 2007; Pellis et al., 2010). Vygotsky (1978) believed that play is a purposeful activity, providing changes in needs and in consciousness, stating that "play creates a zone of proximal development (ZPD) of the child. In play a child always behaves beyond his average age, above his daily behaviour in play it is as though he were a head taller than himself" (p. 102). Vygotsky's sociocultural theory (SCT) focused on two levels of learning; first through social interactions with others, and second, when ideas are integrated into one's mental structure. According to Vygotsky, a child's ZPD represents "the distance between the actual developmental level as determined by independent problem-solving and the level of potential development as determined through problem-solving under adult guidance or in collaboration with more capable peers" (1978, p. 86). Curiosity is the primary motivator of young children, and therefore they are actively involved in their own learning throughout their social development.

According to Daneshfar and Moharami (2018, p. 600), "Children are immersed in a social environment where it represents them with all social, cultural and interpersonal experiences." Daneshfar and Moharami's interpretation of Vygotsky's sociocultural theory (SCT) focuses on the importance of the continuous process of learning, and its effect on cognitive development through social learning. We agree and acknowledge the important influence play has on a child's development and learning, especially when considering science education in play-based settings, as it provides children with opportunities to use creativity and imagination to interact with the world around them.

However, not all critics recognize Vygotskian influences on today's interpretation of the importance of play. An analysis of a translated work of Vygotsky, concluded how "it is surprising that at the end of his paper he does not say more about the further development of play, focusing instead on the way in which it is replaced by 'a limited form of activity, predominantly of the athletic type,' referencing only symbolic play" (Veresov & Barrs, 2016, p. 33). Nevertheless, Bruner focused on a symbolic representation within the context of play, acknowledging the development of tools and strategies resulting in problem solving (Bruner & Haste, 1987). As explained by Petrović-Sočo (2014, p. 242), "Bruner reaffirms Vygotsky's theory which enriches Piaget's constructivism with the emphasis on the importance of the social dimension in the development of a human being, and therefore adds a significant role of culture in human development." Several chapters within this book dive deeper into Vygotskyian influences in support of the importance of play in learning.

Definitions of play vary. Fagen (1974, 1978, 1981, 1995) proposed an ethological view identifying behaviors associated with play, and suggested three categories: locomotor play, object play, and social play. Other researchers have defined play according to the functional and dispositional aspects involved in play. Hughes and Melville (2002) identified 16 types of play (symbolic play, rough and tumble play, socio-dramatic play, social play, creative play, communication play, dramatic play, locomotor play, deep play, exploratory play, fantasy play, imaginative play, mastery play, object play, role play, and recapitulative play), while Miller and Almon (2009, p. 55) included a list of 12 types of play (large motor play, small motor play, mastery play, rules-based play, construction play, make believe play, symbolic play, language play, playing with the arts, sensory play, rough and tumble play, and risk taking play); emphasizing that "play does not stay neatly in categories, but knowing and watching for the broad types helps sensitize teachers and parents to the shifting landscapes children create" (p. 53).

Burghardt (2011) identified five criteria for a given behavioral sequence to be classified as play, which encompass both functional and structural criteria, the nature of the actions, and what it does for the player. Broadly summarized as five categories, Burghardt described play as an unstressed activity with no pressure, it is spontaneous, voluntary, and repeated similarly; it is not aimed at survival and is a pleasurable experience. Other researchers, including ourselves, note that the construction of play often overlaps with other creative activities including object play and aspects of art, such as modeling and coloring for example. As science educators, we maintain that in whatever play genre children display these actions, a foundation of science and engineering is typically present. Gopnik (2009, 2016) pointed out, through a wealth of research papers and popular books for non-scientists, that the variability and flexibility of play promotes innovation and creativity, which are intuitive scientific and engineering-related actions. We propose that during play, children often employ strategies utilized in formal schooling, strategies identified as science, technology, engineering, and mathematics (STEM) educational activities, and, therefore, learn through intuitive play. Often, children will work together and organize a play episode, observing, asking questions and planning what to do, while also selecting what instruments they will use. They evaluate the outcomes and use their findings to interpret their world.

We, as practitioners, need to understand what is play, why it is important, and recognize what the child's as well as adult's role is within the development of play. This includes the context for learning through play, where children organize and make sense of their social worlds as they actively engage with people, objects, and representations. The foundations of learning, in particular learning of content in the subjects subsumed by the acronym STEM, include, embrace, and recognize that these areas overlap and are not exclusive. The Play Cycle described in Fig. 1.1, depicts distinct identifiable stages that can be observed while children are at play. The cycle is particularly applicable to phenomena related to physical science as well as biological and environmental issues that are observable.

The cycle begins when children directly interact with their environment; when they notice something of interest which inspires them to begin investigating and exploring possibilities of actions to take in order to make sense of the item or the phenomena. During the final phase, the child makes decisions to either repeat or change actions in order to reinitiate exploration or loses interest and exits the cycle early to find something else of interest. These variations depend on the science in question and typically

Fig. 1.1 The Play Cycle (Tunnicliffe & Kennedy, 2021)

include communicating and sharing discoveries. Through structured non-participant observation, adults blend into the background and provide an environment where children can act more naturally, hopefully avoiding the phenomena of performing differently for an audience, often referred to by researchers as the Hawthorn Effect (McCambridge et al., 2013). Adults can easily monitor children's progress through the stages of the Play Cycle without interrupting their decision-making processes. "Developmental monitoring means observing and noting specific ways a child plays, learns, speaks, acts, and moves every day, in an ongoing way. Developmental monitoring often involves tracking a child's development using a checklist of developmental milestones" (Linke, 2016, p. 4). For example, the *Act Early Milestone Checklist* (CDC, 2018) and the online *Milestone Tracker* mobile app (for children 2 months to 5 years of age), adapted from resources developed by the American Academy of Pediatrics (Hagan et al., 2017; Shelov & Altmann, 2009), provide easy ways to monitor milestones in social and emotional development, language and communication development, cognitive activity (learning, thinking, and problem-solving) and physical development as children move through the Play Cycle.

Children are both problem solvers and problem generators, constantly attempting to solve the problems they encounter in their environment, while also seeking and creating novel challenges along the way (NRC, 2000a, p. 102). One question often asked—Why do children choose certain items with which to play?—remains largely unanswered. Krapp (1999, pp. 23–24) explains that the theoretical considerations of the interest-construct, including those related to curiosity, attention and achievement motivation, intrinsic motivation, and flow, have often been excluded from scientific discussion, stressing the importance of the "person-object relationship" as well as the "notion of personal relevance and a readiness to engage." Renninger (1990) postulates that the individual represents the potential source of action, the environment is the object of action, and the interest shown is a product of the specific relationship between the two, stressing the specific relationship between the person and their life-space. Regardless of the attraction to specific items, experiences resulting from interactions throughout the various stages of play build on important schemas about the real world, and "encourage aspects of social, emotional, cognitive and physical development that cannot be achieved any other way" (Feinberg, 2010, p. 267).

According to the National Research Council (NRC) of the USA, children enter formal educational settings, such as preschool and early-care education programs, with a substantial knowledge of the natural world, much of which is implicit (NRC, 2007). Active involvement in everyday STEM activities during the formative years occur through play, and through free-choice, unstructured activities. Although the toys or objects children play with are typically designed by adults, children form their own ideas about how and when these objects become important and useful in their play. Play for children means to them their choice of activity and the chance to investigate whatever they come across. Whereas to many adults, play refers to recreational activities such as a game of tennis, golf, football, or card games, and, therefore, children are "just playing."

Schools mandate games and lessons, as well as organize teams to play other schools at sporting events while providing playgrounds, play equipment in primary schools, and play times. However, a recent report in England (Baines & Blatchford, 2019) found that play time in schools (referred to as recess in the United States) had been significantly reduced since 1995. Despite this decline in the time allocated to play, playing games with rules, and frequently including teamwork, is a common characteristic of developing children's play featured in many schools and educational systems around the world. For example, during a recent research activity working with 4-year-old children in a foundation stage class in England, after about 15 to 20 minutes these children usually asked, "can I go and play now?" The activity they had been asked to do was not "theirs," resulting that in their minds it was not "play" nor was it their choice (Bottrill, 2018). Children often become frustrated and bored in directed settings. As Weldon shared when discussing boredom versus free play, "the more we structure children's time, the more we interfere with their own drive to learn, explore, imagine and simply be" (2018, para. 11).

Early years experts have analyzed play allocating various categories to the phenomenon. Goldschmied and Jackson (2004) introduced the term "heuristic play," referring to scenarios where children are provided with different kinds of objects and receptacles with which to engage in free play without adult intervention. Such heuristic play is also recognizable in the investigative activities that children carry out when they visit a room or location where there are "things" which they can touch or pick up in a manner similar to the very young immobile child. As examples, Goldschmied and Hughes (1992) used heuristic play to describe how babies could sit upright and investigate a "treasure basket" of objects, and Forbes and Jackson (2015) described examples of heuristic play during outdoor learning scenarios.

Tunnicliffe (2019) categorized play as either *structured* or *unstructured. Structured* referring to situations when items for play are available, and *unstructured* referring to when a child investigates with whatever is available. *Free choice*, sometimes called *spontaneous play*, is an important element of both aspects and refers to situations when the play items selected are either their idea, the use of the items is as expected by the toy manufacturer, or play scenarios imitate the actions of an adult using similar items, such as what occurs within the context of the play shop, play kitchen, playhouse and dress up clothes. Tunnicliffe (2019) refers to such activities with provided items that allow for *free choice* of action as *mediated* play, whereas when the child is instructed as what to do it is referred to as *facilitated play,* that is on occasion instructional. There is a place for instructional facilitated play when introducing necessary skills, such as using scissors or filling an item with water.

The child as a constructor, who is competent and capable of directing their own learning, begins at 0–3 years of age. This principle is the basis of the child-directed philosophical approach coined *Reggio Emalia* developed by Loris Malaguzzi in 1945 in Italy. The approach focuses on "cooperative experiences and *Progettazione,* projects designed by teachers in cooperation with their students" who share the results of their projects with classmates, in playgroups and other cooperative learning situations, to promote learning from one another (Kennedy & Sundberg, 2020, p. 489). This educational framework, closely aligned with past constructivist studies by Piaget, begins with recognizing that the child initiates their own learning, and that teachers and other adults, families and center personnel can interact supportively and developmentally with the learner, but take the cue for initiating intervention from the child. This approach recognized that learning, at any age, begins with an engaged learner who can actively direct their own learning, with the learner at the center, not the teacher. In this scenario, the role of the teaching adult is to find how to promote the learning of each learner, recognizing the way they think, their aptitudes and skills. This model encourages the participation of families, and all the factors that create the whole learning environment, including the team, the building, and the ambient culture (Bucher, 2020; Rock, 2020).

1.2 Play in Informal, Formal, and Non-formal Education Settings

Most academics agree that distinguishing between the meaning and uses of informal versus formal education is a very difficult task. According to Smith (2002, p. 1), "Many of the debates around informal and formal education have been muddied by participants having very different understandings of basic notions." Simply put, they mean different undertakings to different players. The following definitions generically describe the differences between informal and formal educational settings.

- **Informal education** generally refers to knowledge acquisition that occurs outside of a structured curriculum. It allows individuals to build knowledge, skills, and values from daily experiences, including home, work, friends, and media (Percy, 1997). We contend that informal education also encompasses learning that occurs independently outside of a formal classroom environment and without adult intervention or formalized programming, such as through visiting science museums, zoos, and other public access community settings, often in a spontaneous manner.
- **Formal education** generally refers to knowledge and skills acquisition that occurs through systems of organized learning in which the goals and objectives are defined, hierarchically structured, and chronologically graded. These organized experiences include classroom instruction received from a child's first schooling through higher education. Formal education occurs both inside and outside of school time, driven by curricular aims and under the auspices of the school. We maintain that formal education also includes academic, vocational, technical, and professional training delivered through web-based and remote learning, e-learning courses, workshops, and seminars.
- **Non-formal education** generally refers to organized, yet free choice, leisure education programs and activities occurring outside the established formal school system. We believe that although these activities are structured, with identifiable learning objectives, they are voluntary and often are closely aligned with personal interest. Examples of non-formal education include community education and learning experiences gained from attending organized classes and special

programming at science museums, zoos, botanic gardens, science centers, and other public community settings.

The simplest definition of formal learning is that which occurs within the context of school, while informal learning may be defined as that which occurs away from the typical school classroom environment, through activities on the grounds around the school, outside the classroom, at home, in other venues such as the wide genre of museums, and during leisure time in the learner's community. However, when defining informal versus formal experiences, some educators consider whether the learner has voluntarily visited such sites or whether they are receiving a conscripted curriculum led by educators (Smith et al., 1998). Children taken to a museum by parents or caregivers during out-of-school time, or in the case of pre-formal school learners, in playgroups or in childcare situations, are in fact conscripts too because they are taken, although on occasion a young child asks to be taken, often as repeat visits to locations such as a pond or zoo. Children's playgrounds are another outside learning venue for experiential STEM learning to generate, for example with their body actions, the movements of a swing or discovering gravity effects through experiencing the action of a slide, and as they get older, trying to climb back up the actual slide. These are all foundational learning opportunities.

Museum educators specializing in teaching typically provide educational experiences for children at these informal sites. Most of the programming reported has been created for older children and considers the pedagogies of formal out-of-school learning (Braund & Reiss, 2019). Zhai (2012) considered the pedagogical practices necessary for effective learning in botanic gardens, particularly those practices adopted by botanic garden educators. Often school-organized visits without a booked site educator devise their own pedagogical technique which has all too often been that of filling in a worksheet. However, over the past thirty years, more research has been disseminated about learning in museums, zoos, botanic gardens, horticultural gardens, field centers, science centers, and geological sites, including those of industrial archaeology as well as cultural museums. Many of these sites serve as important centers for environmental education, adding to the growing interest in education for sustainable development (ESD) amongst science educators (UNESCO, 2019b).

The pedagogical position of museum educators is moving from declaring knowledge to employing narrative alongside recognition of the importance of dialogic interactions, together with the emergence of delivering hands-on sessions. Two of the most influential researchers in this field, Falk and Dierking (2016), described five categories of adult visitors by identifying their motivation. They identified a particular category of parents/caregivers motivated to bring very young children to learn, as well as children in preschool and the early years of formal school. More and more out-of-school venues are catering to these beginning learners, developing experiences for those in the earliest of years and their adult caregivers, such as the parent and baby sessions provided by the Museum of London. Activities for toddlers, children from 1–3 years old, include family museum programs as well as interactive exhibits, for example those at the American Museum of Natural History (AMNH) in New York City. Hands-on sessions with objects in cultural museums, biofacts and animals in zoos, or natural history museums including role play in early years classes have grown while themed play areas with subtle educational messages have emerged in museums, zoos, gardens, and science centers, of which some examples are discussed in later contributions included in this book.

Pre-formal aged school children, not in kindergarten or nursery environments where formal learning does occur, learn from observations in their environment. Visitors at any exhibit or out-of-school location, looking at something in their world, generally follow the 4Is sequence: first noticing or identifying whatever has caught their attention, then displaying interest, followed by interpreting, and investigating (Tunnicliffe & Scheersoi, 2010). When looking at exhibits or naturally occurring phenomena, and particularly in the case of experiences in Earth and biological sciences, following the 4Is expands young learners' discussions of their earliest encounters with the world, regardless of experiences inside or in outside environments. The youngest children are predominantly learning names and listening to the rhythm of the language(s) they hear when adults speak with them and answer their questions.

Thus, children first learn from observations and experiences outside of formal education structures starting in their family and community. We know that in animal societies the young learn their culture and language (van Schaik & Burkart, 2011). Such learning applies just as much to humans in learning our group's language and customs. We consider that it is important in the preschool years, which we are regarding as informal since learning is societal but not focused on a formal curriculum, to be the vital precursor of theoretical understanding. Our contention is based on an observation, listening, and doing approach in which, as Gopnik (2009) and others point to, caters to the inherent inquisitiveness and curiosity of a child, particularly in developing basic STEM competencies.

1.3 Play and STEM Education

STEM education has evolved into a meta-discipline. This shift marks an integrated effort to remove the traditional barriers between the content areas of science, technology, engineering and mathematics, to focus on innovation and the applied process of designing solutions to complex contextual problems using current tools and technologies, and to challenge students of all ages to innovate and invent, while promoting problem-solving and critical thinking skills that can be applied to their academic as well as everyday lives (Kennedy & Odell, 2014). Preparing our children for the twenty-first century begins in the early years when they are naturally curious and excited learners and are constantly asking questions. The key elements for developing STEM capital and promoting active citizenship, and a scientifically literate workforce, begin with young children (Kennedy & Sundberg, 2020).

The 5E Model of Instruction (see Fig. 1.2) is recognized as one of the best processes by which educators can employ opportunities to personalize STEM

Fig. 1.2 Evidence-based practices: The 5E Model of Instruction (Graphic used with permission from the San Diego County Office of Education, 2018. https://ngss.sdcoe.net/Evidence-Based-Practices/5E-Model-of-Instruction)

learning for students of all ages, and the model is applicable to even the earliest educational experiences. The five phases of the 5E Model are Engage, Explore, Explain, Elaborate, and Evaluate. The model "has a 'common sense' value; it presents a natural process of learning" (Bybee, 2015, p. ix).

While not all phases of the model are applicable to young learners, the first four phases (engage, explore, explain, and elaborate) are particularly important as children *engage* and focus on phenomena to make connections between past and present learning experiences; *explore* their environment using prior knowledge, generating new ideas through experimentation and trial and error to make sense of their surroundings; *explain* their observations and understandings through their excitement and verbal explanations, further constructing a deeper understanding; and *elaborate* on their understandings through extended activities, building on their initial understandings and applying them to similar situations. The Play Cycle, described earlier in this chapter, aligns closely with the first four stages of the 5E Model, and aspects of both will be presented throughout the book within international contexts.

The research literature is rich in information and reports about developing STEM in primary and secondary education, however, developing STEM in early years education is an evolving field of study in need of documentation to provide effective and creative models for replication as well as promote collaboration amongst programs internationally. While it is safe to say that these experiences provide general understandings about the natural world, and that science concepts can be learned in many ways, "too few researchers take that into account when studying the impact of informal science activities" (Mervis, 2009, para. 4).

Schools in many countries do not teach science in the early years. However, many countries do have policies and practices to share regarding educational opportunities for STEM education for their young learners. For example, the English pre-formal school curriculum, the Early Years Foundation Stage (EYFS), encourages practitioners in formal settings and child care environments to help children explore and make sense of their physical world, their everyday settings, in order to ensure that all areas of learning and development are "implemented through planned, purposeful play and through a mix of adult-led and child-initiated activity" (Department of Education, 2017, p. 9), further stating that "play is essential for children's development, building their confidence as they learn to explore, to think about problems, and relate to others. Children learn by leading their own play, and by taking part in play which is guided by adults." Emphasis on numeracy and language, as well as building social skills, provides ample opportunities to identify STEM in action.

Most learning of STEM is through everyday activities. In this sense, STEM in action includes opportunities for children to experience and observe phenomena of interest to them, in their everyday lives at home and in their community, as well as relate formal school science topics to their local and personal situations. Science achievement in schools has shown to be at its highest "when individual pupils were involved in fully planning, carrying out and evaluating investigations that they had, in some part, suggested themselves" (Ofsted, 2013, p. 6). These everyday experiences and manifestations form a crucial component of the start of a child's learning journey.

Research has shown that students learn to think, talk, and act scientifically through sense-making experiences, and that formal science learning "builds on the knowledge that students bring with them to school from their home cultures, including their familiar discourse practices" (NRC, 2000b, p. 188). Children are born observers; they investigate and collect experiences which become their personal data used in later experiences and when interpreting the world around them.

However, in their play, children also show that they are inherent mathematicians as their early play typically incorporates mathematical themes, identified by Athey (2007) as the basics of play. For example, they collect items such as pinecones or toy animal models and place them in a horizontal line or manipulate building blocks into a balanced tower, a mathematical as well as engineering task. "Toddlers as young as 12 months old are able to recognize numbers" (Swinson, 2018, para. 1), even if they do not yet know the accepted way in which our systems designate the values. Indeed, these types of activities, along with other activities, are traditionally taught in pre-secondary school science such as making a string bridge, interrogating frictions, and engaging in engineering or design and technology activities.

While observations are recognized as the starting point of science (Eberbach & Crowley, 2009; Johnston, 2009), observations are also a basis of the beginning of mathematical understandings. "Approaches to early mathematics teaching incorporate the premises that all learning involves extending understanding to new situations, that young children come to school with many ideas about mathematics, that knowledge relevant to a new setting is not always accessed spontaneously, and that learning can be enhanced by respecting and encouraging children to try out the ideas and strategies that they bring to school-based learning in classrooms" (NRC, 2000b, p. 172).

Mathematical learning and science understanding occur naturally as children begin to explore their personal world, such as by becoming aware of the number of limbs they have, and then individual digits eventually become quantified as a child learns the naming and counting conventions. According to a report by the National Council for Curriculum and Assessment, "In the curriculum, a view of all children as having the capacity to engage with deep and challenging mathematical ideas and processes from birth should be presented. From this perspective, and in order to address on-going concerns about mathematics at school level, a curriculum for 3–8-year-old children is critical. This curriculum needs to take account of the different educational settings that children experience during these years" (Dunphy et al., 2014, p. 128).

We recognize that both the content of what is frequently referred to as 'science' in preschool, as well as the curricular focus during the years of formal education prior to secondary schooling, typically involve aspects of mathematical competencies and understandings. In addition, these experiences often include fundamental engineering actions utilizing basic science content while acquiring understanding, which is intuitive in the earliest of learners. Making sets of like artefacts, according to properties identified by the child, such as similar model animals which they recognize, e.g., cattle or elephants, or red blocks and separating them from blue blocks, involves children developing an understanding of measurement, or "the symbolic-meaning relationship" in the words of Vygotsky (1978).

Indeed, children frequently use graphics or symbols to represent the numbers of artefacts, or, for example, to explain upwards growth of a seedling. This approach is similar to the work of Symington et al. (1981, p. 51), who studied the development of children's drawings of natural phenomena, suggesting that "concepts of symbolism, intellectual realism and visual realism" contribute to processes employed by young children while recording natural phenomena. Children have a need to make marks, as many parents know. Such mark making is the beginning of written communication, be it through letters or numbers.

In their play, children often refer to numbers or quantities as well as shapes and spatial positioning, essential skills and understanding (Carruthers & Worthington, 2004). Hughes (1996), however, pointed out that children generally find it difficult to represent the mathematical operations of addition (+) and subtraction (−), and instead prefer to show these operations by representing a quantity. He suggested that this may explain why children's comprehension of these symbols, and the operations they refer to (addition and subtraction), typically do not progress beyond the context in which they are taught. Thus, children develop a utilitarian use of the relationship between these observations. However, in regard to symbols, such as small lines representing one object, in comparison to small lines representing mathematical actions in exercises (such as + or −), children were reluctant to recognize and use them in other situations.

Developing skills in math and science, essential tools used in the engineering design process, result in future innovation and technological expansion. The word “engineering” derives from the Latin word “ingenerare,” which means “to create” or “to produce.” Engineering encompasses a large range of industries. However, engineering, as a profession, has historically been looked down upon in some countries, such as in England, where it is often viewed as a trade as opposed to an academic profession, such as law and theology for example. However, there is an increasing awareness of the importance of engineering and the technologies resultant in our modern societies, and a recognition of the vital contribution engineering has made to the development of societies from the earliest recorded history.

Unfortunately, a common misconception or misunderstanding held by many members of the public is that the subjects included in STEM (science, technology, engineering, and mathematics) are for older students. Further, many parents question the role of play in their children’s preschool experiences and early formal years, failing to appreciate the key role of play in developing basic STEM competencies. Figure 1.3 shows the progression of engineering capabilities in initial early years learners, beginning with the development of manipulative skills, learning and following safety rules, following instructions in a competent manner, recognizing a problem, planning and recording a solution, recognizing necessary items and realizing a design, evaluating outcomes, and building self-esteem after a successful discovery.

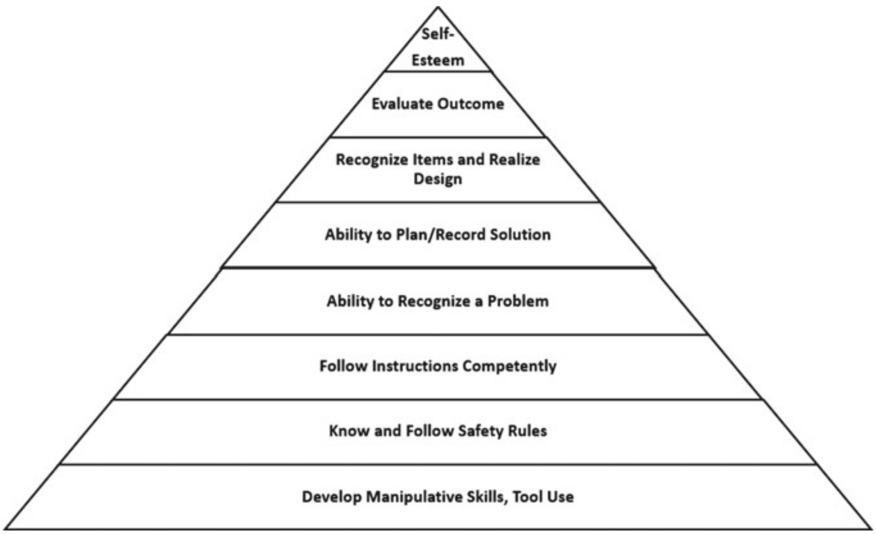

Fig. 1.3 Progression of engineering capabilities in initial early years learners

The recognition of the incidence of fundamental engineering processes in preschool children's play, and in more formal settings of playgroups and preschool, as well as incrementally in primary school curricula, is currently being addressed in schools around the world. Engineering competency is now regarded as one of the essentials of education in these important times when the planet is facing the deleterious impact of human activity. "Science and engineering can be understood as ways of knowing that children can deploy to address questions and issues that matter to them. These investigations can be playful, creative, and sources of joy. They can also be challenging and even troubling as children seek to understand the sources of difficulties and dangers in their lives. Regardless of the direction in which children point their curiosity, young children are developmentally and cognitively capable of making robust, recognizable, and meaningful use of the practices, tools, and big ideas of science and engineering on their own terms and for their own purposes across the contexts of their activity" (National Academies of Sciences, Engineering, and Medicine, 2022, p. 74).

A recent study of the impact of curriculum design, including curricula focused on engineering processes in meaningful and sociocultural contexts in primary (1–3) and middle school (6–9) classrooms, revealed that these learners not only understand engineering practice, but also understand the science involved (Cunningham et al., 2019). These gradually changing perceptions of the role of engineering are key to the success of societies.

Design and technology appeared in the National Curriculum for the UK, before devolved powers were granted to its constituent countries, from the earliest statutory school age, and in the USA, engineering is a key component of the core competencies and cross curricular themes of the Next Generation Science Standards (NGSS) which a number of the constituent States have adopted (NGSS Lead States, 2013). However, due to the rapid development of PreK-3 engineering curricula, Bagiati et al. (2010, p. 22) recommend that engineering educational materials and content "should be offered from universities, museums, foundations, institutions, and other such entities formally recognized to be related to engineering, education, and curriculum issues" in order to ensure the pedagogical fidelity and content validity of curricula and programs implemented.

1.4 Extended STEM Subjects

As STEM education implementation models have evolved, expanded iterations of the acronym for **S**cience, **T**echnology, **E**ngineering, and **M**athematics have been created to include additional disciplines as a more holistic approach to education which focuses on individual students' needs and interests. For example, STE**A**M education refers to a pedagogical approach using Science, Technology, Engineering, the **A**rts and Mathematics as access points for guiding student inquiry, creativity, critical thinking, and communication.

This emerging discipline aims to develop a rounded approach to education, particularly in formal teaching and learning ranging from preschool environments in homes and communities through kindergarten, primary and secondary schools, and to university and vocational education settings as well. STEAM educators believe the arts serve as a mechanism by which children can use artistic expression to communicate and make better sense of their learning, and that it provides expanded opportunities to reflect, imagine, create, express, and represent ideas. This broadening of the curriculum is also viewed by advocates as a way of increasing student interest and engagement in STEM subjects by integrating creative arts with various aspects of inquiry-based teaching and learning, including the role of engineering, whose importance in traditional culture has increased in the last few decades at the end of the twentieth and beginning of the twenty first centuries. After all, as Dewey proclaimed in his pedagogical creed written in 1897, "when science and art thus join hands the most commanding motive for human action will be reached; the most genuine springs of human conduct aroused and the best service that human nature is capable of guaranteed" (Article V, para. 12).

STEAM education also carries with it overtones of the debate introduced in 1959 by C.P. Snow in a seminal book entitled *The Two Cultures and the Scientific Revolution* and its sequel, *The Two Cultures and a Second Look: An Expanded Version of the Two Cultures and the Scientific Revolution* (Snow, 1963), which described his perception of the cultural divide that separates "Science" and "the Arts" through a comparison of the dichotomy between scientists and technologists and that of humanists and artists. The discussion set forth in his book has been considered by academics as one of the most important to influence Western thinking since the end of the Second World War in 1945. Subsequent discussion suggested that the rigid divide in some countries, such as the UK and the USA, resulted from expectations placed on secondary school children to decide whether to study the Arts or the Sciences in their early teenage years. Hence, in the UK, the cultural valuing of arts but not the sciences and the awarding of university degrees in either Arts or Science. Furthermore, it was argued that Arts were driven by patterns whereas Science by logic.

Indeed, the debate does continue, and we now recognize that the two cultures, Arts and Sciences, are not incompatible, for STEM embodies aspects of both. Undeniably, some activities employed in preschool are very much based on patterns, colors, shapes, dance, songs, and actions. Braund and Reiss (2019), recognize the growing relationship between the Arts and Sciences, which more and more practitioners have come to recognize, particularly those working in the pre-secondary and preschool sectors. Braund and Reiss proposed three different levels at which Arts could improve the teaching of science: at a *macro-level*, focusing on the ways in which subjects are structured; the *meso-level*, employing guided approaches that engage students in contexts closely related to Science, Technology and Society (STS); and the *micro-level*, using pedagogical techniques employed in Arts subjects. They suggest that these three strategies garner the possibilities of catching the interest of reluctant science learners. Such a view has often been raised by practitioners teaching in secondary schools, and particularly those in primary school levels, as the research of Avraamidou (2016) reveals. In addition, the introduction of the Next Generation

Science Standards in the USA seeks to address this in some way by including literacy and engineering in the integrated curriculum (NGSS Lead States, 2013).

As science educators, we recognize the use and practice of drawings and their presentational fields as well as the creativity required in investigations. We also identify the importance of recording and dissemination techniques that are key features of our subject practices as well as the visual arts, music and poetry, and other writings which they have inspired. Pre-secondary, preschool and many childcare practitioners tend to be quite skilled in the integration of subjects and provide invaluable insight into successful pedagogical approaches promoting positive outcomes for young children and their families.

An expanded iteration of STEAM education is STREAM, which adds the disciplines of reading and writing. Advocates of STREAM see literacy as an essential part of a well-rounded curriculum, requiring critical thinking and creativity (Fernandes, 2021). Others believe that STEAM education should direct itself toward design and design thinking, thereby coining the acronym STEAMD (Henebery, 2020). In emphasizing higher level thinking skills through design-based learning (DBL), Petrina (2020) argues that C.P. Snow "fails to consider design as a third culture" (p. 2), challenging educators to recognize the benefit of "designerly ways of knowing and a scope of design that includes an expansive definition of artifacts" (p. 4). The tenets of "designerly" ways of knowing and thinking seek to articulate and understand the nature of design cognition, including the processes used by designers such as architects, engineers, product designers, and the like (Cross, 1982).

However, STEAMD has also taken on another debate. The intent of some advocates of using the acronym STEAMD is to extend the approach to learning of the traditional STEM subjects not only by including the Arts, but also by focusing on the use of drama in scaffolding the STEM understanding of learners (McGregor, 2017). In the preschool and early years, learners act out their narratives as they play, whether imaginative or representation narratives and dramas of adult everyday occasions such as tea parties, shopping or visiting medical facilities. The use of various forms of drama are utilized in many places of learning, formal and particularly informal. The creative use of drama to place children in scientific roles and encourage scientific activities has become well documented and implemented widely (Carol-Ann Burke, et al., 2020; McGregor, 2017; McGregor & Precious, 2015; Özsoy & Özyer, 2018).

Although some scholars believe that adding an **A**, **R** or **D** is a dilution of STEM's focus and objectives, most agree that the earlier a child is exposed to STEM subjects, the better their chances are of sticking with them. "Integration within each of these four areas (e.g., within STEM) is challenging enough while deliberate and formal integration across these four and other areas is quite difficult for students and teachers, to say the least. However, as STEM was popularized through the late 1990s, iterations were introduced and rationalized (e.g., STE**A**M, STE**E**M, STE**H**M, letters for **A**rts, **E**nvironment, **H**umanities, etc.). At times, these iterations are symbolic reminders that STEM disciplines are enriched by other disciplines, such as the arts, and at other times they are substantive challenges to integrate" (Petrina, 2020, p. 1). The bottom line is to ensure that all children have opportunities to experience and learn about the natural world, as well as to realize that scientific knowledge is reliable. "Science is based on curiosity, and when children aim to learn more about the world around them, it is science that often holds the clues they need for a better understanding" (Learning Liftoff, 2018, p. 1).

The recent COVID-19 pandemic revealed the critical thinking and problem-solving capabilities of engineers, all genres of medical practitioners, and scientists, in collaboration with design teams producing newly designed equipment items for assisted breathing apparatuses in intensive care units and other innovative solutions to challenges presented. It also provided primary and secondary students with opportunities to develop and share their STEM solutions globally (Kennedy, 2021). These actions and their outcomes showcased the collaboration possible between perhaps hitherto discreet areas of organization, resulting in STEM benefits. The debate between science and the arts has historically been divided, but recognizing Leonardo da Vinci's contribution to both areas, perhaps indicated that the Industrial Revolution's rise of industry caused attitudes related to science and engineering to change as Western societies began valuing the benefits and financial rewards of the output rather than art, and the workforce moved from working the land to working in the factories.

As STEM education becomes more recognized as a societal solution, through applications related to social issues and needs, we are recognizing its use while acknowledging that all content areas, including the arts, reading, writing, and the humanities, design, drama and music, and their allied pedagogies and knowledge effectively integrate into STEM subjects, particularly during the early years. Thus, we will generally use the acronym STEM in this book and recognize the contribution of all content areas subsumed in its application.

In summary, STEM teaching is an innovative and interdisciplinary approach to learning that is extremely effective with the earliest of learners when play, as the primary context for learning, allows children to organize and make sense of their social worlds.

- Through science, children learn about the world around them and gain an understanding about how it works through exploration, gathering information (data), looking for relationships and patterns, and using the evidence they gather to generate explanations and ideas.
- Technology provides opportunities to use tools, such as a magnifying glass to closely inspect the coloration of a caterpillar's body, as well as use digital tools like a tablet or computer.
- Engineering processes help design tools, systems and structures to solve problems.
- Through mathematics, young learners study quantities, structures, space, and chance.

Early childhood settings naturally support STEM learning, especially through heuristic play. From pre-formal school years through the early years of formal school, the role of play in social-intellectual development, as well as in the development of competencies leading to enhanced confidence and resiliency, is critical. "Playful curricular experiences facilitate children developing creativity, inventiveness, and engagement with others and their ideas" (Ornstein & Hunkins, 2017, p. 220).

1.5 The Role of Adults and Children as Initiators and Drivers

According to the National Science Teaching Association (NSTA, 2014, p. 1), "learning science and engineering practices in the early years can foster children's curiosity and enjoyment in exploring the world around them and lay the foundation for a progression of science learning in K-12 settings and throughout their entire lives." Children enter formal educational settings, such as preschool and early-care education programs, with a substantial knowledge of the natural world, much of which is implicit (NRC, 2007). Preparing our children for the twenty-first century begins in the early years, as early as 2 years of age. According to a recent two-year study, "young children are capable of engaging in, at developmentally appropriate levels, the scientific practices that high school students carry out" (McClure, 2017, p. 2; McClure et al., 2017, p. 16).

In the words of Jean Piaget, "Play is the answer to how anything new comes about (…) Children should be able to do their own experimenting and their own research. Teachers, of course, can guide them by providing appropriate materials, but the essential thing is that in order for a child to understand something, he must construct it himself, he must reinvent it. Every time we teach a child something, we keep him from inventing it himself. On the other hand, that which we allow him to discover by himself will remain with him visibly (…)" (1972, p. 27). Research on play and interaction between children and adults is extensive, especially the body of literature focusing on close proximity and joint attention between both children and adults during play. Quiñones, Li, and Ridgway postulate that active positioning between adult and child, keeping continuous close proximity to the child, "can increase the high level of children's play engagement" since affective engagement enhances toddlers' learning and play development, especially when adults "actively position themselves towards infant-toddlers' needs and interests in play" (2021, p. 90). They refer to this as "creating motivating conditions by use of pedagogical questioning and explorative talk" which naturally extends children's play engagement and stimulates learning (Quiñones et al., 2021, p. 92).

Child-led play promotes ownership of learning, allowing young learners to make choices, solve problems that are important to them, and acquire knowledge about their surrounding environment, with no pressure to learn. Interest drives questions and the quest to seek answers which results in learning on multiple levels. According to Elkind, "Play operates as more than a creative urge; it also functions as a fundamental mode of learning" (2008, p. 4). Through exploration, investigation and experimentation, children figure things out on their own, and as a result, gain deeper understandings. Egan (2020, para. 1) adds, "Given that play is such a powerful element of a child's development, understanding our role as the adult in child's play is critical in promoting play and embracing the development and learning. We need to be mindful to support play without influencing or controlling play."

We can think of no better way to close this section than to quote Dewey (1897), who stated, "I believe that only through the continual and sympathetic observation of childhood's interests can the adult enter into the child's life and see what it is ready for, and upon what material it could work most readily and fruitfully" (Article IV, 3.4). The key then, is to allow young children the freedom to experience discovery, and intentionally explore and make sense of their environment. Our role as adults is to help them realize and expand their STEM capacities in a manner that fosters, guides, and builds on their interests (Early Childhood STEM Working Group, 2017, p. 12). Early STEM experiences shape the minds of the next generation in very powerful ways. Science literacy is acquired through everyday experiences. The key elements for developing STEM capital and promoting active citizenship, and a scientifically literate workforce, begin with young children and revolve around play.

1.6 Outline of the Book

Play and STEM Education in the Early Years: International Policies and Practices provides examples of the diversity of early STEM activities occurring around the world, highlighting the policies and practices uniting play and STEM education in the early years. Our goals are to recognize and acknowledge that the "leaky pipeline" issue in science education (Huyer, 2015) begins in the early years, and to provide model activities and creative experiences that involve young learners in STEM.

The following 21 chapters bring together 47 STEM experts from 16 countries (Argentina, Australia, Belgium, Canada, England, Finland, Germany, Israel, Jamaica, Japan, Malta, Mauritius, Mexico, Russia, Sweden, and the USA) spanning all six regions of the world, to provide insights into informal and formal play scenarios crucial to developing young children's interest in and ability to learn science.

The map in Fig. 1.4 shows the global distribution of contributors to this book, whose expertise spans institutions of higher education, museums, zoos, governments, policy making and NGOs. Topics covered include STEM pathways in early childhood, play-based behaviors, STEM experiences in preschools, conceptual knowledge and learner variability, engineering in the early years, policies and practices to integrate STEM in the early years, museums and outdoor learning, mathematics and project-based learning, changes in young children's lives and society, and the transition to STEM learning in primary schools and beyond.

This book focuses on STEM activities occurring globally for young learners 3–4 years of age, as well as students attending formal-nursery school, early primary school, and the early years classes post 5 years of age. It discusses the many strategies that have been identified around the world to successfully build twenty-first century skills including child-centered education and learning pedagogies, whole child development strategies, play-based learning concepts, as well as cooperative, blended, flexible, and differentiated learning structures that are consistently evaluated through formal assessment practices and a combination of learning domains (Ross, 2019).

The content of the book is divided into four parts: (1) Play as the foundation of STEM experiences during a child's learning journey; (2) Policies and training

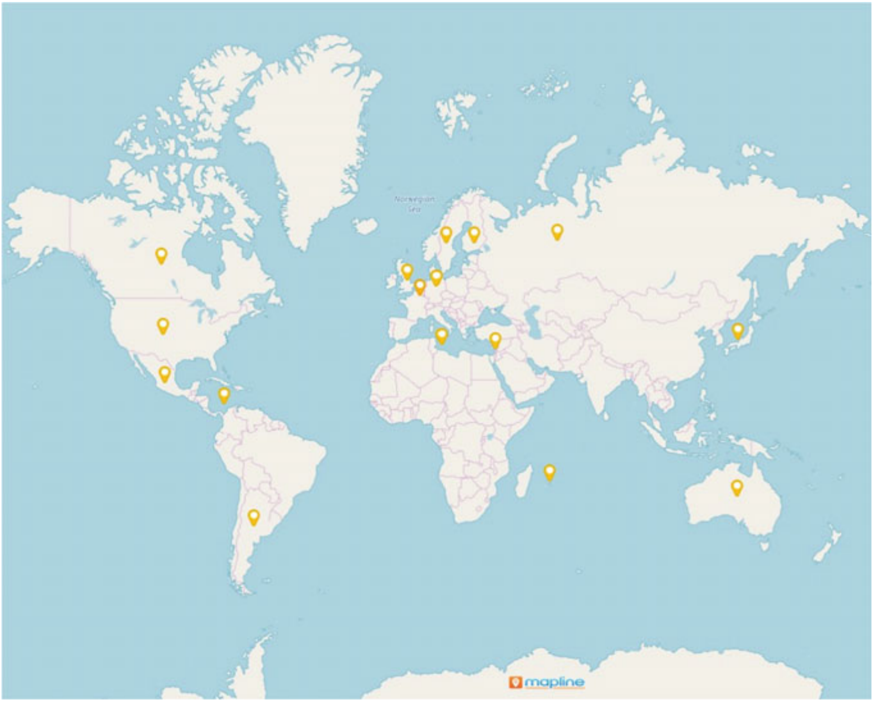

Fig. 1.4 Global distribution of contributors to this book

for formal education environments; (3) Early years experiences in kindergarten and formal schools for 5–8-year-olds; and (4) Informal Settings and family involvement in play. A description of the four sections of the book, along with short summaries of the contents of the chapters included in each section, are described below.

1.6.1 Part 1: Play as the Foundation of STEM Experiences During a child's Learning Journey

Chapters 2–9 present perspectives from 13 science educators representing six countries in three regions: Asia and the Pacific (Australia), Europe (England, Germany, and Russia) and North America (Canada and the United States).

In Chapter 2, Sue Dale Tunnicliffe provides an overview of the beginnings of play. The chapter points out that play is not confined to young humans but to other, particularly mammalian species, where it is a rehearsal for adult skills. She describes in detail the way play has differing genres, from spontaneous free choice play that is a child's choice to other play occasions that are inspired by items provided for them to explore. The general message is that "play" is what children do, it is their work, and it does not have to have another purpose or an end.

Chapter 3 focuses on the work of Valerian Gabdulchako and Evgeniya Shishova from the Republic of Kazan, Russia, as they explore the issues related to the role of children's play in the development of cognition, emotion, imagination, and creativity in childhood. A thorough discussion of Vygotsky's cultural-historical conception as the methodological basis for inclusion of play in preschool activities is included. They also provide an overview of the rationale for preschool education in Russia and discuss their research on teacher quality, the degree of popularity of the features of play activities in day-care centers in Russia, and the effectiveness of teachers on children's STEM learning.

In Chapter 4, Lara Weiser from Germany describes the organization and training of practitioners for early years provision. After exploring the development of play in the first years, she points out that there is no such thing as "just playing" and outlines a published taxonomy of play and the role of play as an 'engine' for a child's development. Although German children spend much time indoors, as is the case in many developed countries, she explores the benefits of outdoor settings, describing how natural settings support STEM development.

Eric Worch, Michael Odell, and Mitchell Magdich from the United States of America also explore the benefits of science learning through outdoor play in natural settings in Chapter 5. They note that past generations of children experienced a rich heritage of self-directed play unencumbered by safety concerns and the distractions of modern society and digital media, while today, most early years children spend little time outside in self-directed play using objects in the environment like stones, bushes, and branches. Time spent in natural settings is however recognized as beneficial to well-being, emotional regulation, and cognitive function. These authors focus on the relationship of different types of play to specific science learning behaviors as children engage in outdoor play.

In Chapter 6, Eirini Gkouskou and Sue Dale Tunnicliffe explore play in pre-formal schooling in England and describe how play develops understanding in STEM subjects at home, in structured play settings, as well as on playgrounds. They particularly explore the progression of play in specific examples as a child develops skills, understanding, and experience as they play and develop. Moreover, the activities they observed and documented reveal the natural tendency of children to discover and use basic engineering techniques which are essential for the understanding of biology, physics, and in general, STEM education. Their research study also suggests that children, as emergent scientists, accomplish progression via the activities they choose, which provides a firm experiential base for later formal learning.

Monica Smith also provides perspectives from England in Chapter 7, outlining the role of play in mathematical understanding in her classroom of 4-year-olds, during the year before statutory schooling begins in an inner London primary school. Her chapter describes the Early Years Foundation Stage (EYFS) curriculum that sets the standards for early years learning in England, the learning areas and provisions in English nursery classrooms, as well as the main paths to qualify as an Early Years practitioner.

In Chapter 8, Coral Campbell and Chris Speldewinde provide insight into science and engineering learning through play in early childhood education in Australia, discussing the roles of government, the curriculum documentation, and educators' involvement. Early childhood education in Australia is directed by government legislation at both the Federal and State levels. They describe the guiding document for early childhood educators, the Early Years Learning Framework (EYLF), which provides direction for the structure, care, and practice in early childhood learning and development across the country. Their chapter discusses several initiatives which are influencing current policy and practice and uses recent research findings to comment on the engagement of science and engineering presented through children's play experiences.

Chapter 9 takes us to Nova Scotia, Canada, where Michael Bowen, Eva Knoll, and Amy Willison provide an overview of the provincial early learning curriculum documents for early childhood and kindergarten education in Canada's ten provinces. They explain that educators are strongly encouraged to use play-based approaches to achieve learning outcomes at both pre-kindergarten and kindergarten ages and therefore initiatives to use technology such as Bee-Bots, small floor-based programmable robots for early ages, have begun in some provinces in order to develop foundational understandings of math, science, and literacy which will be built upon in kindergarten and later grades. They also discuss the implications of these robotic technologies for professional development with early childhood educators.

1.6.2 Part 2: Policies and Training for Formal Education Environments

Chapters 10–14 cover policies and training for formal environments from the perspectives of 18 science educators representing seven countries in four regions: Africa (Mauritius), Asia and the Pacific (Australia), the Caribbean (Jamaica), and Europe (Belgium, Finland, Malta, and Sweden).

In Chapter 10, Coral Campbell, Kerstin Backman, Thijs Eeckhout, Chris Speldewinde, Annie-Maj Johansson, and Anders Arnqvist, early childhood educators from Australia, Belgium and Sweden, provide examples from their respective countries to consider research designed to help them understand cultural influences that have affected the teaching of STEM, the factors that affect their decision-making processes, and how the policy and cultural backgrounds of their individual countries have influenced teaching practice and pedagogy.

Chapter 11 focuses on the Finnish educational system. Jaakko Hilppö, Jenni Vartiainen and Pasi Silander discuss how twenty-first century skills, along with other skills such as computational thinking, could be advanced in early childhood education via science, technology, engineering, arts and mathematics (STEAM) education. They present three distinctive approaches to early STEAM education developed in

Finland: (1) phenomenon-based learning, (2) children's maker-spaces, and (3) children's projects. In addition, they discuss and provide suggestions as to how these approaches could potentially address the concerns of Finnish early years STEAM educators who are cautious about implementing STEAM and phenomenon-based learning.

Karlene DeGrasse-Deslandes and Nicole Morgan discuss play-based learning in Chapter 12 as a natural teaching strategy in Jamaican preschools. Although play-based learning has been encouraged by national initiatives, a debate persists in the country as to its purpose and the value of play during the preschool years. They discuss the challenges related to implementation as well as consider the experiences of early childhood practitioners using play-based learning to encourage STEM in early childhood environments.

In Chapter 13, Ravhee Bholah, Rajeev Nenduradu, and Jyotsanah Thaunoo from the Republic of Mauritius describe how the 2010 National Curriculum Framework Pre-Primary (3–5 years) developed, along with its six areas of learning including body and environmental awareness, and mathematical and logical thinking. This policy document has influenced teacher education, curriculum development and the practice of STEM. They highlight the role of relevant educational institutions, particularly the Mauritius Institute of Education, in preparing the early year practitioners. The mainstreaming of STEM in teacher education programs, the development and provision of learning resources, the use of ICT and other pedagogical supports are also explored.

Chapter 14 provides yet another perspective to national curriculum reform measures as Jacqueline Vanhear, Alexis Reid, Isabel Zerafa, and Melanie Casha Sammut describe implementation efforts in Malta to prevent early school leaving. Their chapter provides details about their use of the Universal Design for Learning (UDL) approach to scaffold STEM learning experiences and provide all students with an equal opportunity to succeed in STEM subjects. Focus is placed on brain development in the early years and establishing learning environments through intentional design. They also provide examples of their initiatives focusing on UDL specifically highlighting how executive function is explicitly scaffolded into early years STEM learning experiences.

1.6.3 Part 3: Early years Experiences in Kindergarten and Formal Schools for 5–8-Year-Olds

Chapters 15–18 describe early years experiences in formal schooling for students aged 5–8 years from the perspectives of six science educators representing five countries from five regions: Asia and the Pacific (Japan), Europe (Germany), Latin America (Mexico), the Middle East Region (Israel), and North America (USA).

This section begins with a description of the educational recommendations made by the Israeli Royal Academy of Engineering to engage in engineering education from childhood, specifying six Engineering Habits of Mind (EHoM): systems-thinking, problem-finding, visualizing, creative problem-solving, adapting, improving. In Chapter 15, Ornit Spektor-Levy and Taly Shechter describe their research study consisting of two hundred preschoolers, 5–6 years of age, from six urban classrooms. They identify early EHoM indications among young children during a problem-solving play-like task and include examples of how to enhance preschoolers' cognitive capabilities in a play-based manner through learning environments that provide open-ended materials.

In Chapter 16, Timo Reuter and Miriam Leuchter from Germany describe a guided play learning environment for 5–6-year-old kindergarten children that aims to foster children's conceptual knowledge about their *gear play environment*, which consists of gear construction sets and a choice of task cards focusing children's attention on turning direction and turning speed. They describe the process that adults follow to verbally scaffold children's play towards the learning objectives and the overall results from their study on guided play to facilitate scientific learning in kindergarten children.

Manabu Sumida describes how problem-based and socially implemented play is expanded from local to the national and global levels by reorganizing traditional play activities for Japanese children in the context of current 'glocal (global+local)' issues in Chapter 17. Young Japanese kindergarten children learn about natural disaster prevention through STEM play that utilizes sand play, toy building blocks, water play, and play hoses, items that are traditionally familiar to them. He explains that at the start of the twenty-first century, in highly information-oriented societies such as Japan, it is important for young children to acquire science literacy to prevent information poverty while acquiring the competencies necessary to change their lives and the society in which they live.

In Chapter 18, César Mora Ley describes the incorporation of STEM challenges into the PreK and Kindergarten curriculum in Mexico, describing student opportunities for play and discussion. The multidisciplinary approach to student exploration in Mexico places high priority on developing STEM-skills facilitating students to think and act as scientists and engineers in their earliest experiences of play through hands-on, minds-on activities, with the goal of ensuring students are comfortable with and engaged in STEM in their later academic years, igniting a life-long love of exploration and learning.

1.6.4 Part 4: Informal Settings and Family Involvement in Play

Chapters 19–22 describe early years experiences in informal settings involving family and the community from the perspectives of 11 science educators representing three countries from three regions: Africa (Mauritius), Latin America (Argentina), and North America (USA).

In Chapter 19 Ana Prieto and Teresa Kennedy describe the Argentine educational system and the implementation of STEM learning experiences balancing unstructured and structured play in outdoor environments with two third grade classrooms of the María Auxiliadora Institute (IMA) in the city of Junín de los Andes, located in the northwest of the Patagonia region of Argentina. Students were exposed to different audiences including professionals, NASA scientists, educational community members, science fair participants and others while serving as role models to their younger siblings at home and providing them with authentic scientific experiences leading to their own free choice unstructured play scenarios in their backyard environments through data gathering activities with the GLOBE Program. The results of this citizen science application of the GLOBE Program are analyzed and discussed providing an example that can be replicated in other countries.

Chapter 20, by Jayantee Naugah, Bhamini Kamudu Applasawmy, Ian Li Kim Khiook, Sookdeo Rungoo, and Aman Kumar Maulloo, describes how the Rajiv Gandhi Science Centre implementes its early science education program in Mauritius. They discuss their systemic approach, which is implemented through a collaborative strategy between teachers, parents, children, as well as supervisors of the early education sector. Their educational program includes a science exhibition by preschoolers and the continuous professional development of teachers.

In Chapter 21, Scott Pattison and Smirla Ramos-Montañez discuss the diverse and interdisciplinary ways that children and their families engage with STEM in their everyday lives. Over the last several years, the Head Start on Engineering (HSE) initiative, based in Portland, Oregon, USA, has been developing a family-based program to engage preschool-age children (3–5-years-old) and their families from low-income communities in the engineering design process, and then study how these experiences support long-term family interests related to engineering. The findings from a retrospective interview study with parents one to two years after they participated in HSE revealed three distinct interest pathways (a) engineering focused, (b) prior interest focused, and (c) family values focused. The findings problematize traditional approaches to studying STEM-related interests and highlight the importance of understanding the complex ways families make sense of and engage with STEM through play and other informal learning experiences.

In the final chapter of the book, Chapter 22, Jamie Wallace and Jenny Ingber explore early childhood educators' experiences and perceptions of young children's play and learning at dioramas, portrayals of frozen moments in time depicting three-dimensional scenes of the natural world. Their study includes a sample of ten early childhood educators at the American Museum of Natural History in New York, exploring examples of play-based, diorama-based science learning activities, as well as teaching strategies and affordances of dioramas. Their findings suggest that play and learning inspired by dioramas look different across classes of differing age groups and contexts but are perceived as vital in sparking imagination and creativity for young children when integrated into experiences that afford unique opportunities for role play, games, and discovery. Their study highlights how dioramas can be integral in play-based science learning, making museums that are not traditionally designed for children into places for play.

The editors recognize there are many ways in which various governments and institutions contribute to the promotion and delivery of STEM in the early years, and that our collaborative global efforts will result in building the worldwide STEM capital that will inevitably move us into the next century through the development of vital skills such as problem-solving and critical thinking, which young children intuitively possess and utilize. In addition, we recognize that preschool and early formal school experiences and pedagogy differ according to cultures and government initiatives, as well as the confidence in the science content teachers are facilitating as practitioners. Simple everyday life experiences can deeply engage young children for extended periods of time, building interest in the world around them and fostering a seamless transition to STEM-focused pathways in primary school and beyond. These activities promote creativity as children question, explore, investigate, and construct meaning through problem-solving and applying previous experiences, all important skills employed in the STEM learning paradigm which includes most academic subjects and promotes the development of twenty-first century skills. We hope that this book will facilitate readers to continue down an enriching path in STEM education, and ultimately inspire and facilitate the children around them to become STEM-literate lifelong learners.

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Chapter 2
Play and STEM Foundations in the Earliest Years

Sue Dale Tunnicliffe

Abstract Experiences at the beginning of life form the basis for funds of knowledge of the emergent learners. In playing, these earliest of years children are observing and investigating from what they find out for themselves, forming their own interpretation of the world which they experience. Even before speaking they begin communicating to others. Once they can talk, they will talk about what they do and ask questions. The majority of play activities, whether with everyday objects or human designed and constructed artifacts or toys, involve STEM actions which we seek to identify so that when formal learning is initiated such experiences, with particular reference to England.

Keywords Early years · Play · Categories · Progression · STEM · Adults

2.1 Introduction: What Are the Early Years?

Children are born, as are other organisms, into this world as part of the biological domain. We humans are a living organism experiencing life processes in common with other organisms, hence we are part of this domain. Yet, in order to function, our system utilises aspects of the physical domain such as force for movement. We are dependent on the Earth Science domain for our habitats and indeed our very existence.

Play experiences in the early years, essentially before formal school, particularly free choice play in everyday circumstances, by the child, are essential experiences for STEM learning. We do not deny that play is also essential in the development of other aspects of human development, such as socialisation, communication and learning to reading and other basic skills in our society. However, skills and experiences in science, technology, engineering and mathematics have hitherto been understated in early years studies and play.

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What are the Early Years? UNESCO defines Early Childhood as the years between birth and eight years. Recently, medical experts researching Early Years and maternal-child bonding and subsequent development, and hence benefit to the child's learning, consider the first 1001 days of life, from conception to two years. The most critical time for the developing brain is at this pivotal stage in a child's life. Furthermore, the child is also shaped and influenced by the environment and people around them but most importantly their mother (Lakhanpaul & Smih, 2019).

Early Years, a blanket term for the beginning steps in learning, is divisible in to three sections:

i. formal school.
ii. in some kind of formal school such as nursery school and kindergarten and the age of formal schooling varies from country to country.
iii. free choice play, at home, in childcare or other venue.

Hence, when discussing early years, it is vital to describe the age of the children and whether they are experiencing some formal schooling. Formal schooling is a different experience. Before formal school, at home, in their community and in informal preschools, the child sets the agenda and determine their free choice actions In contrast, in formal the learning environment, whilst recognising the children's own actions, teaching by talking and demonstrating actions is a focus as is assessing the acquisition of skills such as mark making in mathematics and other communications. The early years are the start in a child's learning journey. STEM is experienced in non-formal settings and in formal ones where STEM is introduced and the adults have a planned agenda (Clements & Samara, 2016) but, as Clement et al. (2020) point out, children with disabilities are often not afforded such an opportunity. STEM provision must be for all children and appropriate.

The observation, of a child's play activities in the before formal school is an increasing area of interest to educators. However, the age of formal schooling varies between countries. Therefore, in discussions about the pre- and in-school child, it is imperative that the age of the children and their stage in education, at home, in childcare, in nursery and other formal pre-school or in kindergarten is defined. In some countries, such as Germany, formal schooling begins at seven years of age. Following several years of Kindergarten. Whilst there is increasingly a recognition by parents and authorities, particularly governments, that Early Childhood Education (ECCE) is key in the development of the child's social, emotional, cognitive and physical needs. However, it is important to be aware that learning does not occur in a linear manner, but in a constructive and progressive one. Moreover, an increasing influence on Education in many countries is the effect of the neoliberalism policies of many governments. A business model is applied and accountability measured by, for example, test results of the children, publications of local school league tables and more and more schools being taken under the control of boards closed of business people looking for financial results. The child is the only player in this scenario who is not consulted but the object to be educated to satisfy the demands of the system in place (Roberts-Holmes and Moss, 2021).

There is increasingly a recognition by parents and authorities, particularly governments, that Early Childhood Education (ECCE) is key in the development of the child's social, emotional, cognitive and physical needs. However, there is a central tension between play and learning where free play is associated with the child's interests and free choice and development whereas learning is directed by adults and predominantly the view on schools and formal preschools where they are accountable to governments. The starting point for play is having their attention caught through initial observations which are then extended by the player, followed by experiences. These early learners are necessarily active learners. They link new observations and insights through experiences, acquiring increasing mastery of skills and developing competency, in a progressive learning process.

The starting point for play is observation by the player and applies to STEM actions in play as it is for the other areas, (Johnston, 2009). The early learners are necessarily active learners. They link new observations and insights through experiences, acquiring increasing mastery of skills and developing competency, in a progressive learning process. There is too an acceptance that learning is not necessarily a solitary activity of the learner. The Russian psychologist Vygotsky recognised the role of cues from another source in helping a learner to build on where they are in an activity. "What a child can do with assistance today she will be able to do by herself tomorrow" (1967, p. 5, 6-7). The role of co-construction is also a contribution to learning, in this case of both learners, adult usually and child. It is important and understanding to accommodate, such may also be a social activity with development of those skills of social interaction and communication.

Science, Engineering, Technology and Mathematics, often referred to by the acronym STEM A child's STEM learning journey begins with *play experiences* in which they involved in their first few years. Their understandings begin from a holistic foundation for lifelong learning and well-being. Such play is free choice, instigated by the player. Their play informs the foundations of their learning, including literacy and the ways of their culture. In these early pre formal school years STEM can be regarded at STEM-E, adding an 'E' for experiences to the acronym, emphasising that this is not learning in the school sense meeting targets set by curricula but the players understanding of their world, including their cultural basis through experiences in their play. These early interactions further a child's understanding, skills and competencies from experiences they chose in their own free choice play by themselves. They are enhanced by observing and replicating actions in their communities and at home. Early Childhood Education has the possibility to nurture caring, capable and responsible future citizens. In the child's everyday life they are observing tasks around them and may gradually become involved or investigating for themselves phenomena noticed and 'playing'. Such interactions may be with constructed toys with which they play or in using artefacts found in their home. Children able to go outside and interact with objects and features they encounter, such as leaves, boxes, old bicycle tyres which 'older' early years children in for example Bangladesh and Nigeria, roll as hoops. They may construct 'dens', build dams across steams, draw pictures in the dust, construct structures from stones and bricks, all under the heading of free choice play. Children in a number of countries develop their own toys from arterfacts. Older early years boys in Ghana for example play a game called Chaskele. The children flatten drinks cans, use sticks as a bat. The game is to try to hit the can into the centre the centre of the car rim which is lain on the ground (Communication F. Awaah, September 10, 2021) to use as bats It is these actions which we seek to encourage parents and carers, as well as teachers, and recognise them as STEM-E in action providing experiences on which learning can be built. Thus, STEM begins from this holistic foundation for lifelong learning and well-being.

Play in very young mammals is not universal. This phenomenon is only observed in a few species and varies in form (Fagen, 1981, p. 24). Biologists have suggested that the developmental play in warm blooded animals may be the result of their having more energy than cold blooded organism which spend their energy on food searching. Smith (1986) provides a comprehensive account of play in other animals and in humans**.** However, the youngest animals, including humans, have to learn to be one of their kind. How various animal species achieve this is a timely perspective before considering the role of human play in children (Safina, 2020). A research team (Ridley et al., 2018) considered from their work that prehistoric children played with a variety of objects, man made by themselves. Furthermore, Ridley and his colleagues proposed that this observation is similar to the interactions and changes effect on the environment by organisms like beavers for example, that the play of children in these societies with objects is similar. Such play is an in that important stage in apprenticeship for their adult roles. In their society, toys are small versions of weapons or hunting tools, or of household tools. Studies of play across cultures in the lives of children found that play is relevant amongst children and often as a distinct apprenticeship for adulthood (Callaghan et al., 2011). Play occupies much of many children's time and is considered by many one of the keys to their future development (e.g. Lillard et al., 2013).

Babies experience at first hand properties of being alive, breathing, need for food and excreting as well as being aware of their immediate world. Through using their senses, they begin interacting with objects. When they are able to sit up they interact objects near to them, thus they begin their STEM experiences, extending their learning further than their own basic biology. Goldschmeid (Hughes, 2010) named the phenomenon of babies finding out for themselves about artefacts, usually constructed by humans but also of naturally made bio facts such as a vegetable or geofacts like pebbles that they encounter 'heuristic play'. It is a first step in STEM-E experiences which may lead to learning.

In the second decade of the twenty-first century there has been an increasing awareness of play in the early years of a child's development in importance of play. Whitebread et al. (2012) said that society should promote awareness of and work to change the attitudes in society towards play. These researchers pointed out that play is the work of children and essential for intellectual achievement and emotional well-being. Whilst adults regard their own play as recreation, a relaxation episode instead of their paid employment, for the young child it is their work (Roth et al., 2013). Play is often very much problem solving (Moyles, 1989). It is an integral part of a young child's needs. However, it is typical to hear children in the beginning year of formal school to ask when they have completed a task, "If they can go and play now?", meaning focus on an activity of their own choice, not a task set by an adult, or constructed (Tunnicliffe & Gkouskou, in press). We now recognise that play is crucial to the development of a child (Moyles, 1989) and that society should promote awareness of and work to change the attitudes towards play. 'Just playing', is a phrase has been used in a derogatory sense by adults, who consider that their 'play' is their recreation and their choice as opposed to their work which is usually a paid job. However, as Delgado-Fuenetes points out, non Anglophone countries do not consider play as the prerogative of children only but consider play to be part of everyday life for all in a community. With festas for example and thus an intergenerational occurrence. Moreover, play, games and toys are regarded as cultural artefacts an considered as part of human heritage (Delgado-Fuentes, 2021).

Beginning at an early age, children eagerly observe, explore, and discover the world around them. Young children are curious and passionate learners. "From birth, children want to learn, and they naturally seek out problems to solve" (Lind, 1999, p. 79). Exploratory play allows young children from birth to age of three years a means of understanding their environment, provides opportunities to construct conceptual learning, and encourages them to employ the practices of reasoning and inquiry in natural settings. Wilson (2007), expressed this as follows, "in their pursuit of knowledge, young children are prone to poking, pulling, tasting, pounding, shaking, and experimenting" (p. 1). Young children are natural scientists (Gopnik, 2011) but recognised as such by Piaget who regarded then as, 'A lone scientist working actively on materials, objects, events and the environment to construct knowledge and understanding' (Wood & Attfield, 1996, p. 21). Children are problem solvers and play after all is often very much problem solving (Moyles, 1989).

2.2 Importance of Everyday in Foundations of Science, Engineering, Mathematics and Technology Understanding.

Those of us who have taught science in pre-secondary school have realised that much done under the heading" 'Science' embraces some fundamental mathematics and engineering concepts together with recognising the intuitiveness of the youngest children as 'scientists;' observing, questioning, planning an investigation., carrying it out and noticing patterns, effectively collecting data (Gopnik, 2011). These experiences supported by the community and individuals lead to capable and responsible future citizens. However, in the everyday activities' others around children look and gradually becoming involved or investigate for themselves, phenomena and 'playing', often creating 'toys', that is, objects with which to 'play' from what they find. They may construct 'dens' build dams across steams, draw circles in the dust, contract edificies of stones and bricks, for example all under the heading of play.

It is these actions which we seek to encourage reaching them as STEM in action. These earliest STEM actions of children are before they enter school can be assessed and often are by mothers and others associated with the children.

We are all practitioners of STEM but rarely realise this. Because Science and engineering are in action is all around us in our everyday! In our homes for example, we may use slices of bread to make toast, or cook raw eggs and notice that the, ice of bread, the cooked egg or rice has changed irreversibly from the uncooked state, all irreversible. Whilst there are scientific explanations for such changes,young learners, and adult practitioners, do not need to know the theory of these procedures and outcomes they use it in their everyday lives. However, it is so important for these adult practitioners to recognise and point out the science in action to the youngest child, so they start learning and noticing the effects of science in action, or the engineering and technology which is used. A fundamental science concept is irreversibility of some actions like baking bread but of reversibility of other phenomena as a melting ice cube melts the resulting water can be changed back to the hard ice cube if the water is in a container which provided the template for the water's frozen state. People devise project management sequences, plan, use tools and invent items in their homes or elsewhere. Hence, most individuals are everyday scientists and engineers, Action Scientists Engineers in Action. These are the classrooms and 'laboratories' for young children emerging as learners their home, their communities, their everyday environment. Formal school laboratories and workshops are but one aspect of these subjects and not always accessible to learners.

Parents and other caregivers that create a positive and safe environment at home, promoting exploration and discovery and nurture curiosity. Children learn through trial and error, many times experimenting on their own. These activities promote questioning, exploring, investigating, and constructing meaning, all important skills employed in the learning paradigm of STEM (Science, Technology, Engineering and Mathematics), which includes most academic subjects including language arts (communication) as well as art and design (creativity). Simple everyday life experiences can deeply engage young children for extended periods of time, building interest in the world around them and fostering a seamless transition to STEM-focused activities in primary school. Design and Technology, which encompass design and making, art and associated activities, all of which are precursors of engineering are important aspect for children to experience. They need an opportunity to solve problems, after learning required techniques, such as using junior saws, measuring, linking, use of hydraulics and pneumatics, as well as art instigated activities, all of which require creative, possibility thinking as does solving science challenges in inquiry-based science or possibility thinking (Cremin et al., 2006). The rise of Maker Spaces is a welcome innovation in encouraging children in STEM activities.

Everyday science is observable at home, through the child's play with, for example, blocks, card-boxes and toys, natural objects such as water, sand, mud, sticks, and through gardening, repairing a bike or other household objects, participating in cooking, and even watching and helping at everyday tasks. Such activities and observations made by children do, we have observed in our practice, become part of their fund of knowledge which they have used in re-enactment play and in solving their problems when free choice playing inside home and outside. Technology also plays a role in science discovery through photography, recording and listening to sounds of insects and animals, and virtual play on educational websites and games (Sakr, 2020).

Science and engineering are inextricably linked. Piaget's research on conservation is about grasping the concepts of volume, length and mass (Piaget, 1952; Piaget & Inhelder, 1974). All are essential concepts for further science and mathematics learning, as well as learning to function in an inherently increasing technological everyday world. Whilst playing, these early learners, are also learning fundamental mathematics to include numeracy, space and measurement (Tunnicliffe, 2015). Moreover, as children play in their early pre-school years, they absorb experiences and, even if they do not yet voice their observations or questions, subconsciously collect experiences and observational science concepts crucial for effective basic engineering, mathematics and science capital development. Such active learning continues always in informal play but also in formal play opportunities in nurseries, play groups and pre-schools and in participating in tasks set as part of their statutory early year's curriculum.

Play appears to be intrinsically motivated, indulged in for the player's need (Berlyne, 1960). Other researchers postulate that play satisfies an innate curiosity of what can be done with an object (Hutt et al., 1989). Hutt suggested that play in earliest years were of two types, epistemic and ludic. Essentially, they are a continuation of the heuristic experiences of a baby exploring objects with their senses. Epistemic play answers the question, "What does it do?". Whereas ludic play answers the question, 'What can I do with this?', and develop a little following established familiarity with objects which is after all an exploration of materials. Hughes (1996) compiled a list of 16 play varieties observed in pre-school children, and gradually emerging as the child develops. These categories ranged from object play, symbolic play when an object represents something else in a child's imaginative play, like using a small card box as a telephone, to role play.

Play develops progressively with a child's development. Thus plans for developmental play have to be tailored to a child's progress (Copple & Bredekamp, 2009). Play begins from a child's birth. Goldschmeid (Hughes, 2010) introduced the term *heuristic play* after her observations of babies and their early activities. This name recognises the universal occurrence of babies finding out for themselves about artefacts, usually constructed by humans, but also of naturally made bio facts such as a vegetable or geofacts like pebbles that they find. She suggested providing a selection of such in a basket or other container, a treasure basket. They explore the properties of materials they encounter. They touch and try manipulation for example. She introduced the of concept 'treasure basket' where items were placed in basket or another container for the non-mobile child, once a baby could sit up unaided. However, once mobile any environment in which children are becomes a site and opportunity children indulge in heuristics play. From a science point of view this is Inquiry based learning. In any structured play whether children left alone to choose what they do and how they use provided items or rules, children will, 'Do it their way', not as adults who designed the items ant coated and would expect them to be used. Instructional play is a remedy to this tendency of a child employing their natural way of finding out, inquiry, it is self-will!

One size does not fit all in play. Play is a progression and not necessarily a smooth one. Play experiences are constructed hence the term constructivism. Piaget (1962) noticed that first of all experiences and understanding is accommodated into the existing schema of a child but then assimilated. Toddler Richard is an exemplar of accommodation and assimilation. This toddler noticed something move in the sky? He was told that it was a plane. The next time he noticed something moving in the sky he announced, 'Plane'. He had accommodated that there was a new category for him of things moving in the sky. After a short while he assimilated this knowledge. Namely that there is a category of things moving in the sky, However, he soon learnt that there are different things in the sky beside planes! This is also the process that happens particularly in classification and taxon only which is not just a process of biology although a fundamental one.

Observation is the foundation of developing awareness of phenomena in action and understanding what they do. Young children are curious and passionate learners. They experience basics of physical and material sciences but also of Earth science, aspects of mathematics and engineering. They are intimately living biology but also have an affinity for other biological phenomena, organisms and behaviour. In relation to living things they develop ideas based on first-hand observations. Tomkins and Tunnicliffe (2007) studied pre-secondary pupils of two age groups: aged five to six years in the first year of formal school and nine to ten years in their fifth year of school and analysed the responses of these English children to natural objects and specimens. The researchers found that the responses of these children followed the pattern referred by Klahr (2000). This step-wise process of scientific thought which he defined as inquiry, analysis, inference and argument, this sequence of thinking and actions is increasingly referred to as inquiry science with various elaborations and names such as 5E permutations is increasing of the four.

Free choice play as well Guided play in Kindergarten often impacts general understandings of basic engineering principles combined with utilising basic technologies in toys and other artefacts with which children observe and interact (Reuter & Leuchter, 2021). Science and engineering are inextricably linked. However, the engineering aspects of science and the science concepts on which engineering is based are seldom realised in early years and primary education by practitioner sunless they have a STEM identity.

In the first decades of the twenty-first century the development of digital tools as an activity has developed. Digital play in early childhood and is increasingly recognised as a fundamental part in the developed world in a child's development develops social and communication skills too (Sakr, 2020). Children who play digital games learn to problem solve and take quick decisions Playing games with other children Pretend play and imagination are important for cognitive development helping children to reflect and regulate their own cognitive behaviour and reflected upon and gain a deeper understanding of the mind (Goswami & Bryant, 2007, p. 2). The term Free Flow Play (Bruce, 1991), was introduced, with a number of defining criteria of this play as an active process without a product and intrinsically motivated, with children moving from one activity to another, of their choice and timing. Bruce (2011) also suggested that play is a rehearsal for what children can actually do in their lives often re-enacting adult observed occupation, such as having visitors for tea in a play kitchen or buying items in the play shop, human constructed or made themselves as symbolic presentations as they compose their narrative. It can help them conceive what never experienced in real world, cars on rough surface, floating/sinking or weighing the same amount of a mass as one large piece of many different shapes.

STEM learning is phenomenological. These observations through carrying out activities, trying out their ideas and elicit questions in the mind of the observer, even from unpublished field observations in non-verbal children (Tunnicliffe, 2015, p. 4) who may then investigate in some way to state their curiosity and establish an answer fitting their interpretation. In carrying out these investigations children often use objects, or in the case of the living world and earth science observing, noticing patterns and interpreting. Indeed, the exploring and conceptualisation and decisions taken situating and effecting the investigation based on some understanding reflects the manner in which researchers work.

Science and engineering are inextricably linked. However, the engineering aspects of science and the science concepts on which engineering is based have hitherto seldom been identified in early years and primary education. Such an important component as Creativity is ‘possibility thinking’ (McConnon, 2016). It is also an important aspect of STEM developed in the first years of formal schooling, and before, in the way the child uses art and craft. Observers of pre-school children playing in situations can identify a STEM one employ possibility thinking but frequently called inquiry. Relatively little has been written about the role of play in a child’s acquisition the foundations of STEM knowledge and understanding.

Much of a child’s time, whether pre-school or in formal school or when at home, is taken by their playing (e.g. Lillard et al., 2013). However, very little has been written about the role in play on acquiring Stem foundations. Tunnicliffe and Gkouskou (2019) identified some basic science concepts experienced by pre-school learners when using typical play equipment such as climbing frames, slides, toys and materials such as sand and water.

2.3 Play, Learning and Progression

Play is a pleasurable experience. Play occupies much of many children’s time and is considered by many one of the keys to their future development, e.g. Lillard et al. (2013). Much research has been on the development of symbolic play, one something standing in and representing another item into the child’s everyday world e.g. (Pellis & Pellis 2007; Pellis et al., 2010). Whereas the other frequently referenced researcher Vygotsky (1980) only refers to symbolical play, 1962, defined play according to the behaviours exhibited but players for example, sensori motor, symbolic play and games. Fagen (1981) took an ethological view identifying behaviours and had suggested three categories, locomotors, object and social. Young mammals in particular play fight-practising moves if they are predators that will be necessary for their survivals and for hunting for food involved. Other researchers defined play is according to the 'functional dispositional which the play actions are involved. Play is a free choice activity. The action is repeated over and over again. Moreover, the play is not related to the context, that is it is not functional for the context in which it is practiced. The play is not aimed at the survival of the organism primarily the play is a pleasurable experience. Play is not of one universal form. Burghardt (2011) identified five criteria for an activity to meet to qualify as play, which encompass both functional and structural criteria, the nature the actions and what it does for the player. Broadly summarised as five broad categories: These are: (1) An unstressed activity—no pressure on play; (2) It is spontaneous; (3) The play action is repeated similarly; (4) The play is not aimed at the survival of the organism primarily and not the usual activity for whatever is used in the play activity; (5) Play is a pleasurable experience.

Akman et al. (2015, p. 240) observed that there are two categories, of play: classical theories and modem theories. Classical theories.in particular cited are those of Piaget and Vygotsky. Modern theories are those which were involved in matching developing of the child with understanding the effects of play associated with such. They focused on modern theories beginning with Freud's theory and that of Erikson.

The classic understanding of play began with Piaget (1962) who for example categorises play as observed categories of behaviour and identified three main ones: sensori motor play, symbolic play and games with definite rules. Symbolical play utilises objects to stand in for another object for presentation of a partial function or purpose even though the object in use bears no resemblance even though the object in use, e.g. a small box being held in pace of a telephone. Or a soft toy such as a teddy bear representing a child when a game of' school', the child re-enacting what they feel is in the role of teacher, is being played such is what other researchers named as pretend play Lillard (1993). Whereas games have a definite way in which players are meant to participate, alone or with older children who will play together, devised by a child. Vygotsky (1980) focused solely on symbolic play where he argued that youngest children learnt to separate the object used from the resemblance of object it represented and its usual actions.

As a scientist specialising in education, I maintain that whatever play genre according, to psychologists, children do display in their own play, that the actions of children in much play renders them intuitive scientist and engineers In investigating objects and phenomena when playing children utilise what are, in formal schooling, identified as STEM activities, but do so intuitively in their free flow play (Bruce, 1991). In child selected play the child choses with what they want to 'play' and how they will do it. It is a development of Goldschmeid's treasure basket and 'heuristic play'. Hence, babies find out for themselves, 'do it their way', and learn through experiences of skills, actions and outcomes. Often older pre-school children will work together and organise a play episode. Effectively early learning is by observation and personal experience, children observe, ask questions, planning what to do and decide what implements they use. They evaluate the outcomes and use such findings and interpretations to interpret their world.

An aspect of play is the use of objects or natural phenomena such as items in a landscape, rocks, streams and organisms such as trees and flowering plants which take a bush form. Such are particularly part of a child's experience in some learning situations such as play groups. In children developing experiences of objects ad learning their properties and capabilities or as a backdrop to a narrative being composed as in game of hide and seek or chasing 'an enemy'. Such experiences embrace aspects of science and engineering principles such as building of' dens be it with sticks outside or boxes inside.

Play can utilise outdoor phenomena, natural, or, a German educator Froebel, in the early nineteenth century, believed that "self-activity" and play were essential in early learning. An adult's role is to encourage children in what they were doing but not instruct them in a formal teaching instructional model and believed such play should be accompanied by music. He designed ten 'gifts" or occupations were Based on basic mathematical shapes. The first was woollen balls, with a string. He believed that use of these 'gifts' in the developmental progression stimulated learning, they began with the sphere and the last gift was points, the end of lines. A feature of gifts was that materials returned to their original shape after use. Some of his work was with wooden blocks (Tovey, 2013). Pollman (2010) developed activities with blocks, which are a popular choice of activity with even the youngest child and found that such developed spatial skills. Children with competency in block play re likely to follow STEM careers. Interestingly adults in an Early year's workshop for practitioners provided with an assortment of various sized boxes instantly spontaneously began constructing towers finding out about stability and balance. At the end of the class held at the Rajiv Ghandi Science Centre Mauritius in 2019, declared they had been 'playing'.

Children's free choice play with objects or imaginative situations helps them think and develop problem solving capabilities Children's free choice play with objects or imaginative situations helps them think and develop problem solving capabilities (Rogoff, 1990). Robson (2014) reported on the importance of analyzing children's creative thinking framework form their creative thinking very much part of play.

I described (Tunnicliffe, 2019) genre of play from my observations of what the child at pre-formal school, stage including kindergarten, chose to do (5 years being statuary start for school). Four different genre were identified. Firstly, Free choice unstructured play which is a free choice heuristic play. When the player uses items not designed as toys, such as resources that you can find outside, or/and inside. Some items in playgrounds such as swings, or slides lend themselves to play. Secondly, I named this as play when toys are available and the children choose with what they are 'playing', moving often from one to another. As mediated play, the toy mediating then experience. However, when specific items are made available and the child is expected to 'play' with them, she designated that as facilitated play but recognised that children often adapt the items for their own exploration, which is not the way the toy was designed by adults to be used! Lastly, in terms of adult interaction I recognised Instructional play. In such the child tries an activity or artefact but trigger questions and a strategy is planned by an adult, reflecting previous knowledge and understanding and requiring organisation logistics of items needed for investigation and action plan, together with assessing the outcome. Guided play and Discovery play are similar, and an approach often used in Early years research, e.g., Reuter and Leuchter (2021). Identifying which kind of play is being used, by watching children working through a play process can usefully inform an observer about a child. Such activities are STEM but recognising creative make believe, social play and so on which involves STEM actions enveloped in a child's narrative is important and increasingly recognised as such. Bulunz (2013), working with 6-year-olds in Kindergarten in Turkey, suggested that integrated play and science interaction does develops a science understanding.

I believe, after many years of working with children, that the starting point of STEM learning is for the children to experience involvement with items or phenomena of their choice which catches their initial interest (Krapp, 1999) which will develop as the children develop and build on their experiences and discoveries to more formal learning experiences into a sound experiential 'science or STEM capital'. My observations developed into a STEM Play cycle (Fig. 2.1) which is a progressive cycle continually turning. Hence can be used to monitor progression. By numbering the stages and following a longitudinal study. Objects have elicited learning in their genre, particularly in museums, botanic gardens, zoos and other animal collections as well as in field work. Objects in museums also can elicit understanding of particularly basic physical and earth science (Tunnicliffe & Gkouskou, 2018). Animate and inanimate objects arouse curiosity and investigations in children (Tomkins & Tunnicliffe, 2001) and learning from museums objects, which frequently involves handling in museum education classes is an important aspect (Eberbach & Crowley, 2005).

Thus, children lay the foundations of their knowledge and understanding in their pre formal school years in their home and their community. They observe and explain to their causation, they acquire names and other information too from adults and the media, particularly from pictorial children's fiction books and cartoons. The adults who care for them, often mothers, are the first and most important teacher of the child. In some places around the world that role is also fulfilled by other relatives or indeed by a while community.

Play but with specific reference to STEM is an important stage in developing a "Science' or STEM identity of someone. It is likely that most adults encountering this age group at home or in formal setting do not have an identity as a science or STEM confident person (Avraamidou, 2016). The recognition by parents and other practitioners that nearly childhood experiences are mostly play of one category or another matched with guided play. The name given by practitioners to a child's activity designated 'play' varies. Teaching science through playful, hands on experiences produced more understanding than did direct instruction. As work with six year old kindergarten in Turkey showed (Bulunz, 2013) Thus, suggesting that real

Fig. 2.1 The STEM Play Cycle. A cyclical phenomenon. Developed from non-participant observations (Tunnicliffe, 2021), and later refined into the diagram depicted below (Tunnicliffe & Kennedy, 2021)

hands-on experience is a more effective experience from which these kindergarten children learn.

A recent development in Scandinavian countries is the recognition of the importance of 'risky play' (Sandsetter, 2007) and the provision of supervised 'risky playgrounds' (Van Rooijen et al., 2019). Whilst my categorisation refers to STEM but recognising creative make believe, social play etc. The focus is on actions and skills which are identifiable as STEM experiences. the crucial role of literacy, from narratives composed by the child as they use objects to tell a story, or social play when children begin playing alone, then in parallel with another until ultimately collaborating are recognised. Other researchers note that construction play often overlaps with other creative acts such as object play and aspects of art, modelling, colouring for example. Such are precursors of researchers exploring with interventions children's responses to certain things which approach from the basis of the majority of early years science education research papers, the majority of which are focused on physical science. This is illustrated by the work of Lynneth-Solis et al. (2017) or the first investigations of Piaget on measurement for example. One aspect of facilitated play is appropriate assistance, not didactic instructions but an encouraging question, such as "What would happen if…?", "What has changed?", "How could we?", "What do you think will happen? Why?"

In the early years of the twenty-first century there is appearing a consensus that science, which in reality is STEM, learning in education should begin pre-school age (e.g. Eshach & Fried, 2005). There are however different genre depending on where and why the child is 'playing'. Guided play is a term which in the past few years has emerged in the literature related to teacher interaction with early learners in a formal educational setting where they are guided through activities specifically designed to develop their skills and understanding of a concept. This term is a definite genre of a pedagogy with play. But aims to bridge the practice of guided discovery. Particularly in the USA and free play actions very much advocated in Germany (Zosh et al., 2018). The difference between guided play and guided discovery is that in the former the child's participation is free choice, voluntary decision, in contrast to having to participate in guided discovery.

Recognition by the practitioners and family adults that free choice, spontaneous play is an important feature of play. Children find they own play objects in free choice play. However, the way in which any object or situation is provided for children is a very important aspect of the learning foundations of a child. It is instructional for the practitioners and family adults to recognise the different types of play offered and available to children. They should have a mixture but predominantly free choice before formal intervention. The situations with objects, e.g., toys, play equipment, constructed and designed by adults for children to use often, with an intended declarative message are mediated play for example. Whereas, facilitated play is with cues and help from another but instructional play occurs when the player is told what to do and how to do it. Instructional play is of vital importance in developing safe practice in using certain items required for the activity such as scissors. In formal settings these categories may all be employed in planned learning situations by the practitioner.

The discussion of play usually involves the use objects in some form. Much play is based on objects of varying construction and materials. In Goldschmeid's Treasure Baskets for example, different everyday materials, shapes, textures, forms and properties are explored In mediated play very young children begin using building blocks and gain more confidence and imagination as they progress in both confidences, understanding and skills. Such increase with experience as they develop. 'One size does not fit all' in early years play. Such cannot be stated too often. If left alone, in using Goldschmid's Treasure Basket provides a young child the opportunity to learn for themselves about properties, cause and effect and they can control this in some of their actions.is a vital learning opportunity. As they develop, the emergent STEM child learns how to use some objects as they are intended. They learn how to interact with a purpose. A child of about three years, if they had had the pre-experiences, start employing symbolic play, make. Believing say a walking stick, metre rule or broom stick can act in place of a horse, which may develop later into using manufacturer hobby horses. the head represented by a stuffed sock. This merges into constructive play where they use objects for the purposes for which they were intended, they know spoons are used in mixing, cups re for pouring drinks into, and experts suggest that, after all this these younger,pre-school children become involved in imaginative play making up their own narratives with toy animal from example or Lego models they have built.

As scientist specialising in education, we maintain that whatever play genre according, children do display in these actions, there is the foundation of some science, mathematics and engineering. Gopnik in a wealth of research papers and a popular book for non-specialist (Gopnik, 2011) pointed out that the actions of children in play renders them intuitive scientists and engineers. In much play children utilise actions, which are, in formal schooling, identified as STEM activities, but they do so intuitively make actions in their free choice" play", learning through experiences skills, actions and outcomes. Often, older preschool children will work together and organise a play episode and effectively learn by observation and personal experience. They observe, ask questions and plan what do and what instruments, tools, they use. They evaluate the outcomes and use such to interpret their world,

2.4 Adults, STEM and Play

Young children are natural scientists. Beginning at an early age, children eagerly observe, explore, and discover the world around them. Young children are curious and passionate learners. "From birth, children want to learn, and they naturally seek out problems to solve" (Lind, 1999, p. 79). Exploratory play allows young children from birth to age three, it is a §means of understanding their environment, provides opportunities to construct conceptual learning, and encourages them to employ the practices of reasoning and inquiry in natural settings Such has been described by Wilson (2007) as, "in their pursuit of knowledge, young children are prone to poking, pulling, tasting, pounding, shaking, and experimenting" (p. 1). The adults with whom children spend their time influence the activities of children. To some extent in that they repeat in their way adult actions. Likewise, adults may provide these children with miniature replicas of adult tools so children re-enacting and preparing for adulthood (Callaghan et al., 2011).

Increasingly parents and authorities, particularly governments, recognise the importance of pre-school and early school years. Early childhood education (ECCE) is considered more and more as key in the development of the child's social, emotional, cognitive and physical needs. Furthermore, it recognises the vital role played by communities and the immediate cares of the child from birth, particularly of the mother as the first and most important teachers. However, many of the first 'teachers ' do not realise that they are doing in their everyday basic mathematics, science, engineering and using resultant technologies. Often practitioners do refer to these everyday manifestations of STEM subjects as Science for shorthand purposes, but, in reality, the real world is not in silos of but the constituent disciplines and outcomes of mathematics, science, engineering and resultant technologies, are inextricably integrated in action in our everyday.

Science and engineering are inextricably linked. Piaget's research is about grasping the concepts of volume, length and mass (Piaget, 1952; Piaget & Inhelder, 1974). Donaldson (1978), in her classic work on children's understanding in which they were asked to articulate their understanding of the investigation setting, literally. All these aspects are essential concepts for further science and mathematical learning, as well as learning to function in an inherently increasing technological everyday world. Moreover, as children play in their early pre-school years, they absorb experiences and even if they do not yet voice their observations or questions, subconsciously they are collecting experiences and observational science and mathematical principals, applications and concepts crucial for effective basic engineering. Such active learning continues always in informal play but also in formal play opportunities, nurseries and tasks set as part of their statutory curriculum.

Science and engineering in action are all around us in our everyday. We are all practitioners of STEM, but rarely realise this. In our homes for example, we may uses slices of bread to make toast, or cook raw eggs and notice that the slice of bread, the cooked egg or rice has changed irreversibly from the uncooked state, all irreversible Whist there are scientific explanations for such changes young learners, and adult practitioners, do not need to know the theory of these procedures and outcomes they use it in their everyday lives, but it is so important for these adult practitioners to help access such science in action to the youngest child so they start learning about the science, mathematics and engineering in action, and the technology which is used.

There are fundamental science and engineering concepts, irreversibility of some actions but for instance, such as a melting ice cube, the resulting water can be changed back to the hard ice cube if the water is in a container which provided the template for the water's frozen state. People in their homes and communities devise project management sequences, use tools and invent items in their homes or elsewhere. Hence most individuals are everyday scientists and engineers, Action Scientists Engineers in Action. These are the classrooms and 'laboratories' for young children emerging as learners their home, their communities, their everyday environment. Formal school laboratories and workshops are but on aspect of these subjects and not always accessible to learners.

Hence, working with communities, particularly mothers and carers in the community is vitally important which may be continued in the first years of formal school, or they may not. Such activity awareness and the role in learning is a pivotal aspect of Science Associations, and for example the UK with primary science and the USA in its Next Generation Science Standards. Has embraced such. Indeed, the USA seeks to break down the traditional silo approach with its cross-cutting theses linking language arts literacy with earth science, science and engineering. not only for pre-school, early years practitioners and relevant students, but particularly for parents, carers and communities not just in my country but across the world, and particularly in Commonwealth countries where the Secretary general and the Secretariat, mandated by the Education ministers at their Fiji meeting in Nandi, prompting a childhood years Toolkit for Commonwealth governments.

I consider the early play of children as they explore their everyday world and items provided for children in Western settings/developed countries, then suggest some basic activities with everyday items. Encourage adults who provide the items to let children investigate them. Firstly, by themselves, note what they do, then, secondly, give them a challenge as a cue question. Thirdly, after their achievements scaffold towards the expected outcome with more direct questions and suggestions so they may achieve the outcome a formal teaching situation would aspect. Each stage depends not only on the child's age, but their cultural literacy, experience and development of each child but their learning and language abilities. Adults need to be aware of all such factors.

Many adults in Western developed country acquired an understanding of STEM subjects in their own education which followed the traditional silo approach of discreet subjects. If they are practitioners in early years or pre-school facilities such as play groups, they may be particularly focused on the Early childhood approach of focusing on the development of social, emotions and aspects, focusing particularly on literacy and numeracy as part of developing school readiness. But not on science. However, Early Childhood Education and Care (ECEC) differs from formal school education programmes as it focuses on the whole child and holistic play-based learning (Wood, 3rd ed., 2013). And the STEM actions during a child's play are a crucial in the development of understanding, skills and competencies in STEM awareness.

Alas, scientific understanding of many practitioners is not one of their strengths in most cases and many trained as schoolteachers may still have the cognitive approach of providing facts not scaffolding and developing the child's experiences a skills progressive acquisition. Whilst adults with whom very young children interact are either family members looking after them in the home particularly their mother or other near relative or a carer in their home or in another facility. Thus, Mothers a term which can be used to refer to other personnel assuming this persona, have experience of children playing at home, informally. It is important to consider the different views of play and the role of parents and of providers. Degotardi et al. (2013) discussed the perspectives of parents and the early childhood providers. All adults involved in in this crucial stage of a child's learning need to recognise the STEM learning occurring through play. However, there have been few studies on their attitudes and reflections on this. The work in Australia of Colliver (2016) reveals some interesting observations of mother's perspectives through learning through play.

Researchers have found that focusing on basic literacy and learning is not necessarily the objective of mothers, e.g. Borrell (2005). Other researchers focus on whole cognitive learning or focus on developing both numeracy and literacy (Fung & Cheng, 2012). However, children are intuitive scientists, (e.g. Gopnik, 2011). As many parents at home know children are also naturally intuitive and show their appetite for understanding their world through asking questions, persistently, a characteristic which seems to disappear upon entering school (Tizard & Hughes, 2002). The defining characteristics of effective early childhood science practice were defined by Johnston and Tunnicliffe (2014).

> Emergent science encourages young children to communicate and share their ideas with others … It does not limit children and neither does it advocate didactic teacher-led approaches; rather, it recognises that the best learning strategies often involve the practitioner 'standing back' and allowing children time and space for exploration … (p. 3)

These are hands on science-based activities because practical experiences are vital for the children to appreciate the science in action as well as using and developing relevant skills whether using everyday items at home of more traditional school equipment. Thus, science, during early childhood is absolutely more than play. It is serious business. If we fail our children and students in science, the reasons may include lack of appropriate experiences during early childhood" (Roth et al., 2013). Play is indeed in the vital foundational stage in developing experience and skills in STEM from them or the child themselves and it involves imagination.

Fleer (2019) recognised the link in early childhood children between imagination in science and imagination in play. She observed that imaginative play can promote the learning of science and that teachers could engage with children in scientific play and build scientific wonder and imagination were important factors in developing science play-based learning. She suggested the name of Science Play worlds for this strategy. One of the barriers to the understanding of the value of play of children; adults is their own understanding of Science in particular the identity they feel as people, Avraamidou (2014a, 2014b, 2016) for example focussed on the identity felt by elementary teachers as a science teacher, as many teacher of pre secondary classes are expected to each science m, design technology and associated subject but do not feel an ident as science teachers, particularly because of their own experiences of learning science at school. Jonathan Osborne and colleagues wrote about the attitudes of secondary learners to science in a series of papers in the first years of this twenty-first century, Osborne et al. (2003). Such work has been discussed and developed by them and other researchers. Some of which discussed in by Osborne et al. (2003) Osborne and Tytler (2009) further by Tytler and Osborne (2012)

The term STEM is not necessarily recognised by adults working with young children pre formal school. Their own education had been based on the separate domain approach and experiences of integration of discreet subjects. Moreover, if subjects which provided further understanding of the relationship between science, engineering technology and mathematical concepts, skills and application were not necessarily part of their experience. They may fail to recognise the potential in play. My non-participant observations show that young children play with purpose because they are exploring phenomena about which they want to know or designing an investigation or action to provide a solution for what they want to do in their play.

Teachers trained to work with other age ranges their responses usually believe, as do parents that science is leant in a classroom with the teacher writing much on a blackboard, that 'science' is not in the everyday and is not learnt there. However, home science experiences create a different more utilitarian understanding of science in their lives. On this foundation the theory required for school examinations and assessments can be built with understanding of the theory.

Teachers working in early years, having moved from the age ranges for which they were trained, may suggest teaching these early learners in the traditional didactic way. Which is still their ‘comfort zone’. However, such ideas may change after workshops, using early years item and a challenge approach of discovery. They reflected that the hands-on approach they had used helped them really be involved and work out things. Often in such workshop’s participants remark how much fun they had ‘playing’. Furthermore, these practitioners reflected that a challenge approach rather than an institutional one that they themselves had experienced finding out and asking questions which they sought to answer by doing.

Workshops held in England for parents of children who had just started school (4 years) and children who were following the Early Years Strategy (e.g., early-education.org.uk. page 8–10) used for children in the year before statuary school start age of 5 yrs. and earlier years in other venues. Before starting workshops, the participants maintained that science required white coats, goggles and in laboratory, none of which were present in the school hall. The ‘science equipment ‘items were laid out on tables at intervals and were basic household items such as mixing bowls, whisks, spoons, measuring jugs, sieves and foods such as lentils, pasta, dried beans, as well play dough, biscuit cutters, rolling pins, saucepans, wooden and metal spoons, toy cars and different surface, building blocks toy models of farm and wild animals. Whilst hesitant about using these items to explore a change occurred once their children arrived, excused from the final thirty minutes of their school day to join their parent or parents, or careers of grandparents, these adults watched whilst their children investigated activities with no hesitation and did join in. It was very noticeable that men were more inclined to give instructions to their child on the correct way to meet the challenge! In the introduction we discussed science (STEM) in action such as change of state, reversible reactions with examples such as a slice of bread and a similar slice toasted, ice cubes melting. Their entry and exit questionnaires revealed that they had no idea that such phenomena and sections were science (STEM) in action and were all very positive about working with their children to identify. Some participants were professional scientists working in laboratories who said they had never realised that Stem is all around. Part of the initiative is also to encourage two-way dialogue and vocabulary development as well as social skills, (Tunnicliffe, S.D. unpublished Data 2016–2020). Tunnicliffe and Gkouskou (2019) observed, over a few years, pre-school aged (under five years) children playing and identified Science in action in the activities that the children in pre-school years chose to do. Practitioners may need opportunities to identify for themselves such actions and be able to identify such into their STEM category.

A study by Lloyd et al. (2017) was modelled on an early childhood STEM initiative pioneered a few years previously in rural Bangladesh by Tunnicliffe (2013b). The Lloyd et al. study was on an existing programme a programme of Stay and Play in North London’ multicultural Nursery. Tunnicliffe identified the critical time of very early years children for their acquisition of the foundation’s scientific concepts (Tunnicliffe, 2013a; Tunnicliffe & Ueckert, 2011). This original Tunnicliffe project aimed to develop the children’s science capital from recognising science in actions in their environment and in their everyday activities where they lived so the ideas had a meaningful context whilst. Encouraging the mothers to recognise such too, they were action scientists in all their everyday tasks and help their children observation and talk. She maintained, and found, that in this case the mothers' role is enhanced if they are made aware of the extent of their own existing STEM-related knowledge as their child's first and most important teacher was enhanced. In the case of Strategy and Play the parents and cares were supported in their dialogue by knowledgeable early childhood teachers and practitioners. The programme generated in Hackney encouraged children's engagement and interest. Both practitioners and the parents/carers reported their confidence in their ability to promote young children's natural curiosity at home and in early childhood provision increased. The original initiative was developed to mark the 2010 Commonwealth Year.

2.5 Conclusion

Play, in whatever form, is vital for a child's development. An increasing concern voiced by educators is the reduction in play time, a break from sitting still and the chance to run around and decide what they are doing for children in some type of early schooling. Such concern is voiced by Sahlberg and Doyle (2019) where they implore practioners and policy makers to, 'Let the Children play'. The Organisation for Economic Co-operation and Development (OECD) (2021) reported on the responses of interviews with five year old children in Estonia and England when asked about play, Their responses yield interesting insights into the minds and opinions of these beginning leaners. The presentation of the outcomes of this project can be viewed at (https://oecdedutoday.com/oecd-education-webinars/). The point is made that guided play is necessary for helping children achieve curricula goals set by policy makers but free choice play is essential and should be part of everyday activities for children in any form of early years educational setting.

A beginning of familiarisation of STEM in action through observations, experiences an involvement in its phenomena in action in their everyday world. Free play when the child choses what they are going to do and where and initiates the sequence that using their native wit and curiosity but also previous experiences of properties of materials and cause and effect. However, adults are very much a part of the STEM development through play and observations a child's early life. It is thus important that they have a realistic understanding of how thy might facilitate and scaffold positively the experiences without being instructional, telling them, bearing in mind that some skills and actions do need an apprenticeship so that they do master using them as safely as possible. This is not to deny them risky play, but develop a child's skills, understanding and learning confidence as they apprentice to the adult world.

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Chapter 3
Psychology of Children's Play, Imagination, Creativity and Playful Pedagogies in Early Childhood Education in Russia

Valerian F. Gabdulchakov and Evgeniya O. Shishova

Abstract This chapter explores the issues related to the role of children's play in the development of cognition, emotion, imagination, and creativity to increase the effectiveness of preschoolers' educational activities by improving their educational environments in order to ensure each child's creativity and support children's initiatives, allowing them to be independent and active. Modern experts emphasize the need to support children's cognitive initiatives in the contexts of pre-school education and family support. Vygotsky's cultural-historical conception is a methodological basis for substantiating play as the leading type of pre-school children's activity. The chapter is divided into two parts. The first part analyzes the conceptual framework of pre-school education in Russia, determining the degree of popularity and the features of play activities in day-care centers. It presents the results of research into early childhood educational environments in pre-school institutions and theoretically substantiates a set of psycho-pedagogical conditions, encouraging the innovative development of pre-school education in Russia. The vector of pre-school educational development coincides with the potential of STEM education. The second part presents the ANOVA results and correlation analysis, stating that the quality of preschoolers' education depends on certain indicators of teachers' professional skills which affect the development of the child's play activity.

Keywords Psychology of children's play · Development of imagination · Creativity in childhood · Educational environment · Quality of preschoolers' education

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3.1 Introduction

The development of society has created conditions for reforms in the system of pre-school education, setting new requirements for twenty-first century education in Russia. The implementation of the Federal State Requirements and modernization in the system of pre-school education in Russia determines the transition to a new educational paradigm, changing the approaches to the content and organization of the modern educational environment created for the comprehensive development of each child and their successful socialization. The child's personality develops owing to its interactions with a developing educational environment, which is understood as a system of psychological and pedagogical conditions within the social and spatial-objective environment (Vygotsky, 2005). Pre-school education is the first stage in the modern educational system and its main goal is to ensure the child's physical, cognitive, emotional and personal development. The pre-school period is characterized by children's potential to develop and their greatest period of sensitivity and receptivity, which must be taken into account when designing the educational environment of modern childhood. "Preprimary education in Russia exists in the form of nursery schools (*yasli*) for infants aged six-weeks to three-years-old and kindergartens (*detsady*) for children aged three- to six-years-old. In many cases the two types of school are located in the same building. The facilities include provision for half-day and all-day schooling as well as boarding schools. They vary from year-round to seasonal institutions, the latter predominantly in rural areas" (Education Encyclopedia, 2021, para. 8).

Pre-school learning is primarily characterized by the desire to try new things, which determines the development children's personality through gaining awareness of their own interests and preferences in relation to the phenomena of reality (Einarsdóttir & Perry, 2012; Kudryavtsev, 2011; Smirnova & Ryabkova, 2013). In modernizing the content of the current educational system, of primary importance is the development of the child's personality and the indication of their inner potential, individuality, abilities, independence and initiative. This study is based on the theoretical foundations of sociocultural studies devoted to the role of children's play in the development of cognition, emotion, imagination, and creativity in playworlds and educational environments (Bronfenbrenner, 1999; Elkonin, 1978; Leontiev, 1981; Smirnova, 2013; Vygotsky, 1966).

Play is recognized as the leading type of children's activity as games contain the cultural code of child development (Elkonin, 1978). Thus, play enhances changes in children's activities, brings to the fore their interests and certain traits of behavior, accelerating their internalization. Moreover, play triggers children's emotions and intelligence. Games are of particular importance for shaping diverse forms of children's arbitrariness—from the most elementary to the most complex. Vygotsky called play "a school of arbitrary behavior". Therefore, play, as the freest and most attractive activity to children, organizes both their behavior and inner life, making it more meaningful and conscious. The children's role in play sets the zone of their proximal development and is subsequently internalized. The driving forces of child development are hidden in specific forms of children's activities, the ones which are most consistent with children's needs and capabilities. To achieve effective and comprehensive child development we should make the most of the games they play and their potential in education. A primitive, underdeveloped game cannot determine children's zone of proximal development for it to become their leading activity. Moreover, the game is not a means of learning, but a type of children's activity, involving their agency, independence, and initiative. An adult can stimulate the game, participate in it, but not take the lead and control the actions of children. Game activities should be organized in such a way as to minimize external control on the part of teachers.

Children's play activity, transformed into "children's activities"—a drawing game, a design and construction game, an exploration game, and a game-experiment based on STEM education, can be considered a universal tool for achieving the goals of a new Standard for Pre-school Education in Russia (Federal Standard, 2013). Therefore, the vector of pre-school education development coincides with the potential of STEM education. The implementation of the STEM education model is based on the principles of developmental education and Vygotsky's scientific ideas stating that development is the result of properly organized learning, which contributes to free development, creative initiative, independence, and the child's active cognitive position, thereby increasing children's cognitive functions associated with the development of memory, thinking, imagination, verbal communication, and cognitive activity. Teachers can harness the actions performed by the learners themselves by actively and enthusiastically manipulating and experimenting with the modern object-spatial environment through the organization of project and experimental research activities.

The STEM education model is an important component of many projects, which are implemented in Russia today. To a great extent, its success depends on the creation of a new object-spatial environment of the education system as a whole, on updating the content, the improvement of its software, methodological, financial and technical support, and teaching staff training (Trilisova, 2019). The STEM program in pre-school education has several modules: Froebel's didactic system; experimenting with animate and inanimate things; LEGO construction; mathematical development; robotics; and animation studio "I Create the World". The child's need for new impressions underlies the emergence and development of their inexhaustible search-oriented activity aimed at cognition of their surrounding world. The more diverse and intensive their search activity, the more new information the child gets, the faster and more comprehensively they develop (Volosovets et al., 2019).

The STEM approach in education will make it possible to personalize educational trajectories, to take into account personality characteristics and enable the learners' creative potential to unfold, laying the foundation for the digital transformation of their education.

The research tasks underpinning this discussion are:

- to analyze the conceptual framework of pre-school education in Russia;
- to define peculiarities of play activity in day-care centres;
- to define problems and promising ways of play activity development; and
- to reveal the influence of the quality of the educational environment and its developing psychological and pedagogical potential on the formation of children's personality.

3.2 The Conceptual Framework of Pre-school Education in Russia

In 2013, a new Standard for Pre-school Education was adopted in Russia (Federal Standard, 2013; Kudryavtsev et al., 2013). The implementation of the Standard involves the use of play in the educational process. The emphasis on play as a leading activity was recognized in the Russian system of pre-school education starting in the 1920s to 1930s with the works of Vygotsky (1931). However, this pre-school education practice has not yet received its conceptual substantiation.

The principle of leading activity has been thoroughly developed by Leontiev, Vygotsky's disciple, one among a number of researchers who has determined the form and content of Russian psychology. This principle says that the cognitive sphere and the psychological structure of the personality change in the process of the child's leading activities in each period of their development through building up new relationships, gaining a new type of knowledge and finding ways to obtain it. At present, Leontiev's activity approach to the study of consciousness and the psyche is being developed in pedagogical, age-related, social and other branches of psychology and has its followers in many countries of the world including Germany, France, Italy, Great Britain, the USA, among other countries.

Vygotsky's cultural and historical conception has become the methodological basis for substantiating play as pre-school children's leading activity. The main provisions of cultural-historical psychology are as follows: a qualitative change in human activity serves as the basis for human mental development; the main driving force of the child's mental development is education and upbringing; the initial form of activity is its expanded external (social, collective) implementation; psychological innovations stem from the interiorization of the initial form of their activity; interiorization acts as a constructive mechanism of human socialization that occurs in the course of cooperation, joint activities of the child and other people, which lead to the transformation of the world of culture/the world of "meaning"/into the world of personality/the world of "significance"/; various sign and symbolic systems play a major role in the process of interiorization; the unity of affect and intellect manifests itself in the interconnection and mutual influence of these sides of the psyche at all stages of the development and are important in human activity and consciousness.

Socially conditioned personality development, according to Vygotsky's conception, considers the social environment not as one of the factors, but as the main source and condition for the cognitive development of the individual. According to Vygotsky, the social development situation of a given age is a starting point for all dynamic changes that occur in the development during a given period. It completely determines the forms and the ways, following which the child acquires more and more new traits of their personality, drawing them from the environment as the main source of their development, in this way social phenomena become individual (Vygotsky, 1984, p. 262). Child development depends on two intertwining lines: biological and social. However, it is not a mere addition of one to the other as they have a different "specific gravity" in the development of different functions and at different age stages and are important throughout the whole ontogenetic development. Vygotsky made a great contribution to the solution of the problem of the learning and upbringing ratio by emphasizing the role of learning as the main driving force in the development of personality. Extremely important for educational psychology are the ideas of Vygotsky on higher mental functions, on the stages of language development and the functions of speech, on the zone of proximal development and scaffolding.

Given that in this situation children interact with their educational environment, they display the activity relevant for use of the opportunities provided by this environment and become real subjects of their own development, the subjects of the educational environment, and they do not remain the object dependent on the conditions and factors of the educational environment (Bayanova & Shishova, 2017; Shishova, 2017). In the late 1930s, Galperin formulated a thesis on the role and significance of activity in the mental development of the child, revealing the distinguishing features between the concepts of "education" and "activity". The development process, it was argued, occurs owing to the subject's own activity, while environmental factors are necessary conditions on which the individual identity of a person depends (Galperin, 1966).

Thus, play is able to activate a change in the child's activity, brings to the fore their interests and certain traits of behavior, accelerating their internalization. Moreover, play triggers children's emotions and intelligence. Various aspects of play and preparation for its implementation are described in previously published works (Gabdulchakov, 2011; Gabdulchakov & Shishova, 2017). The significance of play in pre-school and school age children was recognized by many Russian scholars and teachers of the twentieth century (Makarenko, 1987; Sukhomlinskiy, 1981; Zankov, 1975). However, in practice, cruelty and child abuse were an unofficial norm. They existed in the form of various punishments within the family and in kindergartens. Adults could, for instance, subject their children to corporal punishment, lock them up in a room, and deprive them of play. Only in 2013 did the Federal State Educational Standard for Pre-school Education (Federal Standard, 2013) endorse the special status of childhood and the emphasis on play activities.

The European system of pre-school education realized the significance of the play activity owing to the works of Vygotsky, and across Europe play was implemented in kindergartens much earlier than in Russia. Currently, play underpins the content and goals of instruction in pre-school institutions in many countries (Faulkner & Coates, 2013; Hoyte et al., 2015; Hunter & Walsh, 2014).

3.3 Methodology

Our research into the educational environment of early childhood in Russia is based on data collected in 16 pre-school educational institutions in the Republic of Tatarstan (part of Russia), which has a population of more than 3 million people. Among them, four preschool educational institutions are the best kindergartens, according to the results of the municipal rating ("On the rating of preschool educational institutions", approved by the Ministry of Education and Science of the Republic of Tatarstan, dated April 8, 2015). The rest of the subjects were selected from average kindergartens. The kindergarten groups were divided into two parts, based on the results of the municipal ranking. Group A included the best kindergartens and group B—average preschool educational institutions.

Two hundred and sixty-seven pre-school children from three to five years, and their respective mothers, adding a further 267 to the sample, and 33 pre-school teachers participated in the study, totaling 566 participants. For diagnostic purposes international criteria were used to assess the quality of pre-school education, namely, ECERS (Early Childhood Environment Rating Scale) as well as professional pedagogical expertise. In order to categorize the tasks according to the level of play development, the indicators of substitution, implementation of intentions and game interactions were analyzed, and to assess various aspects of the play activity, we used the experimental situation proposed by Smirnova et al. (2018). In this ascertaining experiment, an object environment was simulated in the playroom, after which the children along with the teachers were invited to free play in the room. The diagnostic task was to identify their ability to play independently, free from the suggestions of adults or images embedded in toys. The diagnostic situation did not provide for the active participation of an adult. Toys, carrying a certain image such as dolls, animals, soldiers, cars, for example, were not used and children were therefore left to play with polyfunctional, "open" materials, including fabrics of different textures, a roller made of fabric, ropes, ribbons, laces, elastic bands, small logs and sticks, wooden rings, chestnuts, fir cones, and cardboard boxes of different sizes. All these items were located in zones accessible to the children. Then 3–5 children were invited to the room, whom the adult suggested to play while he was busy with his own affairs, but if necessary, he could help. The time of observation for each subgroup of children averaged 60 min. The analysis included the following indicators: (1) the level of substitution (object, positional, spatial); (2) interactions (organizing and in-game); (3) and the game concept (the level of idea, its development, the implementation of the idea and its stability). These indicators were assessed in conventional points from 0 (complete absence) to 3 (high degree of expression).

According to Vygotskian cultural-historical theory, the key feature of play is the creation of an imaginary situation, i.e. the substitution of imaginary objects and events with real ones (Vygotsky, 2004). Therefore, the presence and level of substitutions in the game were considered to be the most important characteristics of a game story. We used ECERS to conduct the research, specifically ECERS-R which consists of seven subscales: space and furnishings, personal care routines, language-reasoning, activities, interactions, program structure and parents and staff (Harms, 2016). Below, and in relation to game substitutions, we present three sets of quantitative values for the indicators used in the study:

3.3.1 Object Substitutions

These are the use of some objects instead of others and the use of imaginary objects. This parameter was evaluated on the following scale:

0—no object substitutions;
1—the functional use of objects in the game—the use of toy copies or objects in accordance with their intended purpose (for example, sitting on a chair and stick or acting as sticks;
2—the use of substitutes based on their similarity to the object (a stick used as a thermometer or a tree);
3—the construction of game items (for example, a fishing rod created from a stick and a ribbon, a candy made from an acorn, foil and ribbons).

3.3.2 Positional Substitutions

This category of substitutions is concerned with replacing the self with another position or positional attitude in the game, which can be real (acting out the story without accepting a role, for example, "as if we were doing repairs," "as if we were moving"), role-playing or performing the part of a director. Positional substitutions were estimated as follows:

0—no playing position;
1—a real playing position;
2—a role-playing position;
3—a director's position.

3.3.3 Spatial Substitutions

This type of substitution means the creation and semantic differentiation of the play space. Making space meaningful and dividing it into zones according to the story indicates a high level of the play development.

The substitution of a real space by its simulation was rated according to the following scale:

0—space is not taken into account in the game;
1—the functional use of space elements (for example, carpets, and furniture);
2—the simulation of a play area (for example, creating a house, shop, cave with treasures) around which the game plot unfolds, other places are not indicated;
3—the semantic division of space into zones, among which not only houses and places of action are designated, but also additional spaces where the game action unfolds (for example, here is a dense forest, and there is a meadow with flowers, a bus stop, a road).

Using international criteria for assessing the quality of pre-school education, in this case ECERS (a scale of integrated assessment of the quality of education in pre-school educational institutions), makes it possible to obtain a comprehensive and differentiated picture of the quality of pre-school education and thereby gauge the extent to which it meets the specific requirements of the Federal State Educational Standard of Pre-School Education. This research, conducted in the Republic of Tatarstan, made it possible to obtain a comprehensive picture of the quality of early education and to correct, as necessary, the educational programs of pre-school educational institutions in a megalopolis with a population of more than one million people. The research was carried out in accordance with Code of Ethics of the Russian Psychological Society. All participants received an agreement for signing and an information sheet. Participants were free to leave the study at any time. The methods of mathematical statistics (descriptive, inductive statistics, analysis of variance (ANOVA), cluster analysis) and qualitative analysis were used to statistically process the empirical data obtained during the study. The calculations were performed by means of the specialized computer statistical packages Microsoft Office Excel 2010, IBM SPSS Statistics 23 for Windows.

3.4 Results and Discussion

In the first phase of the study, we conducted research into the main parameters of the educational environment of early childhood with the help of the ECERS scales for a comprehensive assessment of education quality. Table 3.1 presents the analysis of ECERS-R average scale values in Groups A and B.

The research results show that pre-school establishments create optimal conditions for the harmonious and all-round development of physical, personal, intellectual, cognitive, and emotional areas of the child's personality. To this end, they should base their activities on caring, developmental, and educational tasks, as well as on the integrity of the educational process owing to the integration of content and the diversity of children's activities along with continuous improvement of the educational environment. Pre-school institutions should also engage in comprehensive developmental and correctional work with preschoolers and health care professionals, such

Table 3.1 Analysis of ECERS-R average scale values in groups A and B

Indicators of early childhood environment rating scale	Group A includes the best four kindergartens	Group B average pre-school institutions: twelve kindergartens		
	Average value	Standard deviation	Average value	Standard deviation
Space and Furnishings	4.72	0.43	3.08	0.99
Personal Care Routines	4.54	0.09	3.29	0.84
Language-Reasoning	4.56	0.85	2.63	1.01
Activities	4.33	0.90	2.51	0.78
Interactions	4.95	0.72	33.58	1.16
Program Structure	3.92	0.88	22.49	0.73
Parents and Staff	4.25	0.41	33.33	0.59

as psychologists and speech therapists, to identify children, who need correctional and development aid, and promptly provide psychological and pedagogical support. The research found that despite the difficulties, the kindergarten staff was trying to create a challenging, hands-on-learning developmental environment, depending on the relevant activities in the group and the interests of the children. Most of the basic indicators were positively assessed. However, the analysis of educational environments in the observed groups of pre-school educational institutions demonstrated that the developing subject-spatial environment in Group B kindergartens was insufficiently intensive and not always available for independent use by children. Further, these twelve kindergartens often failed to create appropriate conditions for game playing and the motor, cognitive, research and creative activities of pre-school children. These educational environments were not aimed at supporting children's initiative and activities in gaining knowledge that contributes to revealing children's individual creative potential.

Fostering communication between children was rare and the teachers did not observe the balance between listening and speaking activities. Teachers rarely spoke with the children in Group B kindergartens about logical relationships and rarely encouraged children to reflect throughout the day. Many members of the staff did not have the required competencies. Thus, the conditions supportive of the development of children's coherent speech, their acquisition of lexical and grammatical categories in speech and logical thinking were unmet. Teachers did not encourage children to reflect and did not rely on current events and experiences to help them in the course of developing their concepts. Neither were the children encouraged to verbalize their thoughts or to explain their course of reasoning when solving problems. Some teachers were not aware that their great efforts to organize a good game for children often completely discouraged them from playing. Under tight external regulations by teachers, these games failed to promote freedom and self-realization in children. Pre-school and primary education teachers need to both understand the technology of game activities with appropriate didactic content and possess greater pedagogical skills. The children's daily schedule was often full of educational activities with little time and attention given to free play. With rigid regulations, classes were not initiated by the children themselves.

In Groups A and B, parents were involved in various forms of interaction: consultations, workshops, hands-on activities, based on a long-term planning. Pre-school educational institutions closely cooperated with their pupils' families. In these kindergartens, teachers used collective forms of work which engaged with the participating mothers through parent meetings, participation in 'a week of health' events, competitions, exhibitions of children's creative work and celebrations of festivals together with their children. The examination of the early childhood educational environment demonstrated that all pre-school educational institutions in the sample had different opportunities and developing potentials.

As a criterion indicator, we considered the presence or absence of conditions and opportunities for developing the child's activity (or passivity) and their personal freedom (or dependence) in each educational environment. The best pre-school educational institutions aimed to ensure individualization, to support ideas, to develop

Table 3.2 The results of the cluster analysis based on the sample of sixteen pre-school educational institutions (average values of indicators-criteria)

Indicators	Culture			
	Cluster 1 (31%)	Cluster 2 (37%)	Cluster 3 (12.5%)	Cluster 4 (18.8%)
	Stimulating-Productive Educational Environment	Learning Environment	Heuristic Educational Environment	Creative Educational Environment
Subject-spatial content of the environment	3.8	4.1	4.8	5.2
Time management	3.3	1.8	4.4	5.5
Adult/child interaction	3.1	3.5	4.7	5.4

creative thinking and to promote the individual development of each child. Whereas statistically, average pre-school institutions were oriented towards preparation for schooling, discipline, and their educational process was strictly regulated.

In order to confirm this thesis, we conducted a mathematical analysis of the data through cluster analysis using diagnostic indicators as criteria for classifying the subject-spatial content of the environment, time management, and adult/child interaction. To analyze the data, we used a hierarchical cluster analysis and the Complete Linkage method, which makes it possible to isolate compact clusters consisting of the most similar elements. According to the results of the cluster analysis, we identified four distinctive modern types of the early childhood educational environment with different variants of indicator combinations. Then, for each group, average values were calculated, allowing us to give a meaningful characterization of the identified types. Let us consider each group separately. Table 3.2 presents the average values of indicators that act as classification criteria for the cluster analysis, to sample the 16 pre-school educational organizations. Analysis of the obtained results allowed us to distinguish types of educational environments depending on the quality of pre-school education, as determined by the following positions:

- The ways the child realizes their right to individual development in accordance with age possibilities and opportunities provided by the institution;
- The ways the pedagogical process is organized in the kindergarten;
- The conditions created in the pre-school educational institution (the educational environment focused on the self-worth of pre-school childhood and the positive microclimate in the team); and
- The system which stimulates qualitative work and creative activities by the staff and the head in the pre-school educational institution.

Thus, the modern educational environment of early childhood can be placed in one of the four main types:

1. "*Stimulating-Productive Educational Environment*" This type of educational environment is characterized by the child's activity or passivity within the framework of a given or initially found way of acting. The child's activity is determined by an external stimulus. In this context the child lacks initiative and independence as the activity is dominated by an external activator. In such an environment, children lack agency, they are dependent and passive, not feeling themselves to be the subjects of their own development. As such, educational opportunities in this environment are realized through external influences and the influence from the pedagogical staff.
2. "*The Learning Environment*" Excessively intensive educational activities, rigid regulation of the educational process, lack of individualization and lack of time, define this type of learning environment. The educational process is carried out in disciplinary school-lesson form. The child is an object of influence exerted by an adult, whose position is that of a mentor, not a partner; initiative and types of activities rest entirely with the teacher.
3. "*Heuristic Educational Environment*" This learning environment is characterized by the child's discovery and acquisition of knowledge as a result of their own activity, it is not simply passive mastering of knowledge and stimulation introduced by external factors. Heuristic education has an accompanying character. Teachers ensure the expansion of educational spheres in each child, that is, the emergence, formation and development of personal educational products, as well as the subsequent comparison of these products with their cultural counterparts. Specially organized heuristic educational situations provide experience of the child's own creative activities, enabling pre-school children to reproduce cultural patterns of life and activity. The heuristic environment is rich in positive emotions and offers a field for the child to manifest their own initiative and independence.
4. "*Creative Educational Environment*" This category of learning environment promotes the development of the child's activity, their ability to create something new, to transform reality, to develop social relations, and their ability to lead their own self-development as the creation of themself. The child learns to independently set goals and realize their own plans. In this type of environment, the discovered empirical regularity is not a heuristic one, but an independent problem. This type of environment is characterized by the absence of a rigid regulatory system and is focused on the individual development of the child revealing their own creativity. In the best pre-school educational institutions, two types of environment were found: "Heuristic educational environment" and "Creative educational environment". In the average kindergartens the following types of environment were found: "Stimulating-productive educational environment" and "Learning environment".

We carried out a comparison of mean values to verify the differences in the degree of manifestations of the children's play activity in the educational environments of differing quality (the one-way analysis of variance was used, $p < 0.05$), as a result of which reliably significant differences were revealed according to the following diagnostic criteria: "substitution" (F = 25.72); "interaction" (F = 29.3), "game design" (F = 13.76); "initiative' (F = 5.25). Thus, veracious differences were found in the levels of play development in modern preschoolers, studying in the best and average pre-school educational institutions.

The issue of play is one of the most acute problems in modern pre-school pedagogy. Its significance for child development is recognized by almost all professionals. It has been proven that play activity is of decisive importance for the formation of the main new formations in pre-school childhood such as voluntary behavior, creative imagination, and self-awareness. It is play that is the content of preschoolers' communication, it develops children's interpersonal relationships and their communication skills. However, despite these generally accepted and unconditional arguments, play is increasingly being pushed out of the pre-school education system. In the daily routine of children's educational institutions, there is virtually no time left for free play. Play development has not become an independent task of pre-school education. As a result, the level of modern preschoolers' play development is dramatically declining, which is confirmed in numerous studies by Smirnova (2013, 2018). The study of Smirnova's, in which three-to-five-year-old children from Moscow pre-school educational institutions participated, showed that a low level of play development (such as manipulations and monotonous actions with toys) was observed in 60%. A high level, which is characterized by expanded role relationships and the creation of a play space, was recorded only in exceptional cases (in 5% of children). Thus, older preschoolers' play activities are mostly at a low level of the development.

3.5 Conclusion

We have obtained results, based on the cluster analysis, indicating four types of educational environments with different learning opportunities that are found in preschool institutions in Russia. A "stimulating-productive educational environment" and a "learning environment" contribute to the development of child passivity and dependence, while a "heuristic educational environment" and a "creative environment" both of which are characterized by their focus on the free development of active children reveal their personal potentials.

The results of the correlation analysis demonstrate that the quality of preschoolers' education affects the development of the child's play activity in relation to their: (1) ability to play independently, free of adult suggestions; (2) chosen features of substitution (object, positional, spatial); (3) interactions (organization and in-game); and (4) game idea (the level of the idea, its development, its implementation, and stability). The development of a child's play depends also on certain indicators of teachers' professional skills in respect of their ability to: (1) ensure self-realization of children's personality; (2) practice empathy; (3) create a reflexive field; (4) use the reserves of children's unconscious activity; (5) use an individual approach to children; and (6) associate communication with children's real needs. Thus, in the course of our study, it was shown that the educational environment contributes to the effective formation of pre-school children's play activity. The effectiveness of the pedagogical process, as an environment in which the child exists, can be of various types: supportive, developing, rich, comfortable, or, in some cases, neutral. Children's game arises from the child's living conditions in the environment. In this case, play does not disconnect people, on the contrary, it unites the "adult world" and the "world of children", ensuring the creation of conditions for their mental development and "growing up", thereby preparing the child for their future life.

STEM education is child-centered, there is no strict regulation of children's knowledge, no subject centrism in teaching; it is based on the principles of developmental education and Lev Vygotsky's scientific thesis that properly organized learning has the development-generating effect. Thus, by modeling intellectual-developmental situations and by involving children in various types of research and scientific-technical creative activities, the teacher creates conditions for developing a personality prepared to live in modern realities (Figs. 3.1, 3.2, 3.3, 3.4, 3.5). Preschoolers' positive personal development most successfully occurs in conditions when an environment is capable to encourage children to manifest their agency and initiative. In this case, it provides opportunities for revealing children's inner potential, for developing their subjective nature and creative thinking, and promotes their individual development. Conversely, extremely rigid norms, lack of variability and support for children's individuality led to a decrease in their cognitive interests, primitivization of their play activities, a limited range of interests, etc. The data obtained can serve as reference points for transformation of the pre-school education system.

Fig. 3.1 STEM lessons 1 engaging young learners and sample materials

Fig. 3.2 STEM lessons 2 engaging young learners and sample materials

3.6 Recommendations

Our experience shows that in the course of organizing STEM games, the teacher should take into account:

– the resilience of the subject-development environment: this environment should ensure the comfort and success of children's play activities, conditions for specific types of these activities and the development of children's intellectual abilities, their critical thinking, the formation of their teamwork skills in the process of cognitive research, and their scientific and technical creative work;
– that the child's immersion in the STEAM environment can begin with designing activities, within which preschoolers, using fragments of various materials (wood, paper, metal, plastic), will acquire elementary technical skills and abilities, and get acquainted with the basics of engineering. Various construction kits will help teachers develop children's creativity and spatial thinking. The solution line should include specialized kits for learning how to do mathematics, outdoor activities and make simple engineering projects;
– preschoolers' cognitive activity integration: the child's cognition during the game should be integrative (interdisciplinary), based on different areas of natural sciences, on engineering creativity, mathematics, and digital technologies. This

Fig. 3.3 STEM lessons 3 engaging young learners and sample materials

Fig. 3.4 STEM lessons 4 engaging young learners and sample materials

integration involves the use of the project method based on cognitive and artistic search with a specific real product as a result of the children's activity;

– the psychology of speech activity in play: the result of play (cognitive-research) activity should be "trapped" in the child's memory and become his own achievement; and
– the focus on the cognitive interests of the child (creativity cannot be imposed from the outside, it is based on the child's internal needs).

Fig. 3.5 STEM lessons 5 engaging young learners and sample materials

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Chapter 4
Young Children's Free Play in Nature: An Essential Foundation for STEM Learning in Germany

Lara E. Weiser

Abstract This chapter focuses on the impact of different outdoor settings on young children's free-play activity as a basis for early STEM education. The free play of three to five-year-old children in western Germany was investigated over several years in different outdoor settings such as natural areas and playgrounds through participant observation. The data were analysed using qualitative content analysis to identify and examine different types of play (e.g. creative or object play). The results show that different outdoor environments differ in their potential to promote STEM-related play types. Areas such as woods were shown to offer children a variety of natural materials that they could freely integrate into their play encouraging them to engage in creative, social, and complex activities, such as building projects. Playgrounds were less beneficial in promoting STEM-related play types, as the playground equipment often limits what and how children can play leaving little room for their own ideas.

Keywords Free Play · Playing Outdoors · Natural Environments · STEM Education in the Early Years

4.1 Early Childhood Education and Its Social Significance in Germany

Kindergartens in Germany have an educational mission. This means that they are obliged not only to care for the children throughout the day, but also to support them in their healthy development in a holistic way. Early childhood education is of great importance both for the individuals themselves and for society as a whole. Kindergartens are considered an indispensable part of the public education system. However, attending a kindergarten before entering school is not obligatory (www.kita.de). Normally, children are required to attend formal school from about the age of seven years.

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Although the individual kindergartens have great freedom in their daily work in terms of organization and content, there is a common framework plan which all federal states follow. The framework stipulates that individual kindergarten facilities should support children in their development in a holistic and life-oriented manner, taking into account the findings of developmental psychology. The children themselves and their parents are also to be included in this process. The focus of the pedagogical work should provide opportunities to strengthen individual competences, supporting the children's urge to discover while educating them in values. In addition, the children should get to know and be able to use set methods and tools of learning and be supported in their adaptation to the world in social contexts (Decisions of Kultusministerkonferenz, 2004).

In Germany, a kindergarten is an institution in which children are looked after by qualified pedagogical staff. Kindergarten teacher is a state-certified profession. The requirements for the use of this professional title is usually a two to four-year apprenticeship at a technical school such as a vocational college. The prerequisites for the start of the training vary in the individual federal states. In some federal states, the profession can also be learned at a university (www.erzieherin.de). The profession is mostly practised by women. Kindergarten teachers earn considerably less than teachers in primary and secondary schools. The professional title does not contain the word 'teacher'. The actual job title is '*Erzieher',* meaning 'educator'.

Attending a kindergarten in Germany is not free of charge. The cost parents must pay for their child to attend kindergarten depends on the specific facility. Often the contribution that the parents are required to pay is dependent on their salary which is determined by the *Trägerschaft* or sponsorship of the facility through which it is managed. The *Träger* or sponsor of a kindergarten provides rooms and financial means and is the employer. In addition, the *Träger* is the contact person for all organizational matters and professionally supervises the pedagogical orientation of the kindergarten. The *Träger* of most kindergartens is the city or municipality. Churches, associations, or even companies can also be sponsors of a kindergarten (www.kita.de). Regardless of who the *Träger* of a kindergarten is, the facilities are subsidized by the state. All kindergartens must therefore follow certain state guidelines.

In Germany there is no curriculum for the educational work in kindergartens. The educational orientation is therefore decided primarily by the specific *Trägerschaft*. Parents, consequently, need to look at the pedagogical concepts of the various kindergartens in their area before enrolling to ensure a good match of educational goals and values. Basically, parents have the choice of which kindergarten they want to register their child in. However, especially in large cities, it is sometimes difficult for families to obtain a place in a kindergarten for their child. Due to the lack of childcare places in kindergartens, for many parents the pedagogical orientation or sponsorship is of secondary importance when choosing a kindergarten and they usually take the first place that is offered to them. However, this availability varies in smaller cities and in rural areas. Early education institutions play a central role for the compatibility between family and work.

The pedagogical work of kindergarten teachers is characterized by the so-called *Situationsansatz* or situation approach. The kindergarten teachers observe the children and their development and choose appropriate opportunities and methods to individually accompany and support their personal development. The catchment area of the kindergarten and the social background of the families also determine the professional work in kindergartens. Thus, whereas some institutions place an emphasis on language, social, or cultural education, other institutions focus on promoting early STEM education. Initiatives such as the foundation *Haus der kleinen Forscher* or Little Scientists' House, offer support to teachers and kindergartens in the field of early STEM education. Their platform enables educators to obtain information, purchase pedagogical materials, and handouts as well as the participation in further training.

Interestingly, although the German term kindergarten has established itself in the English-speaking world, it is hardly ever used in Germany. The term kindergarten was classically used to describe institutions in which children from three to six years of age were looked after before they went to school. Today, the term ***Ki**nder**ta**gesstätte*, or day-care centre, often abbreviated as **Kita**, is more frequently used. This term is a synonym for kindergarten although it also includes the care of children under three years of age or those of primary school age. In German, the term kindergarten is still used when the children are only looked after in the mornings and are between three and six years old. Since kindergartens today usually offer all-day care and take in children before they are three years old, the term *Kindertagesstätte* has become more common to describe a pre-school institution.

4.2 Learning Processes and Child Development in the First Years of Life

In early childhood, children show a great thirst for action and curiosity, and want to explore their environment independently (Lück, 2003). For young children, environmental conditions are not yet self-evident as connections must be discovered. Here, children use all their senses. Perception is an active process in which the child experiences the environment with its whole body and makes itself familiar with the world (Zimmer, 2019). Concrete experiences with objects and the environment are central prerequisites for the development of cognitive structures in early childhood (Piaget, 1964). These sensual experiences of childhood remain strongly anchored even in adulthood. However, although sensual perception seems so typical and natural for children, senses need practice to become sensitive (Zimmer, 2019).

After the exploration of their immediate environment in infancy, the exploration of the animate and inanimate environment follows with increasing linguistic and motor skills (Fthenakis et al., 2009). At the age of around three to five years children have developed their motor and language skills to such an extent that new fields of activity become available to them. These skills enable them to understand much more and ask verbal questions. Therefore, this expansion of linguistic and motor skills also launches an expansion of the child's world of imagination (Erikson, 1994).

For STEM education, the years between three and five are extremely important and interesting, because children in this phase of life develop a special interest in all phenomena of the animate and inanimate environment. Also, in the first years of life, a child's developmental stages lay the foundation for their perception of the world in which they are living, their cognitive structures, and their modes of action (Knauf, 2008).

When exploring their environment, children use a variety of approaches that show some similarities to those used by scientists such as observation and classification (Tunnicliffe, 2020). The so-called children's science (Osborne et al., 1983) takes place in children's engagement with the world in which they live and to which they give meaning through their actions, experiences, current knowledge, and language. This sense-making takes place through the search for similarities and differences, through the organisation of events and phenomena, and through the observation of their environment. In this way, children collect data in a certain way, look for explanations, form models and make predictions (Osborne et al., 1983). Their great curiosity and their implicit desire to understand their living and inanimate environment is what drives children to explore their environment actively, curiously, and generously, albeit more unsystematically and less stringently than scientists (Knauf, 2008).

This early learning is directly linked to the application of newly acquired knowledge and is also referred to as original learning (Ansari, 2009). Such learning is characterised, for example, by the drive to imitate, the urge for independence, the need for intensive physical experiences, the desire for social interactions, and a willingness to practice (Ansari, 2009).

4.3 There Is No Such Thing as *Just P*laying

Taken as a whole, educational institutions for children tend to focus more on encouraging *learning* than on encouraging *play*. While learning tends to be viewed as something initiated by adults, play is more associated with the children initiating it themselves (Pramling et al., 2008). Although the pre-school area is seen more as a place of play and schools more as places of learning, even in early education a distinction is often made between the playing and the learning child, which means that these seemingly different activities are assigned different spaces and times (Pramling et al., 2008). This separation is also reflected in the daily language used by adults who can be heard saying: '*later you'll have time to play, now we are learning*' or '*they are just playing*'. However, play in early childhood and beyond should not be seen as a marginal phenomenon, but as a driving force of the healthy physical, mental, and emotional development of children.

Play is the main profession of children: For a healthy development of their body, mind, and soul, children should have the time for free play at least seven to eight

Table 4.1 Hughes 'taxonomy of play' (1996)

Play type
1. **Symbolic play**—when a stick becomes a horse
2. **Rough and Tumble play**—play fighting
3. **Socio-dramatic play**—social drama
4. **Social play**—playing with rules and societal structures
5. **Creative play**—construction and creation
6. **Communication play**—e.g., jokes, facial expressions, or acting
7. **Dramatic play**—performing or playing with situations that are not personal or domestic
8. **Deep play**—risky experiences that confront fear
9. **Exploratory play**—e.g., manipulating, or experimenting
10. **Fantasy play**—rearranges the world in the child's fantastical way
11. **Imaginative play**—pretending
12. **Locomotor play**—chasing, swinging, climbing, i.e., playing with the movements of their body
13. **Mastery play**—e.g., lighting fires, digging holes, or games of elemental control
14. **Object play**—playing with objects and exploring their uses and potential
15. **Recapitulative play**—carrying forward the evolutionary deeds of becoming a human being, e.g. dressing up with paints and masks, damming streams, or growing food
16. **Role play**—exploring other ways of being, e.g., pretending to drive a bus or be a policeman, or to use a telephone

hours per day (Krenz, 2001). Playing is children's most important activity and their primary language which has similar patterns all over the world (Wilson, 2010). Based on Wilson's work (2010), play can be described as a set of behaviours that are freely chosen, personally directed, and intrinsically motivated. Hughes (1996) compiled a 'taxonomy of play' in which 16 different types of play were differentiated (see Table 4.1).

More important than the differentiation of different types of play is the role of play as an engine for children's development. Through play, children develop important skills including social and cognitive skills, for instance, fantasy play provides children with the possibility to abstract from the real world and role play allows them to reproduce and train for the social rules of everyday life (Leuchter, 2013).

Play has a profound impact on children's development (Wilson, 2010). While playing, children can overcome anxiety and explore 'unwelcome' feelings like aggression. Moreover, based on the theories of Erikson (1994), and from the psychoanalytic point of view, play means the development of children's personality. Through playing, children become familiar with their social and natural environments (Richard-Elsner, 2018). Play is also the starting point for learning science and engineering in the early years (Tunnicliffe, 2015). Therefore, children do not *just* play. Play supports children's healthy development and they use it unconsciously to interpret their world. However, into which 'world' are children in Germany and elsewhere born today and what does the society in which they have to find their way look like?

Technology, scientific topics and information technology as well as digital applications and services shape our everyday life—even for those who do not work in a STEM profession. STEM topics can be found everywhere and children encounter them in their daily lives. In order to support young children in Germany at an early stage to find their way in this reality and to expose them to new opportunities and perspectives, early STEM education plays a major role and is supported by the *MINT Aktionsplan des BMBF* (2019), a STEM action plan of the German Federal Office for Education and Research.

If, as was suggested above, each of the 16 forms of play has its own function which promotes the positive development of children, it could be argued that children should be able to play the full range of types of play (see Table 4.2 for an expanded summary of play types, activities in playgrounds, and activities in natural environments of the children participating in this study). With regard to early STEM education, many of the play types described by Hughes (1996, see Table 4.1) seem particularly interesting. Let us imagine the following scenario: In a combination of social-, creative-, and exploratory play, children build a hut together using sticks and other materials. They explore the materials and test which ones are best suited as foundation walls. Which ones are stable enough? Which ones are suitable for covering the roof? What influence does the ground have? Basic laws of physics are experienced first-hand and lead to frustration or feelings of success. Agreements are made during the construction process. Conflicts arise which have to be negotiated and resolved. Creative play, exploratory play, social play, locomotor play, and mastery play, for example, allow children to gain important experiences at an early age, which could form a sound basis for the further development of specialist and practical knowledge in the STEM areas. Are children given the environments to pursue the full range of play types on which they can later build their future knowledge? The play of children has changed through the influence of modern world where traffic, a lack of natural areas, the media, time pressure, or the anxieties of parents all restrict children's open spaces and free play in Germany (Richard-Elsner, 2018). While certainly not all changes synonymously mean a worsening of children's play conditions, a huge gap in children's developmental play may emerge from the fact that children nowadays often lack of chances to play outdoors.

4.4 Using Play's Potentials for Early STEM Education—Does the Setting Make a Difference?

Nowadays, at least in some parts of Germany, many children spend a lot of their time indoors and often have fewer first-hand experiences due to enhanced media use (Zucchi, 2002). However, play in general, and especially playing outdoors, are

Table 4.2 Play activity summary

Play Type	Activities in Playgrounds	Activities in Natural Environments
1. **Symbolic play**—when a stick becomes a horse	–	Pretending that natural materials are tools or weapons (but at the same time they become real tools and weapons, see creative and recapitulative play)
2. **Rough and Tumble play**—play fighting	Scrambling	Scrambling Fighting with sticks and branches
3. **Socio-dramatic play**—social drama	–	–
4. **Social play**—playing with rules and societal structures	Playing football	Giving each other presents like fruit, sticks, leaves, or nuts and exchanging them
5. **Creative play**—construction and creation	Digging tunnels and holes in the sand (sandbox) Building sandcastles (see also mastery play)	Making tools such as rakes or shovels with stones and sticks Building huts from sticks and branches (see also recapitulative play) Making pictures and sculptures on the floor from natural materials such as moss or small sticks
6. **Communication play**—e.g. jokes, facial expressions, acting	Fooling around Telling jokes Making funny/alternative movements	Fooling around Telling jokes Making funny/alternative movements
7. **Dramatic play**—performing or playing with situations that are not personal or domestic	–	–
8. **Deep play**—risky experiences that confront fear	Jumping down from the climbing frame	Jumping down from elevations/rises Approaching slopes Touching objects such as plants or parts of plants or animals that are classified as potentially dangerous

(continued)

Table 4.2 (continued)

Play Type	Activities in Playgrounds	Activities in Natural Environments
9. **Exploratory play**—manipulating, experimenting	Breaking up or throwing sticks and stones on the climbing frame	Throwing sticks, stones, and other objects into trenches, holes, and water Breaking up sticks and branches on rocks and trees Letting leaves and soil fall/ripple from hands Breaking sticks with feet and arms as natural materials like fruit, flowers, or leaves break apart Peeling fruit and nuts (see also object play)
10. **Fantasy play**—rearranges the world in the child's fantastical way	–	Fairies, dwarves, and other fantasy phenomena are suspected and sought in caves, streams, or other places Searching for dinosaur tracks
11. **Imaginative play**—pretending	Riding imaginary horses Playing a role model/hero like famous athletes or fictional characters from tv series, radio plays or books (see also role play)	Hunting imaginary animals like wild boars (see also recapitulative play)
12. **Locomotor play**—chasing, swinging, climbing, playing with the movements of their body	Playing catch Climbing, balancing, and swinging on the climbing frame Playing with the movement of their bodies	Playing catch Playing hide and seek Climbing and swinging on trees Balancing on stones, roots, trunks, and branches Climbing up the slopes and sliding down Playing with the movement of their bodies
13. **Mastery play**—lighting fires, digging holes, games of elemental control	Digging tunnels and holes in the sand (sandbox) Building sandcastles (see also creative play)	Digging in the ground, making furrows, and piling up soil Playing in water, retaining water

(continued)

Table 4.2 (continued)

Play Type	Activities in Playgrounds	Activities in Natural Environments
14. **Object play**—playing with objects and exploring their uses and potential	Using toys such as balls, jumping ropes, sandbox toys and vehicles such as tricycles and bobby cars	Playing with plant parts such as leaves, fruit, or nuts and other natural materials like stones Collecting nutshells, leaves, sticks, fruit, and other objects based on certain criteria (e.g. size, similarity) Peeling fruit and nuts Letting natural materials and other objects float
15. **Recapitulative play**—carrying forward the evolutionary deeds of becoming a human being, e.g. dressing up with paints and masks, damming streams, growing food	–	Making tools such as rakes or shovels with stones and sticks Building huts from sticks and branches (see also creative play) Damming streams Planting seeds Building a home for animals Collecting natural materials that are classified as potentially edible, preparing, and eating them in a playful way (often combined with the question of whether natural materials are toxic and/or dangerous) Hunting of fictitious animals like wild boars (see also imaginative play)
16. **Role play**—exploring other ways of being, pretending to drive a bus or be a policeman or use a telephone	Riding imaginary horses Playing a role model/hero like famous athletes or fictional characters from tv series, radio plays or books (see imaginative play)	Riding imaginary horses Playing as a role model/hero like famous athletes or fictional characters from tv series, radio plays, or books (see imaginative play)

very beneficial for children's all-round development enabling them to gain first-hand experiences about the physical and, in particular, the natural world (Huggins & Wickett, 2017). Outdoor settings allow and support aspects that are vital for children's development such as learning through movement which is less easy to provide indoors (Huggins & Wickett, 2017). Ethnographic research shows that playing outdoors has played a major part in the history of humanity and remains a natural component of childhood in hunter-gatherer societies (Richard-Elsner, 2018). However, are there any differences between various outdoor settings regarding their potential to support STEM learning in the early years?

Natural areas such as forests and woods provide a rich environment offering stimuli for the emotional and cognitive growth of children since they provide both new and constant phenomena (Gebhard, 2014). Furthermore, natural environments represent dynamic and rough spatial conditions as well as natural obstacles that challenge children and their motoric activity and can, for instance, have a significant impact on children's balance and coordination abilities (Fjørtoft, 2001). Outdoor learning offers great potential for Early Years science and technology. For example, children can find natural materials like leaves and sticks, explore "messy" objects and phenomena like soil more freely, connect with nature, and develop an appreciation for it. These frameworks offer children, for example, the opportunity to improve their designing and making skills or to improve their process and thinking skills, which are an important basis for engaging in scientific and technological enquiry (Earle & Coakley, 2019). Reidl et al. (2005) investigated the differences between free play in playgrounds and free play in natural areas and their impact on children's play in general. The study showed that the free play of children in natural areas is more social, complex, concentrated, and creative compared to free play in playgrounds. In addition, children showed more interest in their environment while playing in natural areas and reported more enthusiastically about their activities. The children created their environment in natural spaces in an active and planned manner and seemed to be more absorbed in their play than children in playgrounds. In addition, nature-based play areas seemed to allow activities for different age groups (Reidl et al., 2005). The fact that settings close to nature seemed to promote behavioural aspects such as creativity, social learning, and the focused examination of objects, living spaces and creatures in a playful way offers potential opportunities for the promotion of early STEM education.

4.5 Methods

In order to investigate the special potential of natural outdoor settings in connection with early STEM education, the following research question arose from previous considerations: Which types of play do children of kindergarten age (three to five years) show during free play in natural areas compared to play in playgrounds?

The answer to this question can provide a more precise picture of the differences in the potentials of the different settings. This in turn provides more detailed information on how environments need to be designed in order to promote STEM learning in the early years through free play.

In this study, the play behaviour of children aged between three and five years in two kindergartens in an urban area in western Germany was studied in various outdoor locations where observations took place during the everyday programme of both institutions. The groups of children were therefore consisted of participants who already knew each other well. Excursions to natural outdoor environments were accompanied by the kindergarten's educational staff. The data set contained N=17 observations (3–4 h each) of children's free play in natural areas such as meadows and forests and $N = 11$ observations (2–4 h each) in the kindergarten's playgrounds. To focus the observations, Hughes (1996) taxonomy of play (see Table 4.1) was used.

Originally, the data set also contained additional observations of the play behaviour of primary school children aged six to eight years in places close to nature and in their schoolyards. These data were omitted from this chapter in order to focus on the pre-school area. This is noted to emphasize that the analysis and interpretation are based on an even larger set of data—so that experiences and impressions could be collected which enriched the analysis as a whole.

The method of participant observation (Lüders, 2000) was chosen to enable a trusting relationship with the children and kindergarten teachers to be established over time. This method intended to ensure that the children and kindergarten teachers were not disturbed by the researcher's presence and that the children included her in their play activities or reported to her about such activities. The cooperation with the institutions continued for a period of one to two years. The observation data which included reported observations, background noises, and conversations, were recorded using an audio device and then transcribed. The data were analysed using qualitative content analysis (Mayring, 2010) and by taking into consideration Hughes's (1996) taxonomy of play. The respective characteristics of the different play types were further differentiated in the course of the data analysis (see Table 4.2).

Situations of free play were observed. This means that the adults did not directly control the children's play through suggestions or instructions and the children determined the type of play themselves. The children also chose with whom, with what, where, and how they wanted to play as well as for how long they were occupied in a specific play type. It should be noted critically that the kindergarten teachers had an influence on the children's play behaviour simply by choosing the playground or the natural environment and by their mere presence. The composition of the children's groups was also influenced by the institutional framework.

During free play the children were observed by the researcher, a scientist and science educator, and the kindergarten teachers. The group size was nine to 13 children per observation. All children were familiar with the presence of the scientist who had known the children for several weeks to months prior to the observations for the studies. This made it possible to compare their playing behaviour in the different play areas and to increase the well-being of the children, and kindergarten teachers, in the situations observed. As the children usually immersed themselves in their play during free play, they often followed different types of play for many minutes, usually at least ten to15 minutes. The relatively small change between different types of play and the moderately small total group size facilitated the observation of the children.

It should be noted, however, that the taxonomy of play, like any theoretical construct, attempts to provide a template for complex situations of daily life. In the reality of children's play, there is often no clear assignment to just one type of play, but rather various mixed forms. This concerns play types like imaginative play, role play or creative play, and mastery play (see Table 4.2). The assignment of the different types of play also represents the subjective interpretation of the scientist. However, the underlying theory, the elaboration, and application of a system of criteria and rule-guided categories and the reflection of her own interpretations with the educational staff of the institutions serve to objectify this process while also increasing the transparency and comprehensibility of the analysis process and findings.

Qualitative content analysis was applied to the transcribed observations. The texts were read by the scientist and marked with the analysis software MAXQDA whenever a text passage matched the criteria of pre-defined codes as shown in the two examples below. By coding the text passages relevant to the research question, the data was gradually structured in terms of content. In concrete terms, this meant that the children's free play, guided by the defined criteria, was assigned to an individual or several categories corresponding to the various play types. This approach resulted in theory-based and criteria-based lists of all observed play types of the children in the different settings. By structuring the content, it eventually became clear in which play types the children had engaged in the sense of the underlying theory and through which concrete forms of action they appeared. The theory could therefore be further differentiated on the basis of the study presented here (see Table 4.2). It should be noted that not only the application but also the development and refinement of the category system itself is an important part of the analysis process of a qualitative content analysis.

To illustrate the process of qualitative content analysis (Mayring, 2010), two examples are provided. For each category, i.e. for each play type (see Table 4.1), a description is given that enables the distinct categorization of the coded text passage according to a pre-defined rule. These rules for each category were developed, evaluated and further refined during the analysis process. Next, a data example is provided to show a text passage that was coded into this category according to its definition. The children's names were anonymized but corresponded to the gender of the child.

Example 1: Mastery play—lighting fires, digging holes, games of elemental control

Coding for passages/observations in which it becomes clear that a child is dealing playfully with the elements air, fire, water, and soil.

> e.g. Lotte, Maya and Amal stand with their bare feet in the stream. Between several large stones the water continues to flow in a concentrated way. The children use their hands and feet and jam the water between the stones alternately and in different places and release it again.

Example 2: Deep play—risky experiences that confront fear
Coding for text passages/observations that make clear that the children playfully dare to take personal risks and test their emotional and physical limits in (potentially) dangerous situations.

> e.g. Ruben and Max are standing in a clearing on the edge of a slope. From here, the path descends about four metres steeply into the stream bed. One after the other, the boys take small steps and make their way towards the slope and every now and then jump back a few steps. Then they look at each other laughing and approach the slope again.

The assignment of the observations to the different categories finally enabled data-based statements to be made about which play types were engaged in by the children at the different locations. In addition, the categories provided a structured insight into the concrete form of the individual play types and the variance of their execution at the different locations.

The results are summarized in the following section and presented in condensed form in Table 4.2. The activities shown in the table were observed at least three times. Individual cases (<3) were not included in Table 4.2. The decision that activities had to occur at least three times for inclusion in Table 4.2 was made at the end of the data analysis. This number was considered to be an appropriate value in relation to other play activities and served to focus the data.

4.6 Findings

In accordance with Reidl et al. (2005), the data analysis showed that children played differently in playgrounds compared to unstructured natural areas as these environments provided different potentials for play behaviour. These differences applied in particular to types of play which have a close connection to STEM learning. The differences seemed to result especially from the objects, variety of surfaces and materials, and other spatial conditions freely available to the children. It could be seen that children in the playgrounds overall showed just slightly fewer types of play than in natural areas. What seems more remarkable, however, is that the variability in the exercise of the different types of play is higher in natural areas (see Table 4.2).

With regard to STEM learning, it was observed that the children carried out activities related to STEM learning more often and more intensively in the natural environments. This observation applied, for example, to the playful examination and manipulation of objects and phenomena. The children examined objects intensively for their properties such as their surface, size, or material. These criteria guided their use: For example, large, stable branches were used for the walls of a hut while soft materials were chosen to create a cushion for a spider. In addition, the children actively, systematically, and creatively designed their environment in natural settings by building huts, laying out 'fields' or building dams, for example.

The exact type of play chosen by the children in the different places seemed to be mainly influenced by the possibilities it offered them (Fig. 4.1). It was observed that

Fig. 4.1 While playground equipment encourages role-playing, for example, it often leaves little room for creative use or modification. Natural materials such as leaves or sticks can be found in playgrounds, but in less diversity than in undesigned spaces such as forests or fallow land. Playgrounds also seem to take into account the needs of adults, as they are often enclosed by fences and have benches on all sides so that children can always be watched and supervised while playing

children often exploited the special potential of the respective place. In playgrounds as well as in natural spaces, there are few types of play that can be played anywhere, regardless of the space or the material available, such as social-, communication-, and socio-dramatic play. However, the children in both settings spent a considerable amount of time playing in groups, talking to each other, exchanging ideas, and being silly with other children.

Play types that required various materials or a specific setting, such as object-, creative-, exploratory-, locomotor-, or mastery play, on the other hand, were exercised intensively. This was especially true for play in natural environments. The play types mentioned were practised here in a particularly wide range of activities. This may have been due to the fact that the natural areas visited contained a large number of different (natural) materials, surfaces, and landscape elements such as slopes or streams, which the children could incorporate into their play freely. In addition, natural spaces often offered more opportunities to actively and creatively shape the environment.

On playgrounds, there were fewer materials lying around that could have been included in the play activities. Moreover, playground equipment was mostly firmly bolted and purpose-built, so that there was little room for changes and creative use. Natural areas such as forests gave children many opportunities for change by building with natural materials, taking apart objects such as dead tree trunks or damming up water. The strongly predetermined structures of the playgrounds also had a restrictive effect on the exercise of locomotor play by providing children with clearly defined movement possibilities and sequences when compared with the movement sequences of children in natural areas (Fig. 4.2).

Moreover, it should be noted that natural areas seemed to offer children special opportunities to pursue deep- and recapitulative play. In contrast to playgrounds, natural spaces offered children many ways to reach their physical and emotional limits and explore their surroundings. It was especially remarkable how intensively and often children engaged in activities closely related to the original survival techniques of humankind, which ensured the survival of people in other places and at other times (see Table 4.2) (Fig. 4.3).

Fig. 4.2 Play spaces in educational institutions such as kindergartens or schools also show this orientation towards the needs of adults: They often appear "tidy" and there is little (natural) material that children can freely integrate into their play. The surface is straight and not very varied in terms of motor skills. Playground equipment prescribes clear movement sequences and cannot be creatively modified or examined more closely due to the fixed assembly. The surfaces are mostly smooth

Fig. 4.3 Play spaces in natural areas allow children to explore a variety of (natural) materials such as stones, fruits or sticks as well as living creatures and diverse soils and water and to integrate them freely and creatively into their play. The environment is often motorically demanding, as the ground is often uneven and covered with various materials and objects. The environment often invites exploration (e.g., branch holes or slopes) or building projects of one's own. Children have the opportunity to retreat as the environments are often more cluttered.

4.7 Conclusion and Recommendations

The results of this study suggest that the free play of children in natural spaces holds great potential for early STEM education. The natural areas visited gave the children more space and possibilities to take the place for themselves and to use and design it according to their individual needs and interests. The huge variety of different materials, which differ greatly in type and composition and which can be freely integrated by children into their play, encourages children to engage in a wide range of exploratory activities, manipulations, uses, and construction projects. The spatial conditions also enable children to creatively and exploratively design and change their surroundings. Natural spaces with their challenging and diverse conditions offer optimal conditions for intensive and holistic experiences with different objects, environments, and materials with their specific characteristics. STEM-related phenomena can be discovered and explored in a playful way and with the whole body. All senses are involved and challenged.

It can be suggested that a similar exercise of the types of play mentioned would also be possible in playgrounds. However, playgrounds do not often leave children the same freedom for independent discoveries and the implementation of their own ideas. This circumstance may be mainly due to the reduction of such places to the seemingly essential, namely play equipment that is apparently suitable for children. Moreover, playgrounds seem to be designed to take into account the needs of adults in particular: They often appear tidy and free of all 'unnecessary' objects such as natural materials. Playgrounds also meet adult-devised safety requirements by providing a soft or straight surface and items of play equipment with a low diversity of materials which are firmly bolted together. Although these structures and precautions give adults a feeling of safety, clarity, and visual signals as to what can be played in a playground and for which age group the playground is 'suitable', they do not give children the opportunity to fully live out their range of play types. In addition, they are deprived of important, fundamental first-hand experience with STEM-related topics.

The results of the study suggest that free play in natural environments holds great potential for early STEM education: Children can playfully gain first and deep experiences with STEM-related topics and phenomena. Here they have opportunities to try new things, to be creative, and, in cooperation with others, to implement their own projects. The curiosity and interest of the children in STEM topics can be awakened. At the same time natural environments offer children an important educational basis which supports them in future learning processes and enables them to connect to their own experiences and knowledge in this area.

Although adults tend to take a back seat in the free play of children, their role is not insignificant. Children play where adults allow them to play. Even places for children, such as kindergartens or playgrounds, are planned and arranged by adults. The experience and freedom of children is therefore strongly connected with the image of adults and their respective social views about children and childhood. However, when it comes to the promotion of early STEM learning, less planned and structured landscapes seem to be more advantageous. If adults want to give children access to diverse materials, objects, and environments and space for creativity and exploration, natural settings with their varied, challenging, and stimulating characteristics seem to be just the right place for children to play freely.

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Chapter 5
Engaging Children in Science Learning Through Outdoor Play

Eric Worch, Michael Odell, and Mitchell Magdich

Abstract Evidence suggests that children spend much less time playing outdoors engaging in self-directed play than their parents did (Moss in Natural childhood. Park Lane Press, 2012; Tandon et al. in Archives of Pediatric and Adolescent Medicine 166:707–712, 2012), perhaps as much as 71% less (Brown in Scholarpedia 9:30,449, 2014). School recess time has also decreased, with childen of color and children living in poverty having even less access to recess (London in Kappan 101:48–52, 2019). However, time spent in natural settings leads to improved mental well-being, cognitive function, and emotional regulation (Burdette & Whitaker in Archives of Pediatric and Adolescent Medicine 159:46–50, 2005; Whitebread in Child and Adolescent Health 1:167–169, 2017). By teachers incorportating play-based outdoor learning experiences into their science instruction, children can have playful experiences in nature, reaping the benefits of being outdoors while gaining content knowledge and developing scientific thinking skills. This chapter focuses on the relationship between different types of play and specific science learning behaviors as children engaged in outdoor play during nine family play events in the Greater Toledo, Ohio Metropolitan Area in the U.S.

5.1 Outdoor Play and Affordances

Play is fun and intrinsically motivating (Brown, 2009). Children play because they want to, and the pleasure children experience during play helps to sustain it (Huizinga, 1950). However, play is more than just fun. Play is the medium through which

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children come to construct much of their reality and discover the implications of their actions (Gardner, 1973; Piaget, 1999). It is the fun element of play, however, that helps to shape youngsters' interpretations of social and environmental challenges in positive directions (Fagen, 1993).

The design of the play environment affects the quality and quantity of children's play (Frost et al., 2008). Play is more likely to occur and be sustained when the possibilities for action in a given space are high. These possibilities, called affordances (Gibson, 2015), are what a space offers the child and may either stimulate or inhibit play. The ability of childen to perceive, access, and adapt affordances may be affected by the overall design and size of the playspace, topography, and availability of natural and manufactured parts (Kernan, 2010). For example, a concrete pad may be perceived as a good place to bounce a ball, while a grassy slope may be perceived as a good place to roll down. A hollow in a cluster of bushes may be perceived as a den. An important consideration when a play provisioner is assessing the affordances of a space is that their perception, an adult perception, may not be the same as a child's perception. A tree with accessible climbing limbs may be perceived as "dangerous" and off limits by an adult, but as an enticing climbing challenge they can accomplish by a child. An affordance is always an affordance, but it can be perceived differently and lead to different actions due to one's perceptions. Play provisioners must think about what affordances exist and how they could be used by the child and not just how the child is using the affordance now or how we, the adults, might use the affordance.

Nicholson (1971) was one of the first researchers to recognize the importance of flexible affordances in learning environments in order to promote positive physical and cognitive stimulation through novelty and challenge. His theory of loose parts is summarized as follows: "In any environment, both the degree of inventiveness and creativity, and the possibility of discovery, are directly proportional to the number and kind of variables in it" (Nicholson, 1971, p. 6). The more interesting or complex the affordance, the more possibilities for action children will perceive.

The perception of affordances is also affected by neophilia (Morris, 1967), the urge for novel things and activities. New is exciting, intriguing, and engaging. Eventually, however, the novelty will wear off. This often causes us to seek something new to intrigue us once more. Thus, play spaces, even natural ones, need constant change in order to keep neophilic urges and child engagement high.

In natural settings, positive affordances may include loose parts, such as sticks, sand, rocks, dirt and water, as well as pails and butterfly nets, topographical features, such as mounds, ditches, caves and paths, and vegetation, such as tall grasses, bushes and trees. Affordances provide opportunities for children to explore, build, climb, experiment, run, jump, hide, and take risks. The positive impacts of flexible affordances on preschool and school-age children's play in outdoor settings have been examined by numerous authors (e.g., Carr et al., 2017; Drown, 2014; Kernan, 2010; Larrea et al., 2019; Rivkin, 2014). Rivkin (2014) concluded that hands-on, spontaneous play and exploration in nature increases student motivation and builds a foundation for classroom learning experiences.

Additional benefits are derived from interactions with nature. For example, interaction with nature is positively correlated with *increases* in self-esteem and mood (Kaplan, 1973; Kuo & Sullivan, 2001a; Maller, 2009; Pretty et al., 2005) and positive emotions and behavior (Catanzaro & Ekanem, 2004; Kaplan, 2001; Maller, 2009) and *decreases* in stress (Bringslimark et al., 2007; Van den Berg & Custers, 2011; Yamaguchi et al., 2006), anger (Moore et al., 2007), crime and violence in urban areas (Kuo & Sullivan, 2001b; Moore et al., 2007), and mortality rates (Mitchell & Popham, 2008).

Wells (2000) examined how children's change of residence in terms of visible naturalness immediately surrounding their dwelling impacts their cognitive functioning. She found that change from a highly nature-deficient environment toward a more natural environment, rather than the overall level of naturalness of the new environment, produces the greatest increase in cognitive functioning, explaining 59% of the variance.

5.1.1 Scientific Thinking and Learning

Children are curious about the natural world (Duschl et al., 2007). From birth, they are constantly investigating their world in order to understand it and, ultimately, to manipulate it. As children explore their environment they gain science knowledge and science skills (Platz, 2004). Their thinking becomes more complex as they mature (Meyer et al., 1992). Kuhn (2011) equated scientific thinking with knowledge seeking in that scientific thinking "encompasses any instance of purposeful thinking that has the objective of enhancing the seeker's knowledge" (p. 497). Similarly, Klahr et al. (2011) concluded that scientific thinking is characterized as both content and process. That is, children participate in the process of scientific thinking to gain content knowledge; however, the knowledge acquired may be incomplete or incorrect.

Zimmerman (2007) posited that a child's investigative mindset, scientist versus engineer, will guide inquiry to either uncover causal regularities or produce effects. This mindset, which is not fixed, can promote hypothesis building or cause-and-effect manipulation. She further suggested that a child selects experimentation and inference strategies based on their prior conceptual knowledge of the phenomenon. Of importance to science educators, is that children tend to ignore non-causal factors and focus on causal factors, which may cause them to develop incomplete or incorrect interpretations of a phenomenon. A finding congruent with Klahr et al. (2011). The instructional challenge is to diagnose and remediate these misconceptions while simultaneously building on correct knowledge (Klahr et al., 2011).

5.1.2 Play, Playfulness, and Scientific Thinking and Learning

Play and playfulness have been linked to creative thinking, verbal intelligence, and divergent thinking in children (Barnett & Kleiber, 1984; Forman, 2006; Root-Bernstein & Root-Bernstein, 2006). Bergen (2009) argued that guided imaginative play that explores the natural world provides experiences through which to teach science concepts to children. Hamlin and Wisneski (2012) noted that play offers opportunities for children to learn science concepts and scientific inquiry. Based on her research on guided play and science learning, Fleer (2019) proposed a pedagogical model by which teachers take children on scientific journeys through playful exploration, role play, and imaginary play to stimulate mental modelling of science concepts. Thus, as noted by Zimmerman (2007), these early playful experiences add to children's conceptual knowledge and will guide their inquiries toward uncovering regularities or to produce cause-and-effect manipulation.

Worch and Haney (2011) concluded that observers are not able to distinguish with certainty whether a child's playful scientific inquiries are motivated by a desire to uncover causal regularities or to carry out an action to determine its effect. Such differentiation requires controlled systematic investigation and researcher interaction with the child, which are not possible when children are engaged in free-play experiences. However, they were able to achieve high interobserver reliability when inferring from children's playful actions whether they were gaining different levels of knowledge by interacting with a phenomenon through mere observation or active physical exploration. Furthermore, when physical exploration suggests purposeful action to test a hypothesis or cause a specific effect, they were able to infer that a higher level of scientific thinking is involved with high interobserver reliability; however, they were not able to reliably separate these two levels of thinking.

The following section introduces and discusses a recent collaborative research project which examined the science learning behaviors of children engaged in outdoor play during family play events in the Greater Toledo, Ohio Metropolitan Area, USA.

5.1.3 Methods

Children of past generations enjoyed a rich heritage of self-directed play. Unencumbered by current electronic distractions, children spent much of their time engrossed in outdoor play. Loose objects, such as sticks, branches and leaves discovered in an abandoned field, were manipulated and transformed by the child's imagination into a fort. The creek flowing through the neighboring woodlot served as a personal swimming hole, complete with a home-made dam. There were few boundaries. Play equipment was not needed or desired. There were no adult schedules or rules to follow. Play was self-directed, imaginative, and fulfilling.

Evidence suggests that children now spend less time playing outdoors engaging in self-directed play. Due to demanding lifestyles, changes in family structure, regimented activities, and electronic diversions, outdoor play has dropped 71% in one generation (Brown, 2014). There is also strong evidence indicating that parental concerns about safety influences a child's access to outdoor play areas. Indeed, the abandoned field and woodlot stream now have far fewer children visiting because of parental fear over their child's safety (Vetch et al., 2006).

To address barriers to outdoor play and provide nature play opportunities, Play Naturally Toledo (PNT) was created as a collaboration between the Toledo Zoo (TZ), Metroparks of the Toledo Area (MTA) and the 577 Foundation (577). The goal of PNT is to reconnect families to nature by facilitating rich nature play experiences. PNT was funded by the Disney Conservation Fund and Toledo Community Foundation.

5.1.3.1 Subjects and Setting

The subjects were 104 children participating in the Play Naturally Toledo (PNT) Project. The children's ages ranged from approximately three years to 14 years and approximately 60% of the subjects were female. Data were collected during nine play events between the months of March and December. The play events were distributed equally among the three project partners, with each offering different levels of immersion in nature.

Nature's Neighborhood at Toledo Zoo is a 1.25 acre constructed, naturalized play space (Fig. 5.1). It was designed as a science playground in which young children were free to fully interact with the play spaces and learn independently from their experiences. Nature's Neighborhood received the Best Exhibit Award in 2011 from the Association of Zoos and Aquariums. In contrast to the constructed play space on Nature's Neighbourhood, the metroparks constituted the highest degree of naturalization, mixing mown lawn and completely untended nature (Fig. 5.2). PNT events were held at three different metroparks across Lucas County, ranging in size from 441 to 5,000 acres, two of which contained a natural river or stream. The 577 Foundation's design lies in between the other two play spaces with a mix of manufactured and natural space and occupies approximately 12 acres (Fig. 5.3). The space is located along the bank of the Maumee River in Perrysburg, Ohio. In this research project, the amount of play space was limited to less than 2 acres at all locations in order to facilitate proper supervision.

5.1.3.2 Data Collection

Observations were made by the same individual and recorded using the HanDBase app (DDH Software) on an iPad. HanDBase® is a relational database for mobile devices that can be tailored to produce interactive pop-up menus from which to select predetermined "values" for each variable of interest using a stylus. An "other" category was used to document unanticipated values. Annotations were used to provide

Fig. 5.1 Nature's Neighborhood, Toledo Zoo, Ohio

specific details, if needed. The site of each play event was artificially divided into unique play spaces based on their location and the kinds of naturally-occurring and provisioned materials available for play. The observer walked a circular route among the play spaces in a counterclockwise direction. Scan sampling of children was employed in each play area for up to a 5-min sampling period without duplication of subjects. If all subjects in a place space were observed before the end of the sampling period, the observer moved to the next play area to begin a new 5-min sample.

Instantaneous recording was used to document study variables, which included the subject's age class (3–5, 6–8, or 9–16 years), play and science learning behavior status, materials manipulated/surfaces touched, number of child interactants, as well as the quality of the interactions, and the caregiver's distance and interactive relationship with the subject. HanDBase's® annotation feature permitted the identification of specific objects touched and/or manipulated. For example, a natural loose object could be further specified as a stick, rock, leaf, etc. Photographs of children playing were taken to help contextualize the data records.

For the purposes of this study, play was defined as behavior possessing some or all of the following characteristics as described by Krasnor and Pepler (1980) and Rubin et al. (1983):

Fig. 5.2 Swan Creek Park Metropark, Lucas County, Toledo, Ohio

Fig. 5.3 The 577 Foundation, Maumee River in Perrysburg, Toledo, Ohio

- it is free choice and performed for its own sake;
- individuals are more interested in the process of doing than the ends;
- there is positive affect;
- sequences of behavior vary from their functional variant; and/or
- there is an element of fantasy or pretending.

The categories of play used in this study were based on Smilansky's (1968) taxonomy, which she derived, in part, from Piaget's (1999) theory of play. With the addition of sensory play to Smilansky's four play categories, play was classified into five categories as defined in Table 5.1. Neither Smilansky nor Piaget included a category for gross locomotor play, such as running and climbing, not associated with games with rules or exploration. Therefore, gross locomotor play was categorized as functional play for this study. Sensory play, or exploration, was added to differentiate behaviors in which the focus of a child's actions appeared to be oriented more around what an object is than what can be done with it. Although there are limitations to this taxonomy, it has been used in other studies (e.g., Moore & Cosco, 2010).

Based on previous research (Worch & Haney, 2011), three categories of science learning behaviors were used in this study: observing, exploring and cause and effect. Although a child may have been engaged in a science learning behavior, this study did not determine whether science learning actually took place. For the purposes of this assessment, observation was defined as visual and/or aural examination of materials or of another child interacting with the materials. Even very young children engage in this type of inquiry (Sunal & Sunal, 2003). Through these experiences, children of all ages can gain rudimentary knowledge, which may compel them to explore with the materials first-hand. Exploration was a more interactive experience in which the child manipulated materials to learn more about their physical properties and what can be done with them.

When a child appeared to take purposeful, planned action to achieve a specific outcome (e.g. hypothesis testing or cause and effect), this behavior was labeled cause and effect (Sunal & Sunal, 2003). For example, if a child discovered through trial and error exploration that leaves could be made to move when a spray bottle is adjusted from mist to stream, and the child then began to purposefully shoot a stream of water at leaves for the apparent goal of making them move, cause and effect inquiry was deemed to be taking place.

Caregivers' behavior was assigned to one of four categories based on their interactions with the child. When children were engaging in free play with no adult involvement, this caregiver interaction was labeled uninvolved. Mediated caregiver interactions were recognized when the adult followed the lead of the child during play. When adults appeared to be directing the play activity, the interaction was recorded as facilitated. Custodial interactions involved the adult providing caretaker services, such as providing food and tying shoes, or signaling an end to a play session.

Table 5.1 Study variables, levels, and operational definitions

Variable/level	Definition
Play behavior	Smilansky (1968)
None	Child is not playing
Functional	Child engages in repetitive or active physical activity
Sensory	Child's repetitive actions are sensory oriented
Constructive	Child creates or constructs something
Dramatic/pretend	Child performs fantasy actions and/or vocalizes fantasy
Games	Child engages in activity with clear purpose and parameters
Science learning behavior	Sunal & Suna (2003)
None	May or may not be engaged in activity; active child does not appear to be focused on scientific element of activity
Observing	Watching closely, hands-off
Exploring	Interacting with environment, making an inquiry, or carrying out a plan
Cause-effect	Making a deliberate action and expecting a certain outcome
Contact material	
No contact	Not touching anything/anyone
Natural loose	Touches loose natural elements such as twigs, leaves, flowers, small rocks, sand, dirt, water, another person, etc
Natural fixed	Touches natural elements fixed to the ground such as trees, shrubs, stumps, boulders, flowers, plants, etc
Manufactured loose	Touches loose manufactured objects such as toys, boxes, pails, rakes, etc
Manufactured fixed	Touches fixed elements such as playground equipment, fence, brick wall, etc
Peer interaction	
Not present	No peers within subject's arm span
No interaction	Peers present, but no interaction
Cooperative	Cooperative working together with other children during the activity
Altercation	Signs of conflict, disagreement, or argument with peers
Caregiver involvement	
Uninvolved	Adult allows children the physical and emotional space for free play
Mediated	Adult follows the lead of the child during play
Facilitated	Adult leads the child during play
Custodial	Adult stops play, provides food, cleans child, ties shoe, etc

5.1.3.3 Data Analysis

HandDBase files were converted to Excel format and pasted into IBM SPSS, which was used for both descriptive and inferential analyses. Chi square tests, adjusted for sample sizes, were used for all between group comparisons. Significance was set at 0.05.

5.1.4 Results

The study resulted in a total of 220 valid observational records. Families were encouraged to participate in each session. Therefore, some individuals were observed on more than one occasion. Overall, the results show that children were engaged in scientific thinking behaviors during play. Furthermore, caregivers' interactions with their children and the kinds of materials available for play in the playspaces were associated with children's play and science thinking behaviors.

5.1.4.1 Play and Science Learning Behavior

Results show that children engaged in significantly more playful behavior (94.6%) than non-playful behavior (6.4%) [$X^2 = 154.88$, df = 1, $N = 220$, $p < 0.000$] during these events. Functional play was observed significantly more frequently than the other play types [$X^2 = 208.709$, df = 4, $N = 206$, $p < 0.000$]; however, no difference was found among the frequencies at which sensory, constructive, fantasy, and game play were observed [$X^2 = 1.415$, df = 3, $N = 82$, $p = 0.702$]. Table 5.2 summarizes the frequencies of observations in which each type of play behavior was observed.

The frequencies of observations in which each type of science learning behavior was observed are also summarized in Table 5.2. Science learning behavior was observed in 206 of the 220 total records. Approximately 94% of all science learning

Table 5.2 Frequencies of play types and science learning behaviors crosstabulation

Play type	Science learning behavior				
	None	Observe	Explore	Cause & effect	Total (*n*/%)
None	2	7	5	0	14/6.4
Functional	7	11	97	9	124/56.4
Sensory	0	0	18	0	18/8.2
Constructive	0	0	21	4	25/11.4
Fantasy	4	1	14	1	20/9.1
Games	7	2	8	2	19/8.6
Total (*n*/%)	20/9.1	21/9.5	163/74.1	16/7.3	220/100

behavior occurred during play, while just 6% of science learning behavior occurred outside of the play frame [$X^2 = 167.564$, df = 1, $N = 220$, $p < 0.000$]. Exploratory science learning was associated with all play types and it was observed significantly more frequently than other science learning behaviors [$X^2 = 283.018$, df = 3, $N = 220$, $p < 0.000$]. When adjusted for sample size, exploration occurred equally across the different play types. [$X^2_{explore} = 4.567$, df = 4, $N = 158$, $p = 0.335$]. There were too few cases to perform chi square texts for observation and cause-and-effect science learning behaviors. However, cause-and-effect learning behavior was associated with functional play, constructive play, and game play and observation was associated with functional play, fantasy play, and game play. Although observational and exploratory science learning behavior were observed during all play types, including no play, neither type of science learning behavior was found to be observed more than expected during any specific type of play.

5.1.4.2 Caregiver Effects on Play and Science Learning Behavior

Children were free to roam among different play areas at the discretion of their caregivers and all materials/objects within a play area were available for play, again at the discretion of the caregivers. Approximately 52.5% of all children's play was free play (Table 5.3). That is, the caregiver was either not present or not involved in the child's play. Forty-eight percent of children's play was in some way mediated by the caregiver, and 11% was facilitated, or led, by the caregiver.

When corrected for sample size, no differences were found between each level of caregiver interaction and the type of play observed [$X^2_{free} = 0.436$, df = 5, $N = 73$, $p < 0.994$; $X^2_{mediated} = 1.857$, df = 5, $N = 83$, $p < 0.869$; $X^2_{facilitated} = 2.053$, df = 5, $N = 20$, $p < 0.842$]. Nor were there any significant differences between each level of caregiver interaction and observational and exploratory science learning behavior. There was, however, a significant difference between cause-and-effect science learning behavior when children were engaged in free play (62.5%) compared to play mediated or facilitated by a caregiver (37.5%) [$X^2 = 21.125$, df = 2, $N = 16$, $p < 0.000$].

Table 5.3 Caregivers' interactions and children's science learning behaviors crosstabulation

Caregiver interaction	Science learning behavior				
	None	Observe	Explore	Cause & effect	Total (*n*/%)
Free	13	11	81	10	115/52.3
Mediated	5	9	64	5	83/37.7
Facilitated	2	1	16	1	20/9.1
Custodial	0	0	1	0	1/0
Total (*n*/%)	20/9.1	21/9.5	163/74.1	16/7.3	220/100

5.1.4.3 Play and Contact Materials

Play and science learning behaviors were facilitated by a combination of fixed and loose materials (Table 5.4) that provided a wide developmental range of play and learning challenges. Children were allowed to transport materials from one area to another. This enabled children to continue playing with a particular loose object and kept the materials available in the play spaces dynamic.

The majority of contact materials were loose in nature (70.1%) and were used primarily during functional play (56.0%). All instances of sensory and constructive play involved loose parts. While the types of materials that were available for contact were dictated by the setting and informal educators, it was clear that children preferred to play with loose parts whether they were natural or manufactured [$X^2 = 59.0$, df = 20, $p < 0.000$]. Likewise, loose parts were associated with the majority of observations of exploratory (77.8%) and cause and effect science learning behavior (88%) [$X^2 = 71.49$, df = 12, $p < 0.000$] (Table 5.5).

Table 5.4 Frequencies of play types and contact materials crosstabulation

Play type	Contact material					
	None	Natural loose	Natural fixed	Manufactured loose	Manufactured fixed	Total (*n*/%)
None	8	2	0	4	0	14/6.4
Functional	16	42	13	39	13	123/56.0
Sensory	0	12	0	5	1	18/8.2
Constructive	0	11	0	14	0	25/11.4
Fantasy	2	4	1	12	2	21/9.5
Games	4	5	0	6	4	19/8.6
Total (*n*/%)	30/13.6	76/34.5	14/6.4	80/36.4	20/9.1	220/100

Table 5.5 Frequencies of science learning behavior and contact materials crosstabulation

Science learning behavior	Contact material					
	None	Natural loose	Natural fixed	Manufactured loose	Manufactured fixed	Total (*n*/%)
None	9	1	0	8	2	20/9.1
Observe	12	4	0	2	3	21/9.5
Explore	9	66	13	61	14	163/74.1
Cause and effect	0	5	1	9	1	16/7.3
Total (*n*/%)	30/13.6	76/34.5	14/6.4	80/36.4	20/9.1	220/100

5.1.4.4 Discussion

Every child has the right to engage in play (The United Nations, 1989). Globally, opportunities for children to engage in free play, especially in nature, have continually declined over the last several decades, and Gray (2011) has argued that the decline in outdoor play has led to more diagnoses of psychopathology in children and adolescents. Therefore, it is incumbent upon teachers, parents, and other caregivers to provide ample opportunities for children to engage in outdoor play, particularly in natural settings. The project described in this chapter, a partnership between Toledo Zoo, Metroparks of Greater Toledo, and the 577 Foundation, was developed to encourage more nature play among families, as well as to further explore the relationships between play, science learning behavior, contact materials, and caregiver interactions.

Play and science learning behavior (observation, exploration, cause and effect) were observed to occur simultaneously in 94% of the observations. In a study of children's play and science learning in a built nature play environment at a children's zoo, Worch and Haney (2011) found that children were both playing and engaged in scientific observing, exploring, or cause-and-effect learning behavior in 80% of their samples. The current study provides more evidence to support the argument that children, indeed, learn while playing (Hirsh-Pasek et al., 2003; Singer et al., 2006; Worch & Haney, 2011; Zigler et al., 2004). In fact, Brown et al. (2013) reported that complex sociodramatic play is positively correlated with better scores on creativity tests, better problem solving skills, positive social interactions, and better social skills.

Two factors were associated with play and science learning behavior: caregiver interaction and availability of loose parts. Cause and effect science learning behavior occurred significantly more frequently when children were engaged in free play (no caregiver interaction) than when the caregiver was interacting with the child (mediated and facilitated). It is known from the field of playwork that adult engagement in children's play can adulterate, or take over their play (Sturrock, 1997), so that their natural play cycle is interrupted (King & Sturrock, 2020). Because cause and effect thinking and hypothesis testing are deeper forms of cognition than observing and exploring with materials (Sunal & Sunal, 2003), it is likely that children need to be in a state of flow (Csikszentmihalyi, 2008) during their play to achieve this level of thinking. Flow is the state in which "people are so involved in an activity that nothing else seems to matter; the experience itself is so enjoyable…." (p. 4). Unnecessary adult intrusion, or adulteration, can interrupt this flow and prevent children from reaching a deeper level of thinking about the phenomenon being investigated during the play experience.

The second factor associated with play and science learning behavior, loose parts, has been studied extensively in relation to play but less so with reference to science learning (Bhattacharya et al., 2003; Fjørtoft, 2004; Woolley & Lowe, 2012). In both indoor and outdoor settings, the availability and quality (including complexity and novelty) of the loose parts available for play impact the quality of children's play. For most children and many caregivers, the loose parts were both novel and complex.

For example, when attending their first nature play experience, most children had never waded in a real stream (water is considered a loose part) with a perceptibly strong current, muddy bottom, plant and wildlife, and rocks and sticks to pick up and toss. Many caregivers were reluctant to allow their children to enter the stream and constantly warned about safety and not getting dirty as if the children were fragile china dolls and clothes could not be washed. Sticks may not seem overly complex; however, compared to standardized building materials manufactured for children, the irregularity of sticks affords them many more opportunities to create complex combinatory structures. Admittedly, few fixed manufactured parts were available to play with at the metroparks; however, logs, boulders and trees were abundant in all settings. Undoubtedly, children's preferred contact materials were loose parts and it was through the manipulation of loose parts that children were observed to engage mostly in the higher levels of science learning behavior (exploratory and cause and effect).

"The pedagogical value of play does not lie in its use as a way to teach children a specific set of skills through structured activities called 'play.' Rather, play is valuable for children primarily because it is a *medium* for development and learning" (Bergen, 2009, p. 7).

5.1.4.5 Implications

The results of this study have several implications for early childhood science educators.

1. Children need opportunities to play in and explore nature on their own terms without an adult agenda.
2. Teacher intervention in children's outdoor play should be designed to nurture children's natural curiosity to keep them in the flow of their play cycle and not interrupt it.
3. The abundance and complexity of loose materials found naturally in the play space or supplied by the teacher impact the flexibility of play and science learning behavior in which children engage.
4. Playful, teacher directed inquiry may keep children more engaged in the learning process and think more deeply about the phenomenon under investigation.

5.1.5 Conclusion and Recommendations

Children engage in science learning behaviors while playing in nature. Furthermore, childhood interactions with nature promote physical, emotional, social, and cognitive development. Unfortunately, many teachers, administrators, and parents are skeptical of playful learning (Bergen, 2009). Further, the absence of the "learning while playing" mindset appears to be pervasive in US culture (Hirsh-Pasek et al., 2003). Educating children, parents and other adults (teachers, administrators, policy makers, etc.) about the value of play to learning seems to be imperative if play is to make its way as a valid component of educational reform. The results from this research substantiate that children do engage in science learning behavior while they participate in safe physical play.

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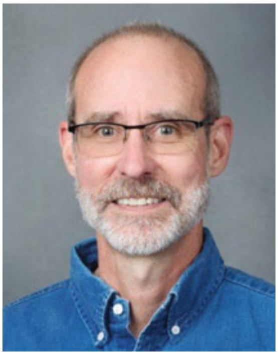

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Chapter 6
Exploring the Possibilities of STEM and Play in Preschool Years in England

Eirini Gkouskou and Sue Dale Tunnicliffe

Abstract Observing pre-school children playing in a free choice environment, either indoor or outside in the immediate area with whatever catches their attention or in settings with objects and activities provided (mediated play) where these emergent scientists are free to choose, that which do reveals the ability to observe and investigate with some planning involved in such activity. They also learn by experience such as building a tower and modify their technique in a further action. This chapter reviews Theories of play and instances of such pre-formal education learners playing in free choice and mediated surroundings illustrating the science actions which are the outward manifestation concepts. It recognises the importance of the adults and their mode of interaction with such early learners. Moreover, activities observed reveal the natural tendency of children to discover and use basic engineering techniques which are essential for the understanding of biology and physics and generally STEM education. This research study also shows that children, as emergent scientists, accomplish progression via the activities they chose and provide a firm experiential base for later formal learning.

Keywords STEM · Play · Parents · Practitioners · Home · Kindergarten

6.1 Introduction

Research in early years shows that young children can investigate, collect evidence and select the actions in inquiry-based activities. Moreover, playful collaborative activities support children in expressing their ideas, their reasoning and talk about their own discoveries in the developing early years, as intuitive scientists, who, interpret the world around them from observing and investigating and also have the ability to acquire viable realistic concepts of the living world when involved in

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relevant activities provided or found for themselves. Many adults consider play a waste of time and it has been stated that 'Play is children's work' but it is *essential* work of children (Roth, Goulart & Plakitsi, 2013). Whitebread et al. (2012) pointed out that such work is essential for both these emergent learner's emotional and their intellectual well-being. What is play? Tunnicliffe and Gkouskou (2019) considered the term as free-choice or spontaneous as freely chosen play when play is not directed by someone else which is 'educational play'. The place and items available for hands-on play opportunities are important in facilitating the STEM experiences, of pre school children Hadzigeorgiou (2002).

Beginning at the end of the last century there has been paradigm shift in attitudes and understanding of early childhood learning. Similar to that which occurred in the 1960s and seventies when primary, preschool, science became recognised as an important area of primary children's learning. The preschool child has always received some attention in childcare and in research studies. Particularly in social interactions, language development and play were analyses into a number of components, such as those of Hughes (1996). The English national curriculum of 1988 introduced science and design technology from the start of statuary schooling at 4 years followed by the early years foundation framework (Dfe, 2020) which embraced Understanding the World, science and including earth science as well as Numeracy.

Research (Jack & Lin, 2014) found that initiatives in science that direct these early learners to focus of science activities, arranged by adults and which show cause and effect, will not necessarily cause these children to be interested in science. Children need to generate their own interest and the adults need to be guided by this rather than impose an approach on them and instruct them. We cannot make children be involved in science we must let their native instinct emerge from birth as intuitive scientists (Gopnik, 2012).

Play is the foundation upon which future learning is built. It is essential in a child's mental development (Vygotsky, 1967). This learning experiences often occurs at home particular in youngest years, alone, or with a relative, in childcare or early years nursery and kindergarten where often a practitioner does try to 'teach'. In countries where there is statutory provision for a developmental curriculum this is the case However, particularly at home a child may discover for themselves, through their own free choice of items, interest, actions and experiences, a practical understanding of STEM in action. Compton (2020) looked at how pre-formal school children talked about their science activities they undertook at home. She pointed out that much research about children's interest in science were not derived from their school experience (Mantzikcpoulops et al., 2009) but recognised as Luce and His (2015) asserted that it is at home that children often are involved from their own motivations in STEM activities. Of course, young children. before statutory school and even in early formal schooling, do not recognise their self-motivated home activities as 'science' (Compton, 2020). Thus, STEM starts early (McClure et al.,2017). In considering play in formal preschool. like Kindergarten, it is important to remember that the age of formal school and kindergarten in other countries is not the same as in England where Kindergarten means before 5 years. Hence research such as that of Bulunuz (2013) is referring to older children than English kindergarten children.

The early years are marked by a series of transitions with ensuing progressions. The first is being born when the baby makes the transition from inside the uterus with its fluid environment to the outside world which is an air breathing environment. Then the transition from being immobile to mobile is another instance and then an ability to explore a much wider environment usually at home. Entering play groups, childcare, or an environment with other unfamiliar children is yet another whilst entering formal school is a tremendous event, as major transition for a child (Hirst, Jervis, Visagie, Sojo and Cavanagh, 2011).

Play occupies much of many children's time as it does for many other species. It is considered by many as one of the keys to their future development (Lillard et al., 2013). Pellis et al. (2014) found in their research that in some vertebrate animals, such as rats and primates, the juveniles which displayed rough and tumble play progressed in cognition, social competence, and emotional regulation later in life. Pellis and Pellis (2007) identified the role of play in the development of social play particularly through rough and tumble and play. However, human children spent much time other play modes starting in solitary play in the earliest years when finding out about their environment and its contents, gradually learning information, skills and becoming competent and progressing to social play, making rules for games, re-enacting experiences m narrative and fantasy play, and copying adult behaviours in their society in role play.

Understanding the perspective of the parents of their child's play at home by the formal education, practitioners in the Early Years settings can enhance the learning experiences of the child (Colliver, 2016). Parents/carers are key when a child starts on their learning journey. They are the first and most important teachers of a child, particularly in the first years of life before children often enter playgroups and nursery. When children do make the transition from home to elsewhere, they still play, it has been pointed out that, if then, formal educators are aware and respect the family's practices are more likely to develop a better relationship with the child as well as the parents.

Various educators have categorised play such as Hughes (1986). Bruce (1991) promoted Free Flow Play which is intrinsically motivated and begins as a solitary activity. Free Flow Play is an active process without necessarily a product and happens as a child develops their particular play and chooses with what and how they play. It is an essentially hands-on activity providing a repertoire of experiences which can contribute to their science and engineering understanding and further activities as they develop. Bruce (1991). was adamant that free play is available to children in playgroups and nurseries. Tunnicliffe and Gkouskou (2019) suggested a category of mediated facilitated play referring to STEM as the play where items are provided, such as playground equipment, constructed toys. There is an understanding too that creative make belief, and social play as well as games children invent and for which they develop rules are an important part of their play experience. Other researchers note that construction play often overlaps with other creative acts such as object play and aspects of art, modelling, colouring for example.

Practitioners and indeed parents, often do not see the potential in their child's play for scientific learning. The focus of play in their eyes often being on socialisation, language development and basic numeracy. However, Fleer (2017) maintained from her research that a child's imaginative play can promote an understanding about science. After observing how early years teachers interacted with children in situations with a possible scientific aspect how they could develop children's play into a scientific narrative often using an imaginary situation in the play.

As scientists specialising in education, we too maintain that whatever play action children are involved the action display use of some science, mathematics and engineering concepts and skills. Gopnik (2012) in a wealth of research papers and a popular book for non-specialist pointed out that the actions of children in play renders them intuitive scientist and engineers. Opportunities for play, particularly outside, are increasingly important in these times when many children spend much of their time indoors, either due to the pandemic circumstances or/and often using the internet and virtual reality. This results in not having first-hand real play-based experiences (Zucchi, 2002).

There are two distance of play in these youngest learners; play at home or their leisure sites and play at formal sites such as nursery school or other childcare facilities. Where adults provide them objects with which children may interact. We propose that in much play children utilise what are, in formal schooling, identified as STEM activities, but intuitively and do things in their free choice" play" and learn through experiences skills, actions and outcomes. Often, older pre-school children will work together and organise a play episode and effectively learn by observation and personal experience. They observe, ask questions and planning what do and what instruments they use. They evaluate the outcomes and use such to interpret their world.

Whilst free choice spontaneous play is a characteristic of early years, the very young children require things with which to play. When they grasp an object within their reach, they seem to ask two questions. 'What is this like? ', They answer themselves by exploring, mouthing, as early years practitioners describe the youngest children's use of their mouth, as one way of exploring an object Hughes (2015, p. 27). Such behaviour is seen with children sitting with a treasure basket. Subsequently, they ask themselves "What can I do with it?". Children seek their answers in their play actions. Whilst by themselves at first, they develop as they age in collaborative explorations relevant to problem solving and scientific investigation. These are basically the ideas introduced by psychologists (Hutt et al., 1989 p. 221), researching in the second half of the last century, name the responses to the tow questions as Ludic and Epistemic play. Science actions and developing understanding have not been traditionally a part of the play focus. The practitioner, including parents and cares are important in play, especially in their formal settings. As Fleer (2017) pointed out, people with children playing could change play into scientific play through developing a particular narrative. Whilst the essence play is hands-on investigating, discovery and learning for the self and thus progressing in competencies and confidence, adults with children, in our experience, find it difficult not to tell the children what to do and explain observations and direct. Whereas scaffolding the child's experiences by careful questions can accourage the child and progress their experience.

The recent work of Fleer (2000) is important for parents, other adults and practitioners alike in changing imaginary play episodes into a scientific narrative needed a different approach in the pedagogical techniques used. They also require the adult to realise that everyday science, basic maths and engineering, are in action every day.

6.2 The English Early Years System

The United Kingdom had four constituent Countries, each with its own educational system run by the devolved government. There is no UK system. There are two distinct groups which both are embraced by the term early years. That of pre-formal school where children learn through play and observing, investigating, and making sense for themselves of their surroundings in their pre-School Play groups organisation and nursery schools where practitioner have different levels of training. In England children generally school start is designated as four in what is termed the Foundation Stage. There is a three terms year with the longest beak being six weeks in the summer, originally so children could help with the harvest. Provision of early years education, formal and before formal school in England is complex, there is entitlement to 30 hours of free childcare for working parents and various rules and regulations on provision. Further details are available on the UK government website (https://www.gov.uk/government/publications/early-education-and-childcare--2).

Parents in England and other countries of the United Kingdom can choose informal childcare with friends or relatives or various creches. More formalised are nursery, playgroup, kindergarten, or children's centres. Some nursery schools take children from a few months. Nursery provision is provided by private organisations and individuals, other nurseries are provided by communities and Local Council or workplace nurseries. Full day care is provided for children aged 0 to 5. And by appropriately qualified practitioners. Childcare is provided by self-employed carers who are registered with OFSTED in England and are subject to regular inspection as are the other pre formal school facilities. It was announced in November 2020 that, beginning in January 2021, this would be every six years.

The early years teacher qualifications may be obtained in a variety of ways and is summarised in the documents Teachers Standards (early years). Full details of training can be seen on the government website (https://getintoteaching.education.gov.uk/explore-my-options/become-an-early-years-teacher). All the routes lead to EYTS but this is not a qualified teacher status which enables them to teach in primary and secondary schools. All candidates have to have obtained the qualification GSCE obtained at 16 years of age in English, maths and science at a pass level 4. Then there are three training routes. Graduates can follow a year of fulltime study. Graduates working in pre-school can follow the graduate employment route and they require further training to show they have obtained the standard of the EYTS. Lastly, there is a full time two, three- or four-year degree course with an early childhood component which leads to the EYTS qualification. There are fees, but many bursaries are available, for all these courses. However, there is an Assessment only route, paid by the candidate, for graduates, particularly experienced teachers of early years from overseas, who meet the Teachers Standards (Early Years).

Discussing play and its role is an important aspect of learning to be an early year's practitioners. These learners have their own ideas about play. A research study took place at an English University, where among others was exploring the practitioners' perspectives of play and its definition (Gkouskou & Tunnicliffe, in press). 43 University students were participated in this research study, 41 females and 2 males. The researchers conducted semi structure interviews with the participants and among others explored the definition of Play in Early Years. The vast majority of the participants recognised play as a mean where children can explore the world around them. It is an activity where motor skills rebuilt; It is defined by some as the work of children and is an important tool in 'Early Years' which supports children to develop in all areas. 'Play is a pleasurable experience to develop their knowledge and skills'. Some of the responses from the University students are tending towards experiencing and learning STEM but none specifically mentioned this. However, the ideas discussed in training are important, and as Fleer (2017) points out a rethink of pedagogical approaches needs reviewing in many cases to promote the child's own discovery of information and possibilities form their experiences, scaffolded by an adult understanding the STEM possibilities and development of possibility thinking (Craft et al., 2012).

6.3 Play Is Not Uniform but Developmental and Progressive

Play is not one size fits all. It is progressive, as in the child unable to move away from the spot investigating items in a treasure basket. which is an idea introduced by Goldschmied (Hughes, 2015) introduced for the nonmoving baby. However, once child progresses to being mobile the idea is extended with the child progressively exploring items in a collection or bag and indeed other objects that the child encounters. Older children begin exploring too in facilitated play items constructed especially toys, which become more complex. Children's use of the same activity progresses with age. In longitudinal case studies. The development of skills and activities with one item can be traced.

Using a non-participant observer methodological approach as well as individual interviews with the children based in elements of the mosaic approach and according to British Education Research Association guidelines (2018) the results of this research approach demonstrate that children explore scientific concepts by using everyday items and naming actions in play-based learning. We identified what science concepts were illustrated by the children's actions. In most play occasions, apart for direct instruction, the children are working like a scientist, they observe, interpret, decide on a plan of action, choose items to use and what to do, carryout their plan and evaluate the outcome We realize that the starting point of STEM learning is for the children to experience involvement with items or phenomena which will develop as the children develop and build on their express and discoveries to more formal learning experiences into a sound experiential ‘science capital’. What ‘science actions’ are used? What Maths concepts are utilized? What is designed and conducted? These experiences form the foundation of their science and thus STEM capital.

6.3.1 Science

Our themes and analysis of main basic science idea, gathered from non-participant observations of pre formal school children playing, in England, were compiled into a table identifying Early Years Science Actions and Skills (Table 6.1). However, we recognise mathematical, engineering and technology actions and skills are also embraced in this table based on non-participant observations in the course of their work over a number of years. Such was briefly reported by Tunnicliffe and Gkouskou (2019).

The progression in developing ‘STEM capital’ can be seen from the earliest years when children can sit up supporting themselves and investigating through observations such handling experiencing an object feels like, soft, hard, squashy, malleable, heavy, light, smooth, rough, and what it looks like and what it does and what they can do to it. Such as the boy sitting aside some toys he put out in a specific manner at a babies and toddlers session at Sreepur Village at Bangladesh, when he found two toy buses which appeared identical. He placed them side by side perfectly aligned. Then saw if one would stand on top of other. He repeated this procedure a number of times. Then he directed his attention to a wooden object which was a replica of a tool used local to thresh rice. A piece moved up and down when he pressed the end, *cause and effect actions*, which kept him occupied until the session finished. Early Science activities also employ those of basic maths and of engineering as they construct.

6.3.2 Mathematics

Play is Play. Watching play, we can identify beginnings of understanding and use of Number, measurement, space, and time are important math concepts apparent as pre-school children learn about them, in play and observations. Whilst we can identify elements not only of the STEM subjects but also signs of socialisation, problem solving, physical development and progression in children’s play. However, recognition that children at this age are also learning the basics of STEM through play not reported as often.

It is the adults who become concerned about what the child is learning, and they are giving the actions labels. Carruthers and Worthington (2006, pp. 36–54) discuss Schemas in a child’s early play in general. Much of what they discuss could a be written about science or mathematics schemas or engineering ones from observing

Table 6.1 Early years science actions and skills in play (western)

Activity	Scientific concepts	Science in action actions
Play in general	Nature of science	Observation, recall of past experiences, analysis of issue, planning investigation, choosing what is needed, organising items, other children or adult, instructing, data gathering, recording, evaluation, reporting, communication, repeating investigations, changing variables, identifying patterns, and over time
Sand play	Forces, properties, fillings, mixtures, evaporation, friction, surfaces,	Filling, capacity, emptying, moulding, making tunnels, wet and dry sand
Water Play	Mixing, currents, forces, gravity, ice- change of state, properties of water, absorption	Using senses, hot, cold, tepid, Forces, gravity, buoyancy, measuring capacity, surface tension, light, colour, refraction,
Construction (engineering)	Properties of materials, centre of mass, stability, strength	Making towers, bridges, homes for something, recognising shapes in buildings, fences, triangles, squares diagonals, rectangles, circles appropriate materials
Physical	Crawling, running jumping, rolling Balancing, throwing, catching	How they move, what they use, what happens. E.g. crawling through tunnels, on floor, running, chasing, sitting, dancing, hopping, jumping. Weather effects on body e.g. wind forces, slipping, heat, aching,
Malleable Materials	Forces used to change materials, properties of material, plasticity, joining, drying	Twisting, pressing, cutting shies, modelling shapes, adhesion
Cooking	Change of state, chemical reactions, effect of heat and cooling, heat transfers, evaporation, mass, measuring. Forces in cooking, e.g. pushes, pulls, gravity	Change of state, heating, melting, role of foods, origin of foods, sieving, mechanical mixing
Dolls	Metamorphosis, development,	Caring, re-enacting child care, life cycles, carrying and pushing doll, talking to it

(continued)

Table 6.1 (continued)

Activity	Scientific concepts	Science in action actions
Construction	Centre of mass, stability, balance	Balancing, fixing pieces together, replication, drawing, painting, origami
Wheeled activities	Forces, push pull, twists, taut, friction, construction, gravity, speed acceleration, deceleration	Collecting items and carrying around
Role play		Simulating adult behaviour and tasks, cooking, cleaning, shopping, organizing Socialisation and co-operation. Team work
Biology focused	Metamorphosis, classification, 'Life cycles, adaption, habitats, ecosystems	Painting toy animals, identifying, recognising adaptations habitats, finding habitats for particular organisms how animals move, how self-moves, how plants move, parts of human body, same parts in animals, e.g. knee of cat's back leg and human leg, parts of plants Colours in nature, Growing, seeds, fruits, foods we eat what are they biologically
Outdoor Play	Light, shadows, weather, earth science	Soils, pebbles, stones, weather, rain, snow, hail, ice, appropriate clothing, sky, clouds, sun, recording weather, indicator species, variety of plants and particular habitats, Flight, pets, how animals move, behave
Mud play	Forces, mixing, properties	Role play
Climbing frames etc	Forces, muscle powered, actions, balance	Understanding biomechanics in action and estimating risk
Slides	Gravity, friction, rates of descent with different loads	Using slide, decreasing their friction by sitting on mat running up, running down wheeled vehicles, different sizes and loads, rolling balls down
Ball games	Forces, pendulum, centrifugal forces, co-ordination, speed,	Bat and ball, ball on string, yo-yos
Numeracy	Measuring forces, volumes, mass	Counting, matching, shapes, pouring an amount quantity, measuring an amount

(continued)

Table 6.1 (continued)

Activity	Scientific concepts	Science in action actions
Literacy	Listen to stories, identifying images, matching, speaking, and making symbols, writing. Drawing to communicate	Orientation of using a book, recognising symbols Linking illustrations to text Interpreting illustrations Identifying problem, solving story issue Critiquing, redesigning myth and reality predicting next event, scale

the children's play. These mathematics education researchers also name the marks on paper that children make as mathematical graphics, just as science focused adults can identify biological concepts in early drawings. Scribbles representing, objects and drawings of what they have constructed making with marks. Whilst playing children use mathematical skills for example in planning, estimating sizes and distance. They experience area and space as well as shapes and items that match.

Their understanding depends in the earliest years in how something looks to them and only later they have grasped the concept that something can exists even if they cannot see it. In their play for example wooden blocks are spread out they think there are more of them than when the blocks are touching each other in a line. So, their idea of number is associated with length, space occupied not by individual present.

Children begin to understand spatial literacy, a spatial skill requiring the child to think and perform mental rotation (Pollman, 2010). The role of an adult in scaffolding experiences if they are with a young child is important as long as it is scaffolding but also in using maths words in everyday life, counting how many the blocks they have, referring to the number of a particular colour, how many things they have collected their basket as they pass for a specific point. Hearing adults say the words when cooking for example, measuring out ingredients or collecting the slices of bread to make toast is important, or at play group the number of mugs to put on a table for their mid-session drink.

Counting out loud by adults in the child's presence is very important so that these early maths learners hear an adult count out, for example the number of plates to put on a table. These types of dialogue can be heard by older pre-school children themselves when role playing in the home corner, laying the table for tea for their toys or in playgroup for another child. Children enjoy sorting matching and counting everyday things like bottle top, counters and putting items in a container or/ and taking them out again. They make sets according to their own system, like putting all toy cars in one place and all toy animals in another.

Measuring is very important and involved in play. Water play is very much a science and maths activity pouring from one sized container to another and then to different shaped containers but of the same volume. Children develop maths concepts gradually and through experiences in play. Number, measurement, space, and time are important math concepts. As children learn about them, they are learning about the relationships among objects, and about their own relationships to objects and to the world around them. We use numbers to find the answer to the question, “how many?” Using numbers comes naturality to children. They enjoy counting how many pennies they are holding, or how many children, or family in a home situation, are sitting at the table. They might say, “One two, four, seven, “as they count out four things. Although this is not the way adults count, it is still good practice. Children who practice counting lots of things have an easier time learning about numbers. They also enjoy making collections, stones and pebbles, toy cars, sticks or leaves (Tunnicliffe & Uckeret, 2011) often such collections can be used to develop ideas of science, particularly botany and earth science as well as descriptive words and counting, adding, subtracting, multiplying, and dividing up the components of such collections.

Young children’s ideas about spatial relationships are very much based on how it looks to them. The youngest child has to realise that even though they can no longer seɛ an object, it still exists. A three-year-old with their understanding is of what they can see. They learn directions when they want something they cannot see, like their coat, or toy.

6.3.3 Technology and Engineering

One of the first researchers to investigate young children’s technological activities was Marilyn Fleer (2000) at the beginning of the twenty first century. In Australia investigated technological educational in young children because higher work had looked at older children at the beginning of the twenty first century. She observed young children in childcare planning, making and evaluating when engaged in technology education. She recognised in particular, these young children’s ability to design, and then use their design for making. Moreover, recognised the need for much further work to be done.

Engineering is the process in which techniques and systems are used to design and construct things. It makes a received need, albeit in the earliest years placing similar objects side by side or constructing a tower of blocks, the child doing these actions had a need. Technology, the T in STEM is often unrecognised in play as is the E of Engineering. What is this T? In 2016 Sundqvist interviewed Swedish pre-school staff, (preschool includes 5- and 6-year-olds). This was published internationally in Sundqvist (2020). She looked at Technological knowledge in early childhood provision. Simply she found that there were 5 sections to which responses fitted. Namely Artefacts and systems in the environment of the children and this covered topics such as: i) Learning to handle artefacts: what jobs they do and how to use them safely ii) Learning the application areas and adequacy of artefacts, iii) Learning the purpose of artefacts: how artefacts work, what makes them go such as clockwork toys and solar powered items, iv) Taking apart objects; experimenting with solar cell-driven toys; following water and how it is purified, from the lake to the tap. All of which even the youngest child is involved into some extent. Learning to handle artefacts such as scissors is an important part of instructional play as well as learning the role of everyday items in their lives such as telephones, combs, and spoons.

The second category is the creative process, such as learning about materials building things and creating and solving a problem by constructing something as well as learning about recycling. Hearing adults talk about the third category identifies is Learning what about technology as technology to support children's developing understanding of the concept. Fourthly, the young children gradually learning how to use themselves to obtain the desired effect from pushing items to run, in climb and jump. was the penultimate category. The final one recognised that what can be regarded as technology, such as construction play, designing an investigation, making a system can be named as technology but is also part of the area of other STEM areas, for example using constructed play equipment. She points out too that what can be regarded as technology, such as constructing, using investigations are also technology are used and integral aspects of learning natural science and other content areas. Engineering is regarded by some as the process of generating then product which is the technology. In the first edition of the English National Curriculum, passed into English Law by the Education Reform Act of 1988, the term Design and Technology was used to embrace the engineering and technology, often referred to as Design and Make. Teaching begun in 1989. One of the authors was involved in introducing this, as well as science which was made mandatory in primary schools at the same time, introduced these two subjects to all the primary schools and nurseries in an English Local Education Authority (LEA).

6.4 Progression

Progression can be seeing with the same item but used differently by children of different ages. Toys that have wheels are an often sought out and used toy, especially ones that are big enough for a mobile toddler to sit on and even propel. Firstly, a child tends to plush such a wheeled object bending over to place their hands on a stable part on which they can just, like trolleys that continue blocks for example. An older child finds that they can be mounted and pushed by their feet. In the case of the truck children one of the authors observed propelling it with knee foot like a scooter. Small, wooded bikes were sat on and propelled by fee, often having to carry a passenger as these items were almost fought over by then children involved but sometimes a compromise was met. Two-year-olds in our experience make a dash for wheeled push chairs or other items and propel them around the room at great speed, often using them to collect items as they go. Progressing to role play and pushing a doll carrying a shopping basket.

In a playgroup setting in a Church Hall in England science activities were put on the floor on mats and on a few tables. Play dough was one of the items for that week. We observed an interesting progression with play dough form initial discovery interaction, of a 'what is this like' type, to and older toddler, "What can I do with it‘‘ experimenting using a play knife to cut slices and balance them in a pile, one on top of each other. Sufficiently that his pile stayed up, to an active three-year-old recognising play dough and in passing sticking two fingers in to make a hole and followed by a 4-year-old who carefully collect pieces of playdough, rolled them into small balls and collected such in a bowl. 4-year-old's mother appeared and informed us that her son loved playdough and making balls, which he called 'peas', but she did not allow such at home, because of the mess.

6.4.1 Acquiring a Scientific Literacy

Science is a collection of concepts that explain our world but it is also series of principles and skills which enable the scientifically thinking person find out about the world in a systematic way (Harlen & Qualter, 2019, pp. 7–9). Moreover, Harlen reviews the importance of science education for all in these threatening times to our planet and the imperative need meet the Sustainability Goals. Thus, appropriate STEM experiences in early childhood can be starting points for supporting children's continued successes in STEM at the elementary, secondary, and post- secondary levels. In these circumstances a comprehension of science is important to be able to participate in and understand decisions and needs and as world citizen. In terms of children learning science from their earliest years the process of studying science, with observing issues. The facility to be able to ask questions, devise and investigate a solution to their question through a systematic process which they devise is important. Furthermore, the intuitive understanding of fair test (Turner, 2012) and variables, collecting data and interpreting what they find is a key part of developing scientific literacy.

Children learn about their world and the phenomena and objects in it from their earliest days. Through this process they construct their personal interpretation and understanding. These concepts are particularly based on categorisations of objects, actions and other phenomena. Our work is hence observational trying to identify the patterns and development of these earliest STEM interactions. Bruner et al. (1956 p. 8) pointed out that concepts are developed from perceptions. Such perceptions from observations and experiences are needed by the child so that they can start catergorising that which they observe whether it be a plant or animal, a material such as a solid or liquids, or a weather experience (Koliopoulos et al., 2012). Ideas are formed in these early perceptions. Rosalind Driver (1983) realised and shared her assertion that secondary school pupils (12–16 years) were scientists and had their own ideas about phenomena which might be alternative conceptions, meaningful to the child but differing from those of accepted science. So, to is the case with the youngest child. Gopnik (2012) noted that the youngest child acting as a scientist investigating phenomena, such as dropping an object from a height such as their chair, to the ground and repeating the action when someone picked up the objects and returned it. In this continuing sequence of actions, they were gathering data. In the last quarter of the twentieth century much work on the acquisition of ideas, concepts, was carried out, Susan Carey discussed the conceptual change in children.

Harlen & Qualter (2019, p. 12) discussed with teachers of pre-secondary children about the Big Ideas of Science, In observing these very youngest children laying the beginnings of recognising some of these ideas in action by the children can be observed.

Progression in experiences and interpretation occur gradually as ideas or concepts change. Such may occur spontaneously through observations and experiences or as the result of instruction as in teaching. Such instructional induced conceptual change is one form of learning. This learning might also occurs in the earliest of years in a child's STEM-E, STEM experiences, in their free choice everyday play. This chapter and our work are concerned with the identifying of such experiences and how practitioners can be encouraged and aided in recognising the activities which may be instrumental in a child's concept development. Carey (2000) particularly researched and wrote about the development of biological concepts which is the field in which we have particularly worked. As a child refines and enlarges their interpretation of phenomena it involves a change, adaptation and enlargement, in their existing understanding as further understanding in their terms develops. Teachers may refer to the child's ideas as misconceptions later on and such are difficult to change although Driver (1983) refers to alternative conceptions in her work on the science thinking of adolescent children which first recognised children as scientists. Our work is situated at the beginning of the spectrum of a child developing their ideas and interpretations of their everyday world. However, this chapter is concerned with the initial experiences in whatever domain the occur.

6.4.2 Science Experiences—Biological, Earth and Physical Science

Children encounter the domains of science. Here we will mention in more detail those of biology. However, most actions do also employ forces in pushed, pulls and twist, manifest in picking up an object, putting something down. Biology in action is what we are because we are a biological organism. We do in out physiology utilise aspects of physical science and experience those of earth science particularly through the phenomena of weather and the ecosystems where we live which have been fashioned by earth science. But we experience biology in action and these life systems. Are a child's first experiences of STEM in action, breathing, feeding, excreting, temperature are the main experiences. Thus, children from the earliest years are part of biology.

The starting point of learning biology is with ourselves and an awareness, our anatomy and physiology, we are working systems which physical and material science and rules enable biological systems, such as us, other animals and plants, to work. There are activities for example seeing or noticing that skin is waterproof whereas water dropped on say cloth or ordinary newsprint is not. Having to use a towel to dry themselves is also a learning experience, some hard 'towels are not as effective at absorbing the water from their skin as are softer ones. Other things are waterproof such as foil, plates even paper plates which have a finish coating on their surface.

Biology however has three main dimensions Observations, Systems and Time, which are in action (Tunnicliffe, 2020, 2021). An early years child focuses on observations, recognising salient features, interpreting that which they see and categorising such into groups through eternal features and some behaviours. Such as locomotion, living in water. The first exemplar of a category they meet becomes the type specimen as it were and name of the category to which other instances belong in the child's interpretation. Hence anything that moves is alive, anything living in water is a fish. Something that moves on four legs and is furry is a dog. Gradually these emergent learners begin to distinguish subcategories with differentiation between category members. Classification is one of the systems crucial in biological thinking. The bodily systems as mentioned above are another aspect of systems which children encounter from their earliest of years.

The senses are important to young children in how they notice and interpret their world. Touch is an important sense that these children use in their exploration of their world. Smell is also used. Toddlers are attracted to perfumes of flowers, and bend to smell them. Touch is often utilised in their finding out about things. Touch in the youngest is frequently then associated with mouthing the objects which may be an extension of touch but also of taste. These young investigators are attracted to plants which are static. They do not move from place to place, the child moves to them, the opposite of their interaction with the animals they encounter at this age. Toddlers often pass a green plant with leaves and stroke the leaves, pull parts of the plant they touch which come off. This is particularly so with bushes and herbaceous plants. One toddler walked along the flower border edges with pink tulips and found that the petals were each in turn easy to pull off. Older children may learn that plants are anchored in the ground from which grow but the discovery that they have parts under the soil often amazes them. Pulling up seedlings from a tray of light compost is an activity they enjoy when they have discovered the roots. One boy of three and a half at the church play group to where the activity organised was to encourage the children to press a leaf, with the petiole, into their playdough by laying the leaf flat on the material and pressing in the leave. Removing the leaf so that leaf print shaped was seen. This boy however, planted leaves with the petiole inserted into the playdough and said it was his 'garden.' His mother said he loved gardening.

Time perplexes children. They expect immediate response to some actions and have not yet grasped the change in living things over time. Classic examples of such are the planting of seeds and the change in for example, a fruit tree with the seasons. Seeds don't grow instantly. Often when a seed is planted they expect it to grow out fo the soil as a plant almost instantly. A four-year-old, having seen the apples on the tree in the summer and helped pick a few, wanted to go and see the apples as soon as he arrived again at his grandparents' house for Christmas. He was devastated when he went into the garden that here were no apples, no leaves on then tree either. It was winter. Moreover, there is a progression in what they notice and begin understanding through direct interaction (Tunnicliffe, 2020, 2021).

Earth science is an integral part of a child's day and night experience. It is inextricably linked with the living world. Understanding natural rhythms of earth science and biology the season and rhythm of nature is perplexing to them and is gradually learnt, starting with day and night and the change in the sky, the phases of the moon which many children think they have observed for themselves and are very upset when they discover that other people have noticed the same phenomenon. Earth science phenomena of flat land and slopes, soils, surfaces, rocks, puddles, ponds and rivers for example. Making collections is a phenomenon of early yeas children in whatever environment they find themselves. This, encountering 'bits; of the outside environment attracts children who make collections of items, as they do in early maths activities. A collection of pebbles is a frequent activity of very young children when they venture into an outside environment where there is soil and pebbles, or gravel, twigs or pine cones are other items which are collected. However, working with the same child over a given period of time usually reveals progress in their skills, understanding and problem solving. However, following one child through their preschool development does show one child's progression.

Much of the actions in a child's play are concerned with physical science and materials. Pushes and pulls are the most frequent actions observed in a child's play. Progression can be seeing with the same item but used differently by children of different ages. Toys that have wheels are an often sought out and used toy, especially ones that are big enough for a mobile toddler to sit on and even propel. Firstly, a child tends to plush such a wheeled object bending over to place their hands on a stable part on which they can just, like trolleys that continue blocks for example. An older child finds that they can be mounted and pushed by their feet. In the case of the truck children one of the authors observed propelling it with his foot like a scooter. Small, wooded bikes were sat on and propelled by fee, often having to carry a passenger as these items were almost fought over by then children involved but sometimes a compromise was met. Two-year-olds in our experience make a dash for wheeled push chairs or other items and propel them around the room at great speed, often using them to collect items as they go. Progressing to role play and pushing a doll carrying a shopping basket.

Movement requires energy. Early years soon understand that pushes and pulls produce a moving result but the idea of energy needed to produce the movement is a more difficult idea. However, clockwork toys, pushing a wheeled vehicle moved them with conservation of the energy input experiences in action. Although, producing the energy to the system themselves is provided more difficult for them.

Energy has to be 'put in' for the play action to happen. The source of energy varies but is most often then child initially at this stage with straight forward direct force on the items Providing a store of energy such as electricity, solar water or wind power is a feature of some purchased toys. A toddler, but still in a push chair, loved visiting the local playground with swings. He liked moving up and down when he was pushed. One day he sat on the swing, but nothing happened. He looked round and called for his father who was no longer standing behind the swing. After a little while wriggling around complaining he fund the sewing moved a little. Eventually he learnt to use himself moving backwards and forwards to propel the swing, but he still had to be lifted onto it.!

Blocks, particularly, small wooden ones are an important object in the foundation experiences of western children. They intrigue children from the earliest of years. Observing a baby sitting up by surrounded by blocks, revealed how he used these brightly coloured blocks. He explored with some of his senses, but using a force intuitively as he picked up these wooden blocks, one by one, looked at them, felt them, mouthed one, put one block down and examined another. A few months after and able to crawl, he started assembling blocks in rows or squares, an early Maths activity. With a few more months he began putting one block on top of another and progressed to building a tower. Other mobile children did take an interest in seeing the tower fall and some in causing that to happen. Such activities were foundation experiences in maths, basic engineering. We have noticed that older children at about eighteen months love building towers, particularly with brightly coloured plastic blocs, a tower but laughing and laughing when their tall tower falls, and immediately rebuilds the tower and repeats the activity.

Blocks are made of various material, mainly wood or plastic and these children find that blocks of different materials do respond to tower building differently. Their experience of other materials such as living or once living, e.g. dried, dead leaves in the autumn, bones, is experienced through observing themselves and other biology specimens such as fruits, seeds flowering plants and a variety of animals that they are able to touch or observe closely. Such are often activities animal collections such as zoos and farms provide.

Water is most often explored at home and once a child can sit upright in a bath they start water experiences of their own. However, some play groups and nurseries may provide the opportunity for a child to interact with this material at a water table. Pools and containers of water are often phenomenon of the everyday environment, inside and out. Older children across the world where there is free water seem to be drawn to it and streams are dammed, bridges made to cross and items to float on the surface are constructed. Water was the first material which a new 11 months member of a playgroup met. His mother held him over the water tray. He delighted, with squeals of delight, being held over the water tray. He liked to plunge his hands through then surface and make splashes. He progressed to experimenting with putting things in the water and found some disappeared under the water but some, like the bath duck, floated. He pushed the floating duck back under the water, to remerged, when pushed it under again and so it went on until he lost interest. In all these actions he was experiencing the properties of the water and the items he was submerging after his first encounter, but again the physical interaction was utilising pushes and pulls in particular and linked by his mother to environments of water birds he had seen at the local pond. He had seen a plastic toy duck in the water tray which initiated her dialogue with him. Sand is a frequent material in nurseries and early years schools but not in playgroups or homes. However, these very young children are attracted by silt and fine dry soil on the surface of ground and run a hand grab full through their hands when they first encountered such. In some nurseries, kindergartens and schools enjoy investigating mud. Mud kitchens have become a feature of many formal early years establishments.

6.4.3 Progression in Play

Progression can be seeing with the same item but used differently by children of different ages. Toys that have wheels are an often sought out and used toy, especially ones that are big enough for a mobile toddler to sit on and even propel. Firstly, a child tends to push such a wheeled object bending over to place their hands on a stable part on which they eventually realise they can sit and prope it with their feet or later stand, balance and push themselves along with their foot like a scooter. Small, wooded bikes are sat on and propelled by feet, often having to carry a passenger. Such items which can be made to move are almost fought over by the children involved but sometimes a compromise is met.

Movement requires energy. Early years soon understand that pushes and pulls produce a moving result but the idea of energy needed to produce the movement is a more difficult idea. However, clockwork toys. pushing a wheeled vehicle. Provided them with conservation of the energy input experiences in action. However, producing the energy to the system themselves is provided more difficult for them. A toddler, but still in a push chair, loved visiting the local playground with swings. He liked moving up and down when he was pushed. One day he sat on the swing, but nothing happened. He looked round and called for his father who was no longer standing behind the swing. After a little while wriggling around complaining he fund the sewing moved a little. Eventually he learnt to use himself moving backwards and forwards to propel the swing, but he still had to be lifted onto it.!

6.4.4 One Child's Progression Case Study

Activities and Progression via Play based approach: A case study of one boy from two year two months to four years was carried out and field notes kept. Each activity was not followed throughout this period but activities which were the predominant source of interest to the child at a given period are reported here. The table presents the chosen activities as well as the different age that Child 1(C) was while accomplished the specific stages of the activities.

Table 6.2 summarises the play interest of one boy as he developed from an active toddler of 28 month through to four years old. This table shows he is establishing from his experiences the concept of testing, variables and fair testing. He has intuitively read data on an instrument (digital scales), recorded his results and come to conclusions from his experimental evidence. The play interactions reported here are of the free choice interaction which were the most significant free choice play

Table 6.2 Activities and progression via play based approach: A case study of one boy from two year two months to four years

Activity and STEM actions	Progression		
Playing with wooden magnetic trains (emergent engineering)	2 years and 2 months	2 years and 3 months	2 years and 5 months
	C was creating simple straight train lines with the assembling wooden parts having a start and a finish point.	The straight line was gradually becoming a circle, where the magnet trains was moving in a circular orbit.	C starts making more advanced construction where he placed a bridge and his wooden assembling parts were creating an ‘eight’ shape.
Magnets & Numeracy, Shapes, Spatial awareness	3 years and 9 months	3 years and 10 months	3 years and 11 months
	C is exploring some magnetic sticks and creating mostly straight lines of simple constructions, while he experiences the magnetic forces by placing together the different magnetic poles.	C decides to create a more complicated construction with the magnetic sticks, a 3-D pyramid. During the creation of the 3-D pyramid he needs to consider the magnetic forces as well as how to use the magnetic sticks.	C decides to create several 3-D pyramids, where they will have different side length. He creates a 3-D pyramid with side’s length of one magnetic stick, another one with side’s length of two magnetic sticks, also three and four. At the last stage C was confident with the magnetic forces and the construction of the 3-D pyramid itself and he compares the size of the different 3-D pyramids.
Slopes and ramps	3 years and 3 months	3 years and 4 months	3 years and 6 months

(continued)

Table 6.2 (continued)

Activity and STEM actions	Progression		
	C used his metal cars and by creating different level of inclination he observed how the cars are moving.	He explores the same inclined surfaces by using the same cars or by using different ones	Gradually, he challenges himself by considering other objects with or without wheels and try to predict how these objects might 'behave' when he pushed them while placing several materials at the inclined surfaces, such as sand or soil.
Ball games	3 years and 8 months	3 years and 10 months	4 years
Forces, Projectiles, Variables e.g velocity, size, distance, beginning of Fair testing	C was placing a plastic bottle in a distance and he was trying to knock it by using a ball	He was trying to knock the bottle by using different ways, such as coming closer, pushing the ball harder or even by using one or both of his hands. Then he decides to use different size of balls	After C experienced a variety of different variables such as distance, speed and different size of balls he filled the plastic bottle with water, and he starts by testing all the variables again.
Balances, scales and. Mass	4 years	4 years and 1 month	4 years and 2 months
Collecting, recording, interpreting data. Conclusion with findings	C is playing with a digital scale. He placed randomly different objects and identified their weight by reading the scale.	C placed several objects at the digital scale at the same time and when he identifies their weight, he removes one by one and refers to the number appears at the screen of the scale.	C used the scale to weigh one by one several objects such as toys, fruits and vegetables and while he writes in his notebook their weight he compares and constructs which is heavier or lighter than the other.

activity at that time and show a development of interest and skills before something else caught his interactional interest and he changed his focus. Through these incremental play interactions which increase as he develops this boy was establishing a foundational experiential understanding concepts through observations of actions of forces, friction, linking objects, balance and directional forces. He was learning about three dimensional shapes and the strength of the triangle. Additionally, from his hands on self-initiated activities he was experiencing acceleration and slowing from effects of friction, design of 'vehicle' and energy input though his interventions,. The height above the floor level of start position, are basic ideas we teach in science but also engineering and maths. The observations being with a more static activity for the child with the items provided in a train set with [preformed wooden rails] on which balanced a 'train' with wheels which fitted the rails and connected to carriage by a magnet so the child experienced the magnetic power as he joined but initially he just used a straight line, a beginning and an end. Having mastered such, he explored the circular pieces of rail from the set and managed to connect them making a continuous run. The final stage in his railway design was to develop a scenario in a visual narrative with a bridge and arranging the rails in a fissure of eight. While this boy was challenging himself, the straight line was gradually becoming a circle, as he experimented adding new and differently shaped pieces of rail to the track layout where the magnet trains was moving in a circular orbit. He then starts making more advanced construction where he placed a bridge and his wooden assembling parts were creating an 'eight' shape. Having experienced magnets in the initial play forming the link between the parts of the train, he explored magnets in the form of magnetic stick, firstly on the floor where he arranged the sticks in shapes in one dimension. One month later he added another spatial dimension to his use of these magnetic sticks. He experimented, using the understanding he had gained from his previous play sequences and managed to construct 3 Dimensional shapes, manipulating then magnetic sticks to utilise maximum advantage of the magnetism. A month later he thought out how to use magnetic sticks all for one length to construct a 3D pyramid but then make a larger pyramid with side lengths of 2 sticks. He was thinking in 3 dimensions experiencing design and construction but also recognising the mathematical shape of a triangles and pyramids in this foundation engineering activity. In between this exploration with magnets in several forms he became aware that his toy cars of metal work he provided the energy make them go by a push He then worked out that he could cause them to run faster if he added an observation aspect by starting. He constructed a car run where the car would start from the top of an incline above floor level by making a slope with a piece of card rest down on some books. Having established what happened he then introduced different kinds of cars and compared them with his original ones. Two months later he added two further dimensions to his play. Firstly, by seeing what happened to other objects such as a block, when the pushed them down the inclined slop and then adding different surfaces form the one which had been constant during his preceding investigations. This boy showed as he progressed. We assume using his previous experiences in play with these, with experience of his developmental age that he began to recognise variables. He began creating different level of inclination with flat surfaces and supports like a box or several books and he observed how the cars are moving (3 years and three months). This beginning to design an investigation and note the results. He explored the same inclined surfaces by using different cars, changing one variable, the type of car (he was 3 years and four months). He continued challenging himself by considering other objects with or without wheels on the inclined slop and seemed to predict to himself how these objects might 'behave' when he pushed he then in traduced placing several materials at the inclined surfaces, such as sand or soil (3 years and six months). and noting the effect. These were a complex set of ideas developed without any adult help showing the intuitive aspect of a child's play on the very early years. The examples shown in Table 6.2. show the development of realisation variables. This boy showed as he progressed with experience and developmental age that he began to identify, effectively by trial and error, variables. These were a complex set of ideas developed without any adult help showing the intuitive aspect of a child's play on the very early years.

6.5 Conclusion

Involvement in STEM actions from earliest years contributes not only to a child's developing scientific literacy but to their English everyday functional literacy and numeracy overall as well as their understanding of their world and the beginnings of finding out about the Sustainability goals for our planet (Harlen & Qualter, 2019, pp. 9–10). Children will investigate and try out objects they encounter. This type of activity is what adults call play, equating this child's foundation learning work with adult recreation. These interactions with objects and phenomena are essential in a child's development of understanding and experiences sciences, maths and engineering in action as well as enabling them to develop, enquiry skills and critical thinking. Children achieving outcomes in their play are in our experience pleased to communicate such and play can also contribute to socialisation and the literacy development of these young children. Above all, their play and the results from their initiative, develop a child's confidence and capabilities. Adults anxious to develop a child may need to stand back and leave the child, providing there are no safety issues, to solve interactions and situations for themselves, offering support with scaffolding questions but not telling and instructing. Bearing in mind that there are occasions when instruction in some safety issues is vital.It is the way many young humans begin to start constructing their understanding of their everyday world.

Active play and the experiences that occur are the foundation of STEM. Learning STEM is however progressive and the active supportive facilitating role of any adult with them is very important. Such facilitation support requires a certain pedagogical approach which may require practitioners to change their practice, it is of paramount importance that such issues as play, progression and pedagogical support are part of the training of new practitioners and preservice teachers. Moreover, recognising the role of home and the experiences of a child there can be those which trigger their interest in STEM, remembering children do not find out and learn in our formal school subject divisions, but holistically. Early Childhood education requires awareness co-operation and partnership between home and the practitioners in the variety of early years provisions. The child's learning of STEM through play is a partnership, and not only with the adults involved but mostly with the child.

Play is not of one type. There are a number of genre and the practice of them does depend on the location and context in which the child is playing. There is a distinct progression in the way a child uses play items as they develop skills, understanding and competencies. 'One size does not fit all' and children will fodder. However, the role of their adults is important, not from an instructional point of view unless it is a health and safety issue, but in facilitating and scaffolding the learning experience when appropriate. But first of all, the adults have to recognise in the play situations the opportunities for developing narratives sand focus on the STEM learning possibilities. For this they themselves need confidence in their appropriate STEM identity.

There were clear limitations to this study. First and most notably it was small-scale and qualitative study, making generalisations impossible. Second, the proposed Early Years Science Actions and Skills in Play are presented from a Western mostly perspective and it could be argued that at other parts of the world could not therefore, be adequately represented. Third, it could be argued that the research focused on the children's progression which is possible via the play-based approach and there is a need to explore other different perspectives which accrue from the present study in the future. In spite of the above limitations, the results from this small-scale study are original and suggest that children progression via play-based activities is possible.

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Chapter 7
Play and Mathematics in an English Early Years Classroom

Monica Smith

Abstract This chapter examines play and mathematics in the early years in formal school in England, which are the years between four and eleven. Most English children begin formal preschool at three years of age, and some attend nursery classes even earlier. Mathematics is one of the specific areas of learning in the early years' curriculum in England, a subject that is a lifelong necessity. The 'characteristic of effective learning' *Early Years Foundation Stage Development Matters* highlights the approach to teaching and learning in the early years as one of 'engagement, motivation, and thinking.' Based on this, children will learn to explore and investigate the world around them, develop their interests, and discover and solve problems through play, which is the main source of development in the early years. Play embodies the whole child and is the precursor to the development of early learning, enabling the child to test out learning without the risk of boredom. Play is a more natural and comfortable way to learn to retain information., especially regarding mathematical experiences that build strong connections and relationships between learning and life through their daily activities, interests, questions, and conversations.

Keyword Educational development · Free play · Guided play · Hands-on approach · Practical play

7.1 Introduction

Children learn about the world into which they are born. Thus, we as practitioners strive to learn about the child's mind (Donaldson, 1978) as we seek optimal ways to facilitate their learning. Mathematics is very much a part of this everyday world and relating our teaching from the prescribed curriculum to the child's mind is the task of the adults working and caring for them. Children lack in experience and in these early years are exploring and discovering learning effective strategies for them (Grenier, 2019).

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Children in England begin formal school earlier than in many countries. A child must by law start full-time education once they reach compulsory school age of 5, in the term after their fifth birthday (School admissions, n.d.). However, most children start at 4 years in what is known as the foundation stage. The government document *Statutory framework for the early years foundation stage: Setting the standards for learning, development, and care for children from birth to five* (Department of Education, 2017, 2021) establishes standards for development, learning and care of children below 5 years of age which must be followed by all registered care providers, preschools, nurseries and school reception classes registered with the government through the Office for Standards in Education (OFSTED) and are inspected regularly as are schools (Ofsted, 2019).

The teaching of mathematics in the early years is practical (Ginsburg et al., 2008; McLennan, 2020). What does this mean? Children at these ages use tangible, hands-on resources, movements as in songs and rhymes, percussion instruments, and games that stimulate the brain and make learning more exciting and meaningful. It is also considered to be a more natural and comfortable way to learn to retain information. The enabling environment in the classroom creates a structured play facility where children are stimulated, development matters in considering the learning environment (Early Education, 2012; Griffiths, 1988). However, in some cases, a child is 'over stimulated' with an array of choice of equipment and resources that allow them to experiment with space and measures within the sandpit, with building blocks or water play throughout the learning areas. In most instances, children engage in free play and guided play, spending quality time at any one activity during free play, without intervention illustrating Vygotsky's theory of zone of proximal development (Vygotsky, 1978). In the case of children with English as an Additional Language (EAL) and other culturally diverse needs, a guided intervention approach often helps children come to terms with cultural expectations and to access the curriculum (Whitehead, 2004).

Early Years education in England combines care and education for children from birth to five-years of age. It is a service provided by a range of providers, child minders (in domestic homes), privately run nurseries and preschools, government stand-alone nursery schools and nursery and reception classes within primary schools. Children between the ages of three-and-four years old are entitled to free universal part-time care and education for fifteen hours each week. Full-time services are available for thirty hours per week specifically for working parents earning minimum wage. Children are excepted on or after their third birthday until they enter formal school, at four years of age, which is not compulsory, and provides parents with the option of having their child attend full time or part-time reception classes.

The Early Years Foundation Stage Statutory Framework provides quality early education that is instrumental in setting the standards for early learning. The aim is to foster teaching and learning that offer a broad knowledge and skills that prepare preschool children for compulsory structured learning refers to as 'school readiness' (Department of Education, 2021). The EYFS curriculum has seven areas of learning: communication and language, personal social and emotional development and physical development, mathematics, literacy, understanding the world and expressive arts and designs. In collaboration with the Characteristic of Effective Learning (COEL) in Development Matters (Early Education, 2012) the non-statutory guidance, practitioners are supported to learn about children's learning styles. The Characteristics of Effective Learning are also interconnected through playing and exploring, active learning, and creating and thinking critically (Buckinghamshire Council, 2020).

Successive government and educationalists in England over the past decades have commissioned research that have reported on the value of early years education and have pinpointed the lack of focus given to mathematics in comparison to literacy (Ginsburg, Lee & Boyd, 2008; Kowalski et al., 2001). In addition, policies have highlighted the need for maths and science implementation in preschool environments (Brenneman et al., 2009; Fisher et al., 2011). Research findings found that Early Years practitioners needed more training in early years mathematics. A UK Government cross-party committee for Maths and numeracy (APPG, 2013/2014) revealed that 'twenty-eight per cent of children in England at the end of Early Years Foundation Stage failed to achieve the expected level in mathematics,' with children from disadvantage background vastly underachieving at the end of preschool. They made recommendations that highlighted the need for training, also citing a lack of mathematical confidence and competence among parents and practitioners. In light of concerns expressed in the media, the Department of Education looked to the Far East for teaching initiative in mastery of mathematics in a pilot to reduce the dearth of achievements (Kim, 2011). Ofsted's (2019) inspections of Reception classes (ages 4 -5 years), looked at the end of the Early Years Stage (EYFS) and identified that the teaching of mathematics still did not have, the same prominence as literacy. As a result, OFSTED called for raising the profile of mathematics teaching through investment training. The Early Years Foundation Stage 2020 curriculum has emphasised the teaching of mathematics as a focus with an emphasis on teaching through play that is 'planned purposeful and guided' by the adult, with free play running concurrently (Department of Education, 2021).

7.2 Knowledge and Learning

Early years' is a unique stage of learning that requires time, space, and knowledge of how children learn. It is necessary, therefore, that practitioners are versed in their knowledge of the child, how they think and learn, to ensure that they can recognise and support young children's learning and developmental needs. Practitioners must observe and interact with the children to learn about them. These skills are essential for good early years practice, providing vital knowledge of the child, how they learn, their specific needs, strengths, and capabilities. Thus, mathematics in the early years consists of taught episodes alongside observations of children's self-directed play (Williams, 2020).

Knowledge of the child by their adults is necessary to enable learning and development. The observation, assessment and planning processes are essential in the role of the early years educator in providing, recognising and assessing children's learning needs (Drake & Reid, 2018). Thus, the adult requires knowledge of the stages of mathematical learning, and that of other curriculum areas, in extending the learning of their pupils since adults' knowledge of children's early maths ability appears to be lacking, as well as their confidence to develop that of the children. The Office for Standards in Education Children's Services and Skills (Ofsted, 2017) inspection noted that the Government's initiatives and investments were directed toward literacy development, with less emphasis on mathematics. Similarly, Ginsburg, Lee and Boyd (2008), found that, in the United States, children's abilities were 'underestimated' and that teachers' approach to teaching mathematics focused on the learning of mathematical language.

Parental knowledge of their children forms the foundation on which subsequent learning is built. The importance in the home and parental role in a child's learning has been recognised, and the home as the foundation of a child learning (Cai, 2003; Tizard & Hughes, 1984), including liaison between school and the home. Home visits by practitioners create an environment that allow for the practitioner to learn about the child and their family (Carruthers & Worthington, 2006, pp. 216–227) and to use the knowledge acquired to develop meaningful conversation with the child. It makes transitioning from home to nursery less stressful. Moreover, knowledge obtained from the home visits is used in the classroom as an interactive learning display to help the child settle in, thus offering familiar experiences on which the child can develop early maths skills. In my nursery class, maths begins on arrival when each child finds his or her name and registers, 'I am in' followed by matching their own coat and bag to their names on the coat pegs. These are deemed 'suitable experiences' (Liebeck, 1984), that are familiar and help children to feel secure (Kelly & Blenkin, 1988). It is a daily routine that is supported by parents and practitioners on arrival, before the children are able to do so independently, an endorsement of Vygotsky's philosophy of 'social interaction' (1978).

During the early separation period, I have observed children gravitate to the self-registration wall and family board displaying photographs of their families and engage in observation and talk. The observation provides the practitioner with the opportunity to assess use of mathematical language, social skills, and emerging thinking in maths (Williams & Shuard, 1983). Children show what they know through their play. The young child's development and understanding of spatial awareness comes before early language (Kelly & Blenkin, 1988). Maths in action is all round in these early years classrooms or learning areas and can be explored through playful inquiry through which confidence in maths is built (McLennan, 2020).

Children learn to relate by matching common everyday things (Liebeck, 1984), even if they are not using numbers or comparative language while doing so. It is not uncommon to see a young child walking around the nursery with a toy, usually a rectangular shaped popular plastic brick or wooden block as a telephone. How does she know what shape to select? Children use symbols in the absence of the real object to make representation, a theory both Piaget and Coltman (1970) as well as Vygotsky (1978) identified in pre-school children's cognitive development. Counting and numbers are also widespread in children's play. A young child threading beads for instance, will start counting, singing number songs or while playing with the small world toy, sorting and matching animals or colours. Counting of this kind will also be happening at home, as the child climbs the stairs or helps to lay the table. They are using number names in action. Mathematics is everywhere (Aigner & Behrends, 2010). Moreover, vital information has been elicited about children's early maths ability and its relation to future progress and success at preschool and beyond (Clements et al., 2015; Germeroth et al., 2019).

Vygotsky (1978) found that the child at play 'behaves beyond his average age.' In the English early years settings, guided play or structured play where the learning is directed by the adult, and free play also referred to as child-initiated play where the child creates his learning, are central to early years' practices. These activities tell us what they know through the choices they make, making observing a vital early years tool. In most nursery Early Years (EY) settings, the provisions and learning areas consists of a home-corner, sand, water tray, small world area, large and small blocks, climbing frame, bats and balls, mud kitchen inside and outside, all incorporating early mathematical awareness through exploratory means in solitary play, parallel and co-operative play.

What do practitioners need to know? The English Early Years Foundation Stage (Department of Education, 2021) and Development Matters (Early Education, 2012) non-statutory guidance outlined the expected areas of learning and guidance on children's stages and rates of development. With the child at the centre of the learning, the onus is on the practitioners to create a balanced-learning environment that meets the required Early Years Foundation Stage (EYFS) curriculum Good Level of Development (GLD) through the needs of the child.

In the English Early Years classroom, the opportunity to observe and learn about the child is endless. Research studies of early years maths awareness found that children's concepts of maths develop much earlier than their ability to communicate (Kelly & Blenkin, 1988). It is no wonder this is the case, as children spend much of their time exploring and manipulating shape and space long before they begin to make representation and learn the language. These examples are observed regularly in a nursery classroom, where the child directs the play, learns to solve problems, and seek adult's support to bridge the learning 'gap,' consistent with Vygotsky's (1978), zone of proximal development. Table 7.1 provides examples of learning areas and provisions in English nursery classrooms. Communication and language, as well as personal, social, and emotional development run through all the learning areas. Mathematics also encompasses all the learning areas.

7.3 Play

Play is the vehicle through which young children learn to make sense of their world. Learning through play has long been the philosophy favoured in the teaching and learning of young children. Montessori principles and practices have formed much of the foundation of early years practice today (Lillard, 2016; Piaget, 1962; Vygotsky, 1978). In recent years, studies have emerged that continue to build on the earlier

Table 7.1 Example of learning areas and provisions in English nursery classrooms

Creative area (expressive arts and designs)		
Painting Area • Easel and table • Paint and paint brushes • Chalk, pens, pencils and coloured pencils, wax crayons **Sand & Water** • Buckets and spades of various sizes • Scoops, sieves and funnels • Bottles of various sizes • Shapes, numbers, and Letters • Pots, pans, and spoons • Water animals	**Small World Play** • Farms & jungle scenes with animals • Manufactured construction toys • Dollhouse, play people • Wooden blocks • Cars, lorries, road mats • Magnetic trains • Twigs, leaves, planks	**Home Corner /Role Play** • Table, chairs, play food • Plates, cups and saucers • Plastic spoons, forks and knives • Cooker, washing machine, kitchen appliances • Dress-up clothes **Construction** • Large and small wooden blocks • Magnetic Blocks • Natural Wood and rocks • Legos, Duplo blocks
Understanding the World • People and community, technology and the world • Natural Wood and rocks, conkers, pinecones • Manufactured objects—mirrors, coloured shapes • Mini-beasts, grass, garden • Magnifying glass, magnets • Megaphones, microphones, telephones • Fabric • Outdoor learning and natural environments • Exploring mud kitchen • Mini-beast hunts, experimenting and observing changes in the environment	**Mathematics** • Numbers, Shape, Space & Measures • Numbers 1–10, 1–20, 1–100 • Number games • Number puzzles • Counting and sorting objects • Shapes, 2D & 3D • Abacus • Number stories, number rhymes • Tape measures • Outdoor learning • Shapes in the environment, space, measures • Games	**Literacy** • Writing table • Paper, pens, pencils, chalks, crayons • An assortment of paper • Chalkboard • Books, diaries, • Book-making activity • Children's names • Reading area • Alphabet, books for reading, • Puppets (manufactured and children's own)
Physical development (motors skills)		
Fine motor skills development • Using scissors • Playing with strings for threading and wool for weaving • Using twigs, leaves, planks	**Gross motor skill development** • Outdoor Play • Running, jumping, and skipping rope • Engaging in ball games • Using a hula-hoop	

theories of play as an essential instrument for learning. Wood (2013), as well as Kelly and Blenkin (1988) for instance, advocate the benefits of play in the early years, and Gray (2013) described play as a 'powerful' method for learning in all areas.

Through play, children explore, investigate, and discover their surroundings. It is the way children have evolved with this instinctive behaviour (Gray, 2013). They learn to become sociable, share, practice counting and matching skills, and think and problem solve. The Early Years Foundation Stage curriculum revised in 2020, and the Development Matters (Early Education, 2012) non-statutory guidance endorse play as the primary teaching approach in Early Years Education (EYE). Both stress the need for structure to comply with learning expectations at the end of the foundation stage, an approach that sees its overall meaning adapted to suit the curriculum expectations, thus make teaching and learning through play a two-tier approach where learning through play is structured and unstructured. The terms guided play and free play in this chapter highlight how children through their play explore, investigate, and discover science, technology, engineering and mathematics (STEM) content, teaching already prevalent in Early Years (EY) learning.

Guided play refers to activities that are 'purposefully planned' and directed by an adult. The aim is to ensure that children have varied experience under the direction of the teacher to acquire the skills and the knowledge necessary to meet the expectations of the Early Years Foundation Stage (EYFS) curriculum, Good Level of Development (GLD) by the end of preschool. Much of the current learning in nurseries classes is focused on guided learning. Guided play, a genre of mediated play, has its root in Vygotsky's theory zone of proximal development (ZPD), where the more experienced assist the child to understand through intervention. Free play, on the other hand, encompasses choice, spontaneity, and exploration. It allows for free choice and self-direction. These principles are rooted in Piagetian philosophy that children develop through their exploration of the world, being 'active and constructive' (Piaget, 1962), an approach that can make learning trajectory challenging to process within a structured system of education (Wood, 2013).

In a recent Ofsted report (2017), the view of one nursery head teacher on play described it as a 'rosy and unrealistic view of childhood.' This perception is held by many educators and policymakers whose appreciation of education stem from the formal structure of teaching that favours a top to the bottom approach where young children become accustomed to the academic philosophy of direct teaching. Other arguments against guided play maintain that it does not compliment how children learn and that it impinges on the whole purpose of play. The learning environment and activities are often pre-prepared by the adults which lead to additional concerns that too much adult input could affect the child's time and space to apply and reflect (Abbott & Moylett, 1999). However, there is a gradual recognition of the importance of play-based learning in the early learning of mathematics by practitioners on their learning (Ali et al., 2013).

Among some of the commonly used terms in pre-formal settings in England, describing nearly everything that children do in the learning and activity areas found in nursery classrooms, are labelled as construction play, sand and water play, small world play, physical play, and role-play. Overall, the most distinctive category of play observed in the nursery classroom is parallel play, solitary play, pretends or imaginative play. Play extends to the areas of learning and involved free-play between mixed-age groups of three to four years old.

The term ‘free-play’ in the context of the nursery classroom means the freedom to explore at one’s own pace and time, allowing the child to follow the child’s lead. It is not unusual for the children to transform the teacher’s intention, even if it follows on from their interests, and transport equipment from one place to the next. Several examples of free play follow, beginning with Amy, a four-year-old, who uses her experience to initiate the theme of the play and to act-out a picnic scene with her peers. Working cooperatively, the children explored their ideas that generated their mathematical thinking.

7.3.1 Amy’s Play

Children are playing together in the home corner. They are cooking and serving food. Amy tells her friends, “*We are going to a picnic*,” drawing on her previous experience of a family picnic at the weekend, she had previously shared with an adult. They begin by going on a journey, carrying with them food for the picnic. They travelled to the reading area that became a picnic scene. They invited other children on their journey. At the scene, they laid a cloth on the ground directed by Amy; some used cushions before serving snacks. Everyone has a plate. When they ran out of food, they returned to the home corner for more so that everyone had some. When other children wanted to join, they made space by extending the area beyond the reading area. It became popular as more children joined. They engaged in cooperative play that involved multiple areas of learning for an extended period.

The child, as the initiator, used her experience to develop and extend the play. They applied the use of mathematical language, using the concept of more and less when they ran out of food and replenished. They participated in sharing, ensuring that they all had food and develop one-to-one correspondence. They showed their sense of spatial awareness, when the space got too small to accommodate the additional children who joined, they recognised the need for more space and widened the area. Williams and Shuard (1983) and Kelly and Blenkin (1988) identified spatial awareness as their first mathematical exploration. The observer collected photographs, video and written evidence of the children’s emerging mathematical knowledge and experience, an understanding of how learning takes place and ways to extend their mathematical thinking through planning. To the practitioner who is not familiar with the early years, the range of learning, maths and problem solving displayed in this example may appear chaotic or a missed opportunity. Abbott and Moylett (1999) emphasised that learning needs to be challenging and that ‘powerful learning’ occurs at the junction of order and chaos.

7.3.2 Maths and Feely Bag

A maths lesson through guided play is in this example. Children three-and-four years old explored two-dimensional shapes with the teacher using a feely bag. The learning intention was to find out about two-dimensional shapes using their sense of touch. They took turns to select a shape and describe its features, and then guess the shape before removing it from the bag. The activity continued the next day with a shape hunt. We recapped on the shapes discovered on the previous day before we explored shapes in the outside area in search of the two- dimensional shapes in the built and natural environment. They were encouraged to look high, low, all-around. Sami, a four-years-old boy was quick to share his discovery. "I can see a semi-circle!" He pointed to the top of the building to a semi-circle etched into the brickwork. The practitioner confirmed it was a semi-circle and praised him for his knowledge. Although semi-circle was not one of the shapes explored, Sami was familiar with the shape and was able to link it with his current experience.

7.3.3 Guided Exploration Outside

This example of guided exploration of the outside areas allowed the children to make further connections between the modelled shapes encountered with the feely bag and the built environment. Despite being a guided lesson, it was active and exploratory, which gave the children the scope to explore freely. At the same time, the practitioner observed and intervened to bridge the learning 'gap' consistent with Vygotsky's theory (1978), merging the philosophy of 'social interaction' and Piaget's 'active and constructive' theory (Wood, 2013) in this activity incorporating elements of free play and guided play. This exercise also emphasised how practitioners can merge classroom learning with the broader environment and the real world to develop children's higher level of thinking and understanding of the structure. This STEM activity included exploration of semi-circles, how this shape got onto the brickwork, and lead to the next steps for creative learning about semi-circles and their relationship to circles in more details. The nursery class observed embodied learning, that is the children had the opportunity to lose themselves in new experiences, develop their curiosity, problem solve, and discover more about familiar experiences under the guidance of the practitioner.

7.3.4 A Play-Based Learning Microcosm

The early years' classroom is a microcosm of learning that is play-based. It gives the child the time to explore, investigate, experiment, and develop their mathematics, as well as scientific and engineering skills and ideas. A new child to the setting, for instance, who is accustomed to numbers and counting at home will seek out number activities in any preferred areas of interest. Every activity they choose will be a reflection of personal interest and experience. For example, playing with farm animals, building blocks, climbing up a ladder, throwing and catching a ball, the child with a counting disposition will use the opportunity to explore counting. In the same instance, the child whose interest is building will spend time and use various resources available to build. Through free-play or guided-play, the preschool child has ownership of the learning areas that allow them to follow their interests in the scope provided, to experiment with everyday maths ideas and discover new experiences.

7.3.5 Developing STEM

Much of what is needed to develop mathematics and other integrated subjects in science, technology, engineering, and mathematics (STEM) education, start with the experience and training of early years educators. Repeated reports from government inspectors, Office for Standards in Education, Children's Services and Skills (Ofsted, 2017) called for improvement in the teaching of mathematics in Early Years (EY). Studies conducted in the United States and Canada in pre-formal learning of mathematics has identified the importance of mathematical development at the pre-formal level of education. Clements et al. (2015) identified early maths as a 'predictor to school success' and Ginsburg et al. (2008) found that children's "capabilities are underestimated." Also highlighted in Clements et al. (2015), educators 'underestimate' beginning student's abilities. Lefevre et al. (2009) observed that practitioners in Canada needed to be 'aware of what constitute early numeracy' while in England, the Office of Standards in Education, Children's Services and Skills (Ofsted, 2017) inspectors, highlighted the need for better teaching of mathematics and numeracy in the Early Years, and English All Parliamentary Party Group (APPG, 2013/2014), called for better training and parental support to combat the underachievement of preschool children in maths, in particular for children from the disadvantaged background.

In a system that has a statutory curriculum that requires teaching to be directed by the practitioner, exploratory play that supports discovery learning will be challenged to coordinate the needs of the child with the expectations of the Early Years Foundation Stage (Early Education, 2012), Early Learning Goals (ELG) at the end of preschool.

7.4 The Role of the Adult

The role of the adult is the most critical resource that is necessary to maintain the balance between free play and guided play. The adult's role in a nursery classroom role is comparable to a scattered jigsaw puzzle that requires time and patience to collate and assemble the pieces before understanding the whole picture. It is a multi-faceted role that requires the adult to have knowledge of the child as a learner understands and can create a learning environment that is conducive to learning (McLennan, 2020). That encourages independence, and motivates, and stimulates children to learn. The adult in the early years must ensure that every moment offers a learning opportunity that matches the child's interests and learning needs, through 'positive relationships.' Development Matters the Non-Statutory Guidance (Early Education, 2012) is pivotal to learning about the child. The relationships extend to the parents who have vital information of the child; their specific interests, strength, and skills, to ensure that the child starts from a 'place of confidence' (Kelly & Blenkin, 1988). The relationships provide the practitioner with a holistic picture of the child that will inform the baseline assessment and knowledge of the child's early mathematical development.

Planning and observation of play is important in the role of the early years practitioner as it ensures catering to the needs of the child and usually derives from prior knowledge of the child, observed during free play, guided play, and from the parents' knowledge. These insights into the specific interests of the individual child form the learning activities that inspire and promote free play as well as encourages guided play. Practitioners learn much about mathematical learning through observation (McLennan, 2020), and discussing the planning of the learning environment addresses the needs of the child which is paramount. Given the unique developmental status of the child, the practitioner must apply strategies and approaches to complement children's learning patterns by modelling skills to widen children's experiences and pass on new knowledge through intervention that offers support to bridge the learning 'gap' (Vygotsky, 1978) in the foundation of mathematics. According to Reiss (n.d.), "A proper [STEM] project entails each student, whether they work on their own or in a group, having sufficient autonomy truly to be in charge of what they are doing, so that they can think and act authentically" (para. 16). Figures 7.1 and 7.2 provide an example of a parent and teacher offering and developing the child's learning experiences that matches his interests in bridges and construction.

7.5 Trying Out Prior Learning

There is ample scope for children to try out their prior learning and experience new maths ideas in the nursery classroom. The following example highlights how children, through their play, initiate learning by recalling previous experiences and develop new maths skills. A mixed group of three and four-year-old children are sitting at the creative table. They are playing with play dough. Other resources available at the table include rolling pins, regular two-dimensional shape templates, and plastic cutlery. Using the rolling pin, they rolled and used the templates to cut the dough. Cara, who is three years old, selected a triangle cutter and announced that she is making a pizza. Another girl, Emily, who was also rolling the playdough went to the home corner. She came back with a plate, which she placed on the table. Cara

Fig. 7.1 Leon pursues his interest in building a bridge in his nursery class

cuts out the triangular slice of pizza and puts it on to the plate then walked over to the adult and handed her the plate. “Your pizza,” she said. The adult thanked Cara for a “lovely slice of pizza.” A boy, Stephen three and a half years old, who standing nearby playing with the blocks informed them, “that is not a pizza, it is a triangle.” Adult repeated, ‘thank you for the triangle pizza,’ then told Stephen, “you are right; it is the shape of a triangle.”

Emily associated the serving of food with a plate, showing her awareness of matching ‘common properties’ (Liebeck, 1984). When Cara saw the dough and the triangular cutter, she associated her knowledge of pizza with triangular shapes, although she did not use the word. Kelly and Blenkin (1988) observed that children’s awareness of ‘space and shape develop before language.’ Stephen on the other hand did not associate the shape or the dough as a slice of ‘pizza,’ because ‘it was not real.’ In this example, Stephen chose to use the real name, ‘triangle,’ showing his ability to recognise two-dimensional shape, although he was not capable of using symbols (Vygotsky, 1978). The observation revealed how children’s maths development can be stimulated by the learning provision and how their varied developmental levels comply with their thinking and ability to use symbols. It also provided valuable

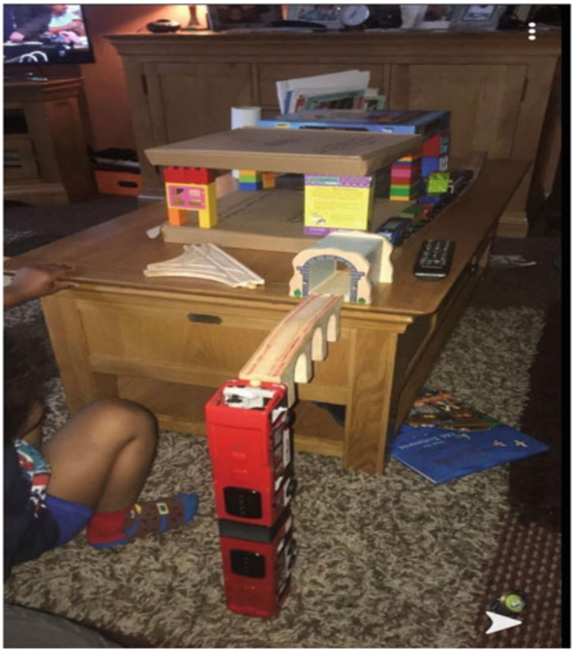

Fig. 7.2 Leon is developing his skills at home

evidence of maths awareness for future lesson plans and record for their learning journal.

7.5.1 Specific Area of Learning-Mathematics

In the English Early Years Foundation Stage (Ofsted, 2019) mathematics is one of the specific areas of learning that focuses on the learning of numbers and shape, and space and measure. The example below demonstrates the importance of the learning provisions, inside and outside, and indicates how the practitioner can add learning props to the environment to contribute to children initiating and challenging their own learning.

The children are counting, recognising numbers, and beginning to understand the value and sense of cardinal numbers. The children are playing with a ball outside. Displayed on the fence of the ball area are numbers from 1–30. Harmony ran to retrieve the rolling ball and noticed the numbers on display. “I can see three,” and held up three fingers. She called to the adult nearby and pointed to the number 3. The adult praised her and asked, what other numbers are there? She counted 1, 2, 3, pointing at each number and stopped at 3. The adult observed and responded. What number comes after 3? She counted 1–6, pointing at each number before running back to the game. Mary, with whom she was playing, watched as Harmony counted.

She too attracted the attention of the teacher, to show her ability. “Miss, I can count to 30.”

She counted 1–30, pointing at each number. “What number comes after 30? 31, but there are no more numbers.” Not only does their play initiate their counting, but it also informed adults of the children’s capabilities. The children’s self-initiated counting made a valuable addition to their learning journal and informed the adult of their maths capabilities. The aim of the numbers displayed in the outdoor environment was to attract the children’s attention so that they become accustomed to seeing numbers all around. Through being ‘active and constructive’ (Wood, 2013), the children drew on their prior knowledge. Vygotsky referred to this as ‘cultural tools,’ learning acquired at home which was encouraged by the adult positive relationships (Development Matters in the Early Years Foundation Stage (EYFS), 2012) who created the opportunity, space, and time, for them to explore, and the confidence to share what they already know. Duncan (2007) and Karsli and Allexsaht-Snider (2015) explained that numeracy is part of children’s play, and Ginsburg et al. (2008) found that children spontaneously show interest in mathematics. The early years educator is an asset in that they facilitate learning through a well-organised ‘environment,’ that stimulates, motivates, and challenges children’s ability (Kelly & Blenkin, 1988), through free play and guided play.

Although child-initiated learning in this setting relies on the adult to pre-select and display the learning activities, the child has the freedom to choose. The adult’s responsibility is to ensure that the activities available encourage and stimulate mathematical development with resources that trigger children’s curiosity and challenge their cognitive ability through free play and guided play. In doing so, we allow children to develop confidence in their ability and ease with their mathematical development.

7.6 Conclusion and Recommendations

Policy makers and the body of research considering the development of mathematical understanding in the early years in English education appreciate the value and the need for improved practice in early years mathematics. They are also aware of the impact it has on children at the preschool level and beyond if the early stages of learning are not in place. One significant step is that there is a framework that is universal. The guidance does not however dictate how practitioners teach, but provides the support that guides educators to find out what they need to know about the child as a learner. It proceeds to make suggestions that assists developmental learning across all areas. It is yet, 2021, far from perfect now, as with use further improvements emerge to improve what is currently on offer. The revised Early Years Foundation Stage (Ofsted, 2019) and Development Matters (Department of Education, 2021) guidance began in schools for the 2020–2021 academic year.

Some of the indicators for the future development of mathematics and the recognition of STEM in the early years requires Government investment, a requirement that has been highlighted in successive such as Ofsted, 2017–2018 reports and the APPG, 2013/2014, cross-government working party. Reports have also specified the need for better training of practitioners to help stop the low maths attainment at preschool. Practitioners' knowledge featured a great deal concerning the early years pedagogy suggesting most of the flaws are the need for better training (Clements et al., 2015; Germeroth et al., 2019; Ginsburg et al., 2008; Kowalski et al., 2001; Williams, 2020). Furthermore, there is a disparity in the training offered to practitioners in English preschool settings. For example, a child minder, an early years practitioner employed in day nurseries privately run and early years teachers in schools, does not have the same training or qualifications despite working in the same field. To improve the quality of Early Years Education (EYE), in particularly maths and other STEM subjects that flow through early years, we must recognise that EYFS is a distinctive phase within itself with different needs and approach to learning.

Play and mathematics are prevalent in the English nursery classroom. The recognition of mathematics within the play is what we need to overcome. Mathematics is all around us. In light of the need to build mathematical competence and the benefit it has, mathematics should become one of the prime areas of learning in the EYFS curriculum, which will give it the focus it needs to thrive. Currently, mathematics shares the specific areas of learning with literacy that has had substantial investment and a higher profile. Given the same focus, mathematics would be better recognised, better taught and better valued.

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Chapter 8
Play, Science and Engineering in the Early Years in Australia

Coral Campbell and Chris Speldewinde

Abstract This chapter provides insight into science and engineering learning through play in early childhood education in Australia. Discussion includes the roles of government, the curriculum documentation and educators' involvement. Early childhood education in Australia is directed by government legislation at both the Federal and State levels. A guiding document for early childhood educators, the Early Years Learning Framework (EYLF) provides direction for the structure, care and practice in early childhood learning and development around the country. In the EYLF, disciplinary-based learning is not mentioned, with the consequence that Science and Engineering education has tended to be unsupported, relying on the educators' interpretation of what this provision might look like. However, with recent Federal Government funding of several programs that are investigating science and STEM provision, STEM education (including science and engineering) in preschools appears to be taking on greater importance. This chapter discusses several initiatives which are influencing current policy and practice and will use recent research findings to comment on the engagement of science and engineering presented through children's play experiences.

Keywords Play · Science · Engineering · Engagement · Policy initiatives

8.1 Introduction

Education in Australia is both a Federal and a State government issue. The Federal Government provides funding to the states, but the states must also use their own state budgets to fund educational institutes such as preschools, primary schools and secondary schools. At the local level, preschool provision is overseen by the local government, under the jurisdiction of the state education department. The

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National Quality Framework provides guidance for 'an integrated and unified quality and regulatory system for early childhood education and care' (Nolan, 2018). It achieves this through a national legislative framework, a National Quality Standard, the Australia Children's Education and Care Quality Authority and the national Early Years Learning Framework (EYLF, Department of Education, Employment and Workplace Relations, DEEWR, 2009). Early childhood education, through the ages birth to five years, is not compulsory and is provided to children in Australia through the EYLF. Preschool education (frequently called kindergarten) occurs in the year prior to formal primary school education and is delivered by both childcare centres (privately owned and managed) and government preschool centres. Children are nominally four to five years of age during preschool. The preschool program is funded by government for 15 hours each week, with 85.7% of children attending pre-school the year before school. Children who are younger than four and five years old, can attend a three-year-old 'kinder' but this is often privately funded by parents.

Although there are guidelines that educators can access through the EYLF (DEEWR, 2009), there is no mandated curriculum. The Framework is designed to outfit educators with a common language about children's learning and to be able to communicate that to children, families and other professionals. The EYLF stipulates five learning outcomes for young children birth-five years that include that children: have a strong sense of identity; are connected with and contribute to their world; have a strong sense of wellbeing; are confident and involved learners and, are effective communicators. The implication for learning in the discipline areas of science and engineering is that without specific guidelines, educators lack support in making sense of children's learning in these key STEM areas.

8.2 Learning Through Play

According to the EYLF, children's learning is recognised as dynamic, holistic, and complex—and developed through play situations, 'Play can expand children's thinking and enhance their desire to know and to learn' (DEEWR, 2009, p. 15). Grieshaber (2010) discusses that the EYLF promotes both free play and play-based learning. However, she indicates that the challenge for educators will be to find a balance between free play, and planned curriculum experiences to extend children's learning in play-based ways. Learning through play allows individual expression of personality, curiosity, and creativity while enhancing children's opportunities to make connections across their experiences. Nolan (2018) highlights that unscaffolded play may not always lead to children's learning but suggests that educators and children become co-constructors in the learning environment. Play-based learning has developed to be explicitly recognised as 'providing opportunities for young children to explore ideas, experiment with material and express new understandings' (Edwards, 2017), with the emphasis on educators intentionally supporting children's learning.

In Australian preschools, children experience what is called 'free play' (Rubin et al., 1978) where children instigate play, which may or may not be supported by the materials available in the preschool environment. This is a form of mediated play where children choose the object and form of their play. With planned activities, preschool settings may be set up with themes which facilitate children play. Specific items are available for the child to play with and possibly experience new ideas. Alternatively, the educator may plan an activity which intentionally leads to the child developing a skill or understanding in a particular knowledge area (instructional play). The EYLF promotes the idea of 'intentional' teaching which can incorporate both planned and what has previously been called 'in the moment' or spontaneous teaching. In these situations, educators may be called into a play activity by a child and asked to contribute, or the educator may choose to enter into the play situation to scaffold new learning, to focus children's attention on something specific, or to provide attention—indicating a valuing of what the child is doing and affirmation of their learning.

Science and engineering (STEM) learning can occur naturally through many of children's normal play activities—for example, informal measurement and categorising (maths). In science, a child climbing a tree experiences the grip of shoes against the tree (friction), the positioning of the body to achieve balance (forces and gravity) the smell and feel of the tree (biology and textures). Children frequently play with loose parts or specific items to construct towers, roadways, and landscapes in their environment, engaging with the engineering process and developing engineering skills. An educator, purposefully moving into children's play, may be able to enhance the learning by asking questions about the tree-climbing experience or by focussing the child's attention on some part of the construction process to assist the extension of the child's ideas.

Autonomy is provided to the educator to design curriculum specific to the local community and specific setting, beliefs and policy. Educators may plan activities for part of the session; however, the preschool day is usually divided into short segments of free play where a child can move back and forth through the resources available to them. There is usually time spent inside with more structured materials such as books, toys, and other material (to suit a learning focus or topic). A significant proportion of each day is also spent outside, and most preschools have an outside area that is designed to be as natural as possible but will also contain features such as a digging area (sand pit), grassed area (for movement), water troughs and outside toys. In addition, many kindergartens now offer 3–5 hours each week in an outside 'bush' or natural environment. This opportunity for nature play in bush kindergartens is starting to impact on the policies of local government councils that are specifying bush kinder as an essential aspect of the preschool kindergarten year. Research by Campbell and Speldewinde (2018a) has highlighted the science and engineering learning benefits of these natural spaces.

8.3 Science and Engineering (STEM) in Early Childhood

At a broader level, early childhood provision is influenced by educational trends and one of the most significant of these is the call by industry and government for science, technology, engineering and mathematics (STEM) education to be incorporated in the early years. Australia has been a late adopter of STEM education (Blackley & Howell, 2015), although earlier momentum led to the development of the National STEM School Education Strategy (2015) which specifies that STEM education should start in early childhood. Additionally, research (McClure et al., 2017) highlights that the early childhood years are essential for laying the foundation for future learning in these subjects. In a review of the directives from the individual states and territories across Australia, Murphy et al. (2019) found that the Victorian 'STEM in the Education State' document (Department of Education, 2016) indicates that STEM education must commence in preschool, however, most state documentation is not prescriptive for STEM in early childhood settings.

In terms of set curriculum documentation in the discipline areas of science, technology, or engineering (STEM), very little exists which specifically targets early childhood education. This is despite the fact that international research into the introduction of pre-school, engineering-focussed curriculum through the introduction of the coherent approach to STEM teaching and learning, has been successful in developing children's engineering understandings (Bagiati & Evangelou, 2015). Some of the state jurisdictions have included some material on their websites, but this is quite sparse. The Victorian State Department of Education (DET) provides guidelines on its website which feature possible knowledge and skills in science and technology (including engineering) for the year prior to children starting school—*Level D, Towards Foundation.* Queensland State guidelines for preschools mention both digital technologies and mathematics, whereas Western Australia documents provide curriculum guidelines which cover science through exploration and mathematics through simple measurement activities. However, this documentation is scant in detail and educators continue to ask for specific direction and professional learning.

The Australian Curriculum, which covers primary and secondary school students, has science and technology as separate curriculum areas, but not engineering. Engineering processes and principles are found in the Technologies curriculum. However, as most early childhood educators are not familiar with the Australian Curriculum, they are strongly influenced by the broader push for STEM, of which engineering is one component.

Recent research in Australia highlights that science and engineering education strategies (within a STEM focus) need to target building children's capabilities, particularly through inquiry and problem-based learning, and enhance educator capacity. This introduces some challenges in early childhood science, and engineering (technology/STEM) education that include:

- While educators appear to be enthusiastic to support early science and engineering (technology/STEM) learning (Edwards & Loveridge, 2011), they indicate a need for help to do this effectively (Campbell et al., 2018). For example, educators need assistance in developing play-based science and technology/engineering contexts which integrate naturally and provide stimulus for children's learning (Robbins, Jan & Bartlett, 2011).

- Educators in early childhood environments need access to more tailored professional development (PD) to effectively engage young children in appropriate science and engineering (technology) learning (Murphy et al., 2019).
  - Unconscious gender bias in relation to science and engineering (technology/STEM) is still prevalent in Australian preschools and needs to be addressed through targeted PD (Hobbs et al., 2017)
  - Learning environments like libraries and museums can support early STEM learning through offering both a child STEM play environment and access to professional learning for educators (Museums Victoria, 2020)
- Children's early learning in science and engineering (technology/STEM) should be positioned within a continuum of learning through to the end of secondary school which builds children's early competencies for later outcomes in STEM (Murphy et al., 2019).
- EC science and engineering (technology/STEM) research needs to continue to provide contemporary advice to the ECE sector and public policy developers (Murphy et al., 2019).
- Strategic communication effort is needed to convey an accurate understanding of science and engineering (technology/STEM) to EC groups and to the broader community to support meaningful policy change around early STEM learning.

There are few resources currently available in science and engineering (technology/STEM) specifically for preschool children, although across 2016–2020, the Australian government funded several projects aiming to address this problem. Currently, some Australian preschools are trialling "Little Scientists" (Little Scientists, 2020), and "Early learning STEM Australia" (ELSA, 2019). In addition, a current research project, the Conceptual Play Lab (Fleer, 2019) offers exciting possibilities for the future of science and engineering (technology/STEM) learning in preschool. At this point in time, the impact of the above programs is marginal as a 'whole-of-preschool' approach needs to be adopted and adequately funded. Many educators rely on the internet, web resources or primary school curriculum materials and adapt to suit their children when they wish to plan a specific learning experience that evolves from child-instigated interest. The introduction of engineering in the preschools years, which uses mathematics and science to solve problems, is often challenging for teachers. However linking engineering to literacy instruction, can elicit children's science understandings (Pantoya et al., 2015). In addition, the Australian professional body, Early Childhood Association of Australia, provides webinars and some professional material developed by Australian educators and researchers for purchase through the association. However, resourcing and time for educators to attend professional learning opportunities are minimal, making early childhood science and engineering (technology) education a challenging task for educators (Campbell et al., 2018). In addition, as indicated by research overseas

(McClure et al., 2017), EC teachers' conceptual understanding and self-confidence in science are often limited and this is found to be similar in Australia (Murphy et al., 2019; Campbell & Speldewinde, 2018a). The three programs mentioned above offer a promise of future learning in science, and engineering (technology).

- The Little Scientists program is being supported by the Federal Government to provide educators with access to professional learning in early childhood STEM. Originally developed in Germany, the program has been adapted to focus on STEM inquiry within the programs of Water, Air, Optics, Acoustics and the Human Body (Little Scientists, 2020).
- The ELSA program, an Australian-based program, has been developed and trialled in over 100 Australian preschools. It is a play-based, digital learning program that supports children's explorations in four specific areas: Pattern and recognition; Location and Arrangements; Representations; Investigations. Children undertake off-computer, hands-on play-based activities and then use an app to represent their thinking. The children are supported by the app for approximately a third of their learning time. Additional resources, such as story books, puppets and concrete manipulative materials have also been developed to support the children's learning in STEM. While piloting is still being undertaken across 2020, the reports from educators involved indicates that the program is very successful (ELSA, 2019).
- The Conceptual Play Lab is a research-based program which supports young children's learning through imaginative play. It is still in the developmental stage, but the basis of the program is the creation of an 'imaginative playworld' which places children into science and engineering play in which they become problem-solvers. Currently, resources are freely available which provide instruction for educators on how to set this up and to build children's conceptual development (Fleer, 2019).
- The Curious Young Minds—STEM Literacy Program (Campbell & Speldewinde, 2018b) provides early childhood educators with practical advice and small STEM tasks that could be implemented in preschools. It offers activities in each STEM discipline and also integrated activities. The educator advice includes the targeted knowledge and skills inherent in any activity, the language to use with young children and some initial questions to focus learning. This program was commissioned by an independent charitable organisation and as such, access is limited.

8.4 Practice Stories from the Field

The following vignettes have been captured from observations at a number of preschool settings in Australia, across a number of years, and are considered typical of children's learning through play. In the following stories, the context and application of the play, the role of the educator, and other children will be discussed in relation to the learning observed.

8.4.1 Water, Water Everywhere!

Lisa was playing with the tap and hose, filling buckets and tipping the water onto the plants and grass in the outside play area of her preschool. Other children were also filling buckets, but they were engaging in parallel play, rather than playing together—each child had their own focus and play agenda. At one point, Lisa accidentally tipped her bucket, resulting in some water hitting the concrete path and flowing along the path. Lisa stopped and watched the water. She was intrigued. She looked around and called to the educator to come to see. She asked the educator for the reason that the water travelled along the path. The educator did not provide an answer, but suggested that she try to find out for herself. Lisa spent another ten minutes repeating her action of tipping water onto the path. Other children joined her to ask what she was doing and she explained her puzzle. She kindly shared her bucket and water, so they could try it for themselves. After a few more attempts, she stopped and moved away from the path. At this point, the educator joined Lisa and asked her what was happening. Lisa gave her a broad grin and said, 'I worked it out. The path is going downhill'.

This observation always fascinated me as it provided me with insight into the potential of children's learning through free play. The role of the educator was to encourage Lisa to undertake her own investigation and to follow through when Lisa was finished. Lisa demonstrated persistence in undertaking multiple repeat investigations, skills of close observation as she watched the flow of the water, reasoning as she came to her conclusions for the repeated events and collaboration in sharing the opportunities for investigations with other children.

8.4.2 Lizards in the Room!

The children came into the preschool room bubbling with excitement. After placing their bags on their pegs, the children sat in a circle on a mat, where the educator was waiting. The educator took the children through some routines, morning greetings, singing songs, and clapping patterns. When the children were more settled, she asked them what was about to happen. They all knew! The Lizard Lady was coming (she was in fact, already in another room). At this point the children all yelled an invitation to the Lizard Lady to join them and she emerged for the side office carrying her container of lizards. The Lizard Lady spent some time gaining children's confidence and asking them questions about their prior experiences with lizards. She emphasised the careful handling of lizards and indicated to the children that she was about to hand around a lizard. Each of them could hold it and pat it, but if nervous—they could just observe when someone else was holding it. Over the next 15–20 minutes, about 5 different lizards were passed from child to child, with lots of 'ohs & ahs'. Finally, she reviewed with the children what they had observed and learnt from seeing and handling the lizards and then left. After she left, the children were given free play time outside as they had been sitting for quite a while, concentrating and learning.

The role of the educator had been to set up the activity based on children's interests which had been displayed in the weeks prior. They had been curious about snakes and lizards and much of their free play involved mimicking these creatures. The incursion was very much an instructional activity, which, while not play-based, was designed to build on children's existing interests and experiences. Children's skills of observation and questioning were developed as they handled the animals. They acquired knowledge of lizards' bodies and their diversity of size, shape and colour.

8.4.3 Robots Taking Over

The educator had undertaken a brief professional learning session on how to introduce robotics to her preschool group. On the floor mat at the start of the day, she introduced the children to the topic of robots and asked for any experiences they had. The children had few responses. One mentioned a robot they had seen on television, and another mentioned a story about robots. The teacher introduced a game which she called 'Being like robots'. This is considered an 'unplugged' activity which provides children with understanding of sequencing commands to produce movement. The children enacted the roles of robots, responding to the educator's commands. After observing that most of the children understood what the commands meant, she introduced them to a small robotic toy which could be programmed with simple buttons. She demonstrated each of the buttons, which aligned with the robot game the children had played earlier. Each of the children had a turn at pushing the buttons and watching the robot move. Once she was confident that they understood the buttons, she set up several robotic toys in a play area and allocated several children to the area for 10 min play times. The other children played with other themed activities areas until it was their time with the robots. Some were still a little challenged by the buttons and programming, but the educator moved into the play to help as needed. Others were able to make the robot move forwards or backwards and to turn corners (Fig. 8.1).

However, this limited movement quickly became boring until the educator suggested that they create a road for the robot to travel along. Boredom disappeared as they constructed roads, garages, and mazes for the robots to traverse. They even had them travelling up ramps.

The educator had set up this instructional activity and had even undertaken external professional learning to ensure that she introduced the robots in a manner that would help children understand. She used age-appropriate language and tasks with a co-sharing of experiences. When the children were assigned to 'play' with the robots, they were not directed in any way. However, this proved to be limiting. Recognising their limited prior experiences with robotic toys, the educator found that she had to build a purpose into use of the robots so that the children's imaginations could then guide their play. Children were learning about sequencing of commands (using algorithms) and computational thinking (the process that finds a solution to an open-ended problem).

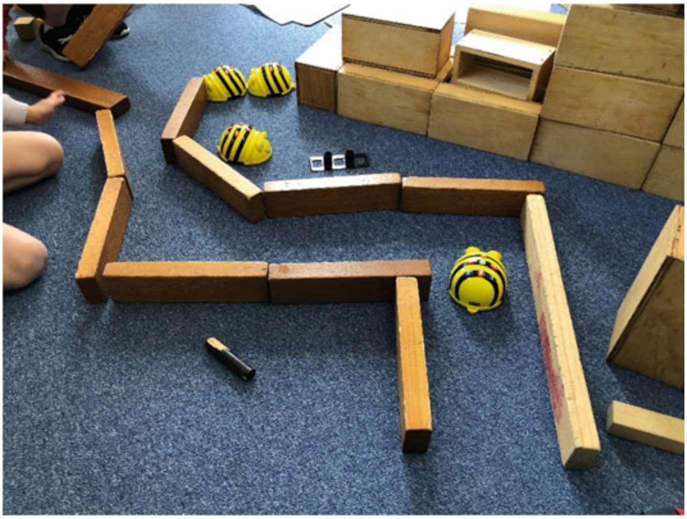

Fig. 8.1 Children's creation of a path for the robot

8.4.4 Science in Nature Play

Tim had found a newly sawn log and, after a few attempts, managed to balance on it. It was a little difficult as the log had the propensity to want to move. Tim found that he had to adjust his feet position several times and he also spread his arms out until he became stable. Callum was watching what Tim had accomplished and approached Tim to see if he could balance as well. Initially, he tried by himself, without Tim on the log, but he just couldn't manage it. After several attempts, Tim stepped back onto the log, managed to balance again and, holding Tim's hand, helped him to slowly step onto the log surface. Callum was still a little wobbly and Tim found that he had to move his feet slightly to compensate and maintain balance (Fig. 8.2).

This was a child-initiated play activity in which Tim wanted to achieve the task of standing on the wobbling log. In achieving this, he was experiencing the science associated with balance, forces and gravity—not that he was really aware of this! He was problem-solving and learnt to move his feet apart to broaden the base of his balance and used his wide-spread arms to provide further stability. When he assisted Callum, he provided him with instructions (peer-tutoring) and demonstrated collaboration. Both children exhibited perseverance in continuing with attempts until they satisfactorily achieved what they had set out to do. The educator's role was to provide children with loose materials in the bush kinder setting so that they could manipulate them in playful ways. There was no specific learning outcome or curriculum focus associated with the provision of the log.

Fig. 8.2 Tim and Callum experience 'balance'

8.4.5 Engineering in Nature Play

Jenna had arrived at bush kinder and sought out her favourite 'place.' However, she found that since her last play, a small piece of animal fur was right where she wanted to play. She wasn't prepared to pick it up (it looked a bit nasty!) and stood, considering how she could remove the offending fur. She wandered off and I thought she had moved on to play somewhere else. However, a few minutes later she returned with two sticks of wood and used them like callipers to try to pick up the fur. This didn't work—one piece of wood was too long, and this didn't allow her to bring the two ends together properly. She left the scene again, but quickly returned with a slightly shorter stick and was able to successfully leverage the ends to pick up the fur and transfer it to another site under some bushes—well away from where she wanted to play (Fig. 8.3).

This was a wholly-child initiated activity with no input from others—no other children or educators were involved in the activity or discussion. In terms of learning, Jenna was involved in design technology (engineering) and was re-purposing materials to suit her need. In manipulating the sticks, she was using eye-hand coordination and an experiential understanding of force—that she had to press the sticks together so that she could hold the fur. She demonstrated reasoning, problem-solving abilities, motivation to succeed and perseverance with a task until she achieved her endpoint.

Fig. 8.3 Jenna's creative solution to picking up the fur

8.4.6 Story Summary

The five stories included in this chapter attempt to capture the diversity of play-based learning experiences in science and engineering (technology/STEM) in Australian preschool settings. Children's play is frequently exploratory, providing them with multiple opportunities to engage in science and engineering (technology/STEM) learning. The role of the educator varies, as can be seen from the stories, from instances of significant pre-planning, through to a hands-off approach which allows children's experiences to guide their learning. In addition to these vignettes, there were many instances of teachers facilitating the learning through scaffolding at the point of need, providing additional materials or subsequent building on children's interests through a targeted experience.

8.5 Conclusion and Recommendations

This chapter set out to provide an overview of play, science and engineering (technology/STEM) in the Australian context. Early childhood education in Australia is developing as an important component of children's learning and is being recognised for the value to young children's future development. National and State governments are not only realising the significance of early years learning but are starting to provide resources specifically to target priorities in language, maths, science and STEM (including engineering). The national Early Years Learning Framework is a valuable document to assist early childhood educators in identifying play as a learning context, however, it does not provide educators with a clear understanding of what learning in discipline areas could look like. Educators are given autonomy in terms of planning children's preschool experiences and while most feel comfortable in the support of free play, there is a general sense that there is insufficient material available to them to develop a full program in science and engineering (technology/STEM). Many educators lack confidence in dealing with the areas of science, STEM or engineering (Murphy et al, 2019). As a result, educators have indicated that further professional learning, and the provision of well-developed programs in science and STEM, are needed to help them make the right choices. Children's free play constitutes a large portion of their time in their preschool setting and educators are encouraged to actively engage in this through intentional teaching. This requires the educator to recognise the potential for learning in a child's play and to be able to support this through asking questions, focussing children's attention or supplying further material. As demonstrated in the stories provided, there are many occasions for children to experience science and engineering (technology) activities and this offers educators opportunities to scaffold children's learning of concepts and skills and to develop these further.

Australian early childhood providers, educators and institutions recognise and provide support for the continuance of children's play as the medium for learning. Additionally, there is a recognition that educator learning has to be supplemented, both pre-service and in-service. With the Australian Early Years Learning Framework now over ten years old, there are ongoing calls for its revision. While there is general recognition of the importance of the inclusion of key learning in science and engineering (technology/STEM), the ideas of 'schoolification' (Clausen, 2015) are generally not supported. Early childhood education should not become subject-centred or school-like as didactic teaching does not sit well within a play pedagogy.

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Chapter 9
Bee-Bot Robots and Their STEM Learning Potential in the Play-Based Behaviour of Preschool Children in Canada

G. Michael Bowen, Eva Knoll, and Amy M. Willison

Abstract An overview of the provincial early learning/curriculum documents for early childhood and Kindergarten education in Canada's ten provinces (constitutionally education is not a federal government responsibility) indicates that while STEM-related subjects such as science, mathematics and literacy are discussed in these documents there is no direct discussion of STEM itself, technology is rarely mentioned (and almost always in the context of digital technology such as using tablets), and educators are strongly encouraged to use play-based approaches to achieve learning outcomes at both pre-kindergarten and kindergarten ages. Initiatives to use technology such as Bee-Bots, a small floor-based programmable robot for early ages, have started in some provinces, and we explore the potential for such robots to be used to develop foundational understandings of math, science, and literacy which will be built upon in Kindergarten and later grades. We conclude by discussing the implications of these robot technologies for professional development with early childhood educators.

Keywords Mathematical thinking · Problem-solving · Coding · Technology · Pre-primary · Inquiry · Investigation · Patterns

9.1 Introduction

We start with a description of early learning education practices in Canada for three- to five-year-old children and an overview of the various STEM-related curricula (e.g., science, mathematics, literacy) laid out in provincial government documents across

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Canada for both early childhood education (before formal schooling) and for the first year or two of schooling (up to Kindergarten/5-year-olds). The chapter concludes with a discussion about a STEM technology recently provided to schools in Nova Scotia that could be used with 3- to 5-year-olds with a focus on how it could be used to achieve learning goals described in the various available government documents across Canada that were first discussed.

Canada is a constitutional democracy comprised of ten provinces and three territories with various roles and responsibilities held by either the federal government or the provinces. The majority (99.68%) of the population lives in the provinces, and these vary in population size from 140 K (Prince Edward Island) to 13.5 m (Ontario) people. Under the Canadian Constitution education is solely a provincial responsibility and there is no federal mandate allowing for formal education to be influenced in the provinces by any federal government policy in the schooling years either through law, mandate or financing. This is also taken to apply to pre-school years education (which in many instances is called "early childhood education" or ECE. One should note that the abbreviation "ECE" can apply both to "Early Childhood Education" programs and to "Early Childhood Educators."). Formal schooling in most provinces begins in the late 4-year-old to 5-year-old age, with attendance cut-offs by age and date that vary slightly by jurisdiction. The 5-year-old level of schooling is called Kindergarten in most provinces (the exception being Nova Scotia where it is called Grade Primary; the remainder of grade levels before secondary school are termed *elementary*) and whether it is required or not varies by province and territory (see Table 9.1). Some provinces, including Nova Scotia, have implemented a school year before Kindergarten/Primary that is called Pre-Kindergarten, Pre-Primary, or Junior Kindergarten (depending on jurisdiction), and this school year is optional where offered.

A review of provincial and territorial government websites was conducted and documents on early learning and (pre-)kindergarten curriculum collected. A recent report on early learning and childcare agreements between provinces, territories, and the federal government provides considerable summary information on the state of child-care in Canada and the plans to improve it in most political jurisdictions (Pasolli, 2019, on behalf of the Child Care Advocacy Association of Canada). This report followed from a 2014 review of Early Learning Framework documents (ELF) created by provinces that was conducted by the Atkinson Centre for Society and Child Development (McCuaig, 2014). These efforts to improve child-care and learning in Canada are considerably politicized. For instance, the ELF documents created under the auspices of a previous Liberal government were subsequently cancelled by the election of a Conservative government:

> The election of the Conservative Party in January 2006, however, brought the Liberal government's plans to a screeching halt. …
>
> Following his swearing-in ceremony on February 6, 2006, Prime Minister Harper immediately cancelled the child-care agreements with the provinces and territories. The Conservative government then replaced the national strategy with the Universal Child Care Benefit (UCCB), a $100/month taxable allowance for all children under six years of age. The federal

Table 9.1 Availability of early years education programs across Canada

	PreK/Pre-primary/Junior Kindergarten	Kindergarten	Early Learning Framework?	Notes
01—British Columbia	No, but program for parents who need supports; 3 h/day, Monday to Friday	Yes	2019 (116p)	
02—Alberta	No, but program for differently-abled & developmentally delayed	Yes	2014 (164p)	
03—Saskatchewan	No	Yes, also program for vulnerable 3- & 4-year-olds	2008 (80p)	
04—Manitoba	Yes	Yes	See notes* 2014, 2014, 2015 (32P, 28P, 458P)	*Multiple ELF documents for infant, early childhood, kindergarten
05—Ontario	Yes	Yes	2007 (191P)	
06—Quebec	Varies by school district, mostly no	Yes	N/A*	*ELF not available electronically
07—New Brunswick	No	Yes-R	2008 (247p)	
08—Prince Edward Island	No	Yes-R	2011 (198p)	
09—Nova Scotia	Yes	Yes-R	2018 (97p)	
10—Newfound-land	No, but 8 h long "Kinderstart" program before K	Yes	2019 (81p)	
Territories				
11—Nunavut	No	Yes	n/a	
12—Northwest Territories	Yes	Yes	n/a	
13—Yukon	No	Yes (full & half-day)	n/a	Follows BC curriculum w/ adaptations

(*R* = Required)

> government did not support a larger federal role in support of [Early Learning and Child Care Framework] from 2006 forward. (Pasolli, 2019, p. 15)

The ELF documents (that were initiated prior to 2006, and in some provincial jurisdictions updated since then) essentially provide a framework for both the structuring of childcare programs and the curriculum for those programs, with variations across political jurisdictions but many similarities.

> Each document was locally constructed using a variety of approaches. Their uses vary. In Quebec, Prince Edward Island and New Brunswick, the ELF is the designated guide for early childhood settings. [British Columbia]'s framework is required for its school-based Strong Start Centres. [Prince Edward Island] and [New Brunswick] mandate certified training in their respective frameworks. While Ontario's ELF is not mandated, the City of Toronto has tied its approaches to its quality assessment criteria.
>
> Despite their different paths to development, the frameworks host many similarities. Families and communities are viewed as partners who strengthen the program's ability to meet the needs of young children. Respect for diversity, equity and inclusion are embraced as essential for optimal development. A planned curriculum, anchored by play, is recognized as best able to capitalize on children's natural curiosity and exuberance to learn. (McCuaig, 2014, p. 1)

In most provinces there are other ancillary or addendum documents which support the curriculum provided in the ELF documents published at varying times (some more recently, others a decade or more ago) in different jurisdictions. The wide variation in time of publication and ages covered by the documents complicates the summarizing of any patterns in the curriculum focus taken in the various provinces. In addition, local practices can vary without apparent changes in the documents. To understand the curricular patterns in STEM-related issues in various provinces we used a crude index of "word counts" for key terms (or word stems) found in curriculum documents for early age childcare settings to Kindergarten. For this word count index we chose the terms "Science", "Literac- ", "Math- ", "STEM", and "Play".

The analysis uses the totals of those words (when used in the appropriate context) for "Early Childhood Education"/"Pre-Kindergarten" documents and "Kindergarten" documents (see Table 9.2). Readers should note that we recognize that our system of using a word-count of the terms we chose to elicit the importance of topics in the early years curriculum documents is imperfect. For instance, the 44-page curriculum document in Nova Scotia "English Language Arts Primary Guide" uses the word "literacy" once, although clearly the document itself is entirely about language literacy. Nevertheless, our viewing of the topics in the documents suggested to us that our approach using word counts is reasonably valid and sufficient as a general comparative index for the purposes of this chapter. In our summary of these word count data we noted that the use of the word "play" stays constant in overall total from pre-Kindergarten to Kindergarten documents, but also noted disparities for some jurisdictions at the Kindergarten level.

- Quebec, New Brunswick, Nova Scotia and Alberta documents had low total levels of usage (under 50 uses of "play") in their Kindergarten documents, with Alberta and New Brunswick having notable declines from the use of the term in documents produced for younger students,

Table 9.2 Topic word count in ECE/PreK & Kindergarten curriculum documents

	Early Childhood & PreK [16 documents in total]	Kindergarten [12 documents in total]
"Science"	16	237
"Literac-"	249	382
"Math-"	82	813
"STEM"	0	0
"Play-"	>2 k	>2 k

- British Columbia, Saskatchewan and Prince Edward Island had medium levels of usage of the term "play" (100–200 words in their documents),
- Manitoba, Ontario & Newfoundland had high usage (>400 uses of the term "play"), representing a notable increase compared to pre-Kindergarten documents.

There are three other notable aspects of the data summarized in Table 9.2. First, the use of the terms "science" and "math-" increases notably in curriculum document from the ECE/PreK to the Kindergarten curriculum. Secondly, the term "STEM" was not used anywhere in any of the documents, even in those which were recently published (including in Bowen and Willison's own jurisdiction where many technology tools (see below) have been provided for use in elementary schools).

This frequent use of the term "play-" (as well as our inspection of the documents themselves) highlights that across most of the provinces a play-based approach is emphasized for the early learning context. This focus on "play" is predominant in the recommended practices for early childhood education (Smith & Pellegrini, 2013). The foundations of recommending play as the basis for early learning derives from the theories of Lev Vygotsky, Maria Montessori and Loris Malgucci (who was the founder of the approach to education used in Reggio Emilia, Italy). Their theories…

> …emphasize the value of complex socio-dramatic play in the children's learning, the social-collaborative nature of early learning, the importance of scaffolding children's learning for optimal development, the key role of relationships and environments, and the importance of recognizing the child's role as an active agent in his/her own learning. (Flanagan, 2011, p. 8)

It is generally thought that children do not play with the intention of learning, but they do learn from playing (Kalliala, 2006; see the review by Lillard et al, 2013). The concept of "play" can be difficult to clearly define (Hewes, 2006) and the ways in which types of play can be broken down into different types can also vary widely. In her overview of play, Hewes lists variants of "play" that include exploratory play, dramatic play, construction play, physical play, socio-dramatic play, games with rules, and games with invented rules (Hewes, 2006, p. 3). Many of these can occur with or without the participation of adults in the actual play. However, if adults are involved what might be "free play" without adults may now include mediated/guided play (that may also involve modeling), and even engagement that involves aspects of episodic direct instruction. Even in circumstances where the adults are not directly participating, they may still be involved in mediating play by providing particular materials or contexts (as described by Willison below; Smith & Pellegrini, 2013) where they are implicitly shaping and guiding the engagement in play behaviour by "stacking the environment" (Bowen & Bartley, 2013) to achieve desired learning outcomes. Hewes (2006) has noted that the movement towards more explicit learning outcomes in educational environments for young children has led to an increase in direct instruction in early childhood settings. Some have concluded that explicitly desired learning outcomes that may not be met by free play are better achieved by guided play (Weisberg & Zosh, 2018) which can occur through even subtle scaffolds and cues.

Willison, one of the chapter co-authors, describes an activity with which she has engaged her own students in the past that illustrates the shaping of learning outcomes mediated by the instructor without direct instruction or even explicitly guided activities:

> I have one activity that engages all of my students. Children have a lot of questions, many that I couldn't answer off the top of my head. As a practitioner of emergent, play-based curriculum I tried to ensure that my role was [as] a facilitator. So I started the "'Google' and/or Question List". Anything I was not able to answer, and some that I could but thought would be good for them to research on their own went on this list by the door.
>
> At the beginning of a school year or with a new group I would explain that "The List" was a "group undertaking of the unknown" (which my students saw as very mysterious). A particularly popular subject on "The List" for a while was based on the book series "Who Would Win?" by Jerry Pallotta. These books would pit two animals against each other to see which one would win in a battle, and the books encouraged them to compare the animals in a number of different categories. I would give a tablet to my pre-school students to research these animals on their attributes, habitat, etc. with the caveat that they should try to work with children who may not have the same spelling or base knowledge skills yet as they do. Apart from learning about animals, this activity also introduced them to Steve Irwin (Note: facilitator led). His real-life death in the field, while having children himself, often led to some amazing web searches and group discussions on questions such as "How old were his children now?", "What did they do when their dad died?", or "Are stingrays aggressive or merely defensive?"...to harder queries by the students about death itself.
>
> Over time "The List" by the door became a conversation point for parents/families/guardians etc. who would sometimes add to this list themselves! Some children made their own suggested answers with their rationale based on lessons learned either at school, books, or other sources. On the surface "The List" was very simplistic, but through online research it became infinitely more.

In this description the reader will note that Willison was engaging her students in asking questions about science, observing animals engaging in activities that addressed their question, and then drew from them their observations and thoughts about what they were observing. And all of this involved "enjoyable" play-based approaches where student engagement was emergent from the children's interests. This description of practice in an early childhood learning environment also highlights the unclear boundary between "free play" and "mediated/guided play" as this segment seems to demonstrate both at the same time.

Our view as scholars is that young children learn best through play, and we maintain that view whether the child is learning skills such as fine and gross motor movement, social competence, and emotional self-regulation or if the child is learning pre-academic and academic skills. Given that, we ask if young children can also learn

Fig. 9.1 Bee-Bot from the front (**a**) From above showing programming pad (**b**)

skills such as coding through play? What about conceiving, creating, and testing algorithms? Surely, these higher order mathematical competencies must be taught to children as part of their formal schooling, particularly in preparation for participation in Kindergarten where they are more prevalent. And given the quite infrequent use of "science", "math-" terms in provincial documents for learning below the kindergarten level we wonder just what sorts of activities might occur in Early Childhood Education that lay the foundation for learning foundational math and science at Kindergarten and up.

Willison's description also provides a model for how STEM-based approaches, where multiple subjects are addressed using an integrated approach, could be used in early childhood education practices with young children. To address how we see this happening, a brief introduction to and discussion of STEM will preface our discussion of the use of a small, programmable floor robot, the Bee-Bot (see Fig. 9.1a) with young children and how it may facilitate later learning of subjects such as science, mathematics, literacy, and coding.

9.2 Introduction to the Idea of STEM Education

The term "STEM" entered the discourse of education in North America approximately ten years ago in 2010 (Bybee, 2013, p. 2). At the simplest level, "STEM" represents an integration of practices that draw from science, technology, engineering, and mathematics in the conduct of an activity. There are, however, many different definitions of what integrated STEM is (e.g., Bybee, 2013; Gardner & Tillotson, 2019), and this can complicate creating and implementing educational activities or curriculum that reflect those different definitions. Recently, the addition of an "a" representing "arts" (such as visual art, literacy, etc.) into STEM to make "STEAM" has further complexified this issue (Land, 2013; Sullivan et al., 2017), as has a further addition which involved bringing computational thinking into the STEM framework (Jona et al., 2014; Swaid, 2015).

The ambiguity of the use of the STEM acronym (Bybee, 2013; Sanders, 2009) and what that means for actual classroom practice confounds its use. How many of the 4 (or 5) disciplines need to be incorporated into an activity for it to be considered a STEM activity? Some? All? And to what degree should they be incorporated? The reality is there are no hard and fast answers for this, although some argue that effectively integrating as few as two of the subjects makes it a STEM activity (Sanders, 2009, p. 21). Recent attempts to build an integrated STEM framework to better guide the framing of learning activities have occurred, and various problematic aspects of STEM and what it means to learn and teach with an integrated STEM approach have been explored (Kelley & Knowles, 2016). However, there are also arguments that we should abandon siloed perspectives on disciplines that are reflected in interdisciplinarity and integration and that a more transdisciplinary perspective on schooling (and therefore STEM) that transcend subject integration and include lay perspectives and alternative knowledges should be engaged with that would allow new understandings to emerge (see Klein, 2010). A recent issue of Science & Education starts exploring issues of this kind to address questions such as "Is there a particular 'nature' to STEM or are there disciplinary variations across the 'natures' of science, technology, engineering, and mathematics?" (Erduran, 2020, p. 1).

9.3 STEM Learning and Young Children

Introducing STEM approaches (and concepts deriving from it) to learning at younger ages is important, as doing so can lead to an increase in children's ability to create and discuss scientific relationships and to an increase in vocabulary and collaboration skills in many STEM subjects (McClure et al., 2017a, b; Moomaw & Davis, 2010; Tippett & Milford, 2017). Use of technology (computers, cameras, etc.) associated with STEM by young children has helped increase student engagement and learning outcomes in subjects such as mathematics (Kermani & Aldemir, 2015). It is important to develop foundational math understanding in preschool children because having competency with math activities is a strong predictor of later academic performance (Duncan et al., 2007; Watts et al., 2014).

Developing young children's understanding and use of technology is often considered part of STEM education (Spaepan, 2017) and it is a widely held view that access to educational technologies, including programmable and remote-control toys, is advantageous for early learners (Jack & Higgins, 2019; Radich, 2013). Some researchers argue that scaffolding and modeling of appropriate use of the technology by adults is necessary (Neumann, 2018; Neumann & Neumann, 2014). A recent exploration of the use of technology by preschool children reported "that children are using it in open and exploratory ways supporting the usual pedagogical approach used in early years. … Adults appear to be working alongside children and scaffolding their use of technology…" in more interesting ways than in the past (Jack & Higgins, 2019, p. 13). The need for scaffolding is even more apparent when there is a curriculum with established learning goals as learning outcomes are maximized through guided play (Weisberg & Zosh, 2018) compared with free play (Alfieri et al., 2011; Fisher et al., 2013).

We noted, however, that amongst the technologies described in most government documents that we examined, "robots" in any form are rarely mentioned as one of the technologies that could be made available for preschool children as part of their introduction to STEM. Our intention, in the coming pages of this chapter, is to provide an argument for including programmable floor robots as part of the education of young children in their introduction to and exploration of STE(A)M and the various forms of technology they learn to use in their preschool preparation for their later, more formal, schooling.

9.4 Coding and the Introduction of Technology in Elementary Education in Nova Scotia

Nova Scotia, one of the smaller provinces in Atlantic Canada, announced in 2015 that the principles of "coding" would be taught across the K to 12 curricula (Province of Nova Scotia, 2015). Following that announcement various STEM technologies were introduced into K to 8 classrooms and teachers were expected to incorporate those technologies into their curriculum and teaching. The Education and Early Childhood Development Minister of the day, Karen Casey, described the plans of the government:

> Coding has been identified as a priority for all classrooms under Nova Scotia's Action Plan for Education, and students in grades Primary to 3 were introduced to coding in September 2015. I was pleased to announce that as part of Budget 2016–2017, the province has invested $1 million to expand support for this initiative.
>
> Coding is integral to the successful development of students and their critical-thinking, problem-solving and creativity skills. These skills are directly linked to many of the growth industries in Nova Scotia, including computer programming, marine (sic)*, manufacturing and communications. This investment in coding means our young people will have the skills they need to be successful in a digital workforce.*
>
> Starting with our youngest students, programmable floor robots will be available in P-3 classrooms in every elementary school. This helps in teaching sequencing and problem solving. Students in grades 4 to 6 will learn more about coding as part of a renewed curriculum and every elementary school in Nova Scotia will receive Innovation and Exploration Kits, which include leading-edge technology and support devices. These kits will contain iPads, Chromebooks, PASCO wireless probes and software—and Sphero robots and Makey Makey invention kits, some of which our young students are demonstrating. (Casey, 2016) [This text came from a press conference w/video.]

The small, programmable robot provided to early grades is called the "Bee-Bot" (middle and upper elementary classes use a Sphero SPRK) and it is designed to be usable by very young children. It is a small, durable floor-based robot, depicting a cartoon-like version of a bee, that is intended for use by young children (see Fig. 9.1a). They are provided for use in the Primary to Grade 3 program but are available to the recently introduced Pre-Primary program in Nova Scotia (for late 3 to late 4-year-olds) as well. In the following discussion we explore the possibilities offered by the Bee-Bot for the potential for learning of 3 to 5-year-olds who engage in play activities with them.

The Bee-Bot has no “default” actions that it performs, to do anything it needs to be “programmed” by a user. This programming is done by pressing a series of action buttons (7 in total; See Fig. 9.1b) two of which depict movement (forward, back in six-inch increments), two that pivot the Bee-Bot on its mid-point by 90 degrees (turn left, turn right), and three others that (a) clear the memory, (b) allow a “pause” to be programmed in the action, and (c) the “Go” (or initiate program) button. On the bottom are two slide switches, one turns on the Bee-Bot, and the other activates sound cues (a single beep when each program function is programmed or initiated, three beeps when all actions are completed, and a “trill” when it is going into rest mode). The Bee-Bot pauses between each individual command when “Go” is pressed, which can help in solving any programming errors. The eyes also light up. Both eyes light up and blink once when a program button is pressed or when the program is played (one two-eyed blink at the start of each program step, coinciding with the “beep”). When all of the steps of the program have been completed the eyes blink on and off in sequence (R-L-R-L-R-L) coinciding with the three beeps. There are no external controls for this technology toy, the Bee-Bot does not have any sensors other than the action buttons, and its battery is an internal rechargeable battery that charges via a USB cable.

In addition to the Bee-Bot itself many schools have “mats” that have been designed for the Bee-Bot (usually based on a 6-inch square grid pattern). Examples of available mats can be found at the Bee-Bot emulator page (see https://www.terrapinlogo.com/emu/beebot.html) or elsewhere online. Teachers can also make their own mats. These mats have various content including depictions of the alphabet, numbers, shapes, colours, illustrations/maps for telling stories, number lines, games (such as snakes and ladders), pictures of items you wish children to learn names of, and on and on. There are even “blank” plastic mats that can be written on or others that are clear plastic with pockets so teachers can insert their own graphics.

The use of the Bee-Bot is straightforward enough that many young children can discern how to program it with just a short period of free play. We have noted that a single demonstration of its use results in considerable enthusiastic engagement. In preliminary, informal interactions with preschool-aged children who were using a Bee-Bot in a daycare without questions or guidance, Bowen observed young children play with the Bee-Bot technology in ways that facilitated a variety of learning outcomes. For instance, some children appeared to develop their understanding of counting and directionality (left versus right, how multiple turns could create a circle). He noted that, in a few children, more sophisticated stages of play were reached that allowed them to move the Bee-Bot in meaningful movement patterns and sequences leading to hypotheses and predictions about estimated distance where

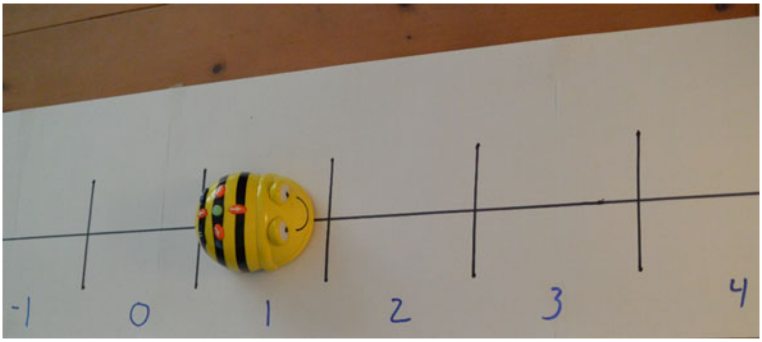

Fig. 9.2 Bee-Bot on a number

they programmed movements and turns to follow routes they planned to get the Bee-Bot to specific locations on the table in front of them. This type of mathematical play can provide the foundations for working with addition and subtraction using number lines in the future (because of the punctuated program delivery Bee-Bot program entries can clearly be "counted" forwards and backwards both in coding it and in the program being run, see Fig. 9.2).

Because of access limitations deriving from Covid-19, we were unable to explore these possibilities further with children. However, as authors we represent a broad range of experiences with children (Willison, 25 years experience as an Early Childhood Educator) and subjects (Bowen, STEM and Science in education, 5 years as an elementary and middle school teacher; Knoll, Mathematics and Art in education) that we used as a starting point to engage with the Bee-Bot ourselves. We used our engagement to elicit the various possibilities we believe a Bee-Bot offers to preschool children in the classroom when they have the opportunity to engage with it as part of their own play-based education as they prepare for formal schooling in Kindergarten and onwards. In the following section we summarize our discussions about the various ways we see that Bee-Bots could be used in activities with three, four and five-year-olds to provide foundational aspects of knowledge in science, mathematics, literacy, and technology.

9.5 Understanding STEM Technology Learning Possibilities in Young Children

Knoll and Bowen observed and interacted with both the physical Bee-Bot and the Bee-Bot emulator to explore the various affordances of the floor robot for foundational math, science, literacy and technology concepts. We note that given the various ways in which these subjects are inextricably intertwined, various aspects of each will be present in almost any activity that we discuss even when we are focusing on a particular topic. Further complicating our discussion of this learning tool is that for some young children approaching the Bee-Bot using a free-play perspective would be appropriate, whereas with others some degree of scaffolding could be necessary. Given that, our discussion will center around a guided/mediated play-based description (within which the mediation may occur by either an Early Childhood Educator OR a peer) but which we recognize could well arise in a free-play environment with some children or might need to be engaged with in a more guided, Socratic approach, or even possibly in an explicit instruction approach, with others.

Children could just be given an "activated" Bee-Bot and be allowed to play with it. Many children, even those three or four years old, would engage with the robot independently and would ultimately learn what the buttons did. Some may need one or two demonstrations, but peer-mediation and teaching arise where children who have learned how to use the Bee-Bot show others how to get it to do what they want. For some a simple demonstration by an adult (with whom some children will stop, listen and watch when they will not with their peers) of which buttons to press and when is all they need to learn the basics of Bee-Bot operation. Bowen has informally observed this happening with young children using the Bee-Bot in small groups. When this point of basic facility with the Bee-Bot is reached, what various learning outcomes and conceptual understandings do we see arising from its continued use?

We see the following emergent STEM subject concepts (italicized) arising from Bee-Bot use with young children:

1. *Cause-and-effect* determinations could be made through free or mediated play as competency with basic use of the Bee-Bot emerged. These arise through *trial-and-error* processes, with implicit *problem solving* arising in an emergent fashion. *Predictions* could also be tested, and both implicitly and explicitly *questions* could be asked and answered. Imbedded in this free play is the idea of *programming* or *coding*. (Science, Math)
2. Children who are three and four year's old can still be having difficulty understanding the concepts of "*left*" and "*right*" and that could be demonstrated and reinforced using the direction arrows on a Bee-Bot. (Math, Literacy)
3. Initial use of moving the Bee-Bot, such as in free play, can lead to the ability to work with implicit number lines and it could therefore be used to teach counting, addition/subtraction, and negative and positive numbers – associated math concepts could be initiated through free-play (by having the teacher tape a number line with 6-inch divisions to a desktop before children showed up to class and letting children play with the Bee-Bot on the table when they arrive). It could also be done by the teacher asking prompt questions "What happens if you press the forward button two times on the Bee-Bot, put it on the number line at zero, and press 'Go'?" "What number did it show?" "What number do you think it would stop at if we pressed 'Go' again?" "Okay, let's try that and see what happens."….and so forth. Variations on doing this could be done involving pressing the forward button two times, and then another two times, and then seeing how far the Bee-Bot went. Asking the children to *predict* how far they think the Bee-Bot would go on the number line would be teaching

them *hypothesis testing*. This is simple *addition* being practiced and tested. Using the "back" button would then lead to understanding *subtraction*. (Math)

4. There are any number of Bee-Bot activity mats available which can be used to teach *number recognition, counting, arithmetic operations, storytelling, letter identification, spelling*, and so forth. Using a Bee-Bot "mat" can be used to teach many things directly and indirectly, using games or puzzle activities. Implicit in children using mats with Bee-Bots is that they are teaching about *cartesian coordinates*, a difficult topic in many math classes. (Math, Literacy)
5. A Bee-Bot can be used to teach several *shapes* including squares, rectangles, and circles. Jagged triangle shapes could also be demonstrated using a Bee-Bot. Using the "notch" on the rear of the Bee-Bot a pen could be inserted, held with tape, and the shapes could be drawn (See Fig. 9.3). Using a Bee-Bot to draw shapes according to the instructions entered is a STEAM connection with regards to *creativity and art*. (Math, Art)
6. *Measuring distance and distance estimation* could be scaffolded using a Bee-Bot. (Math)
7. Moving a Bee-Bot from point A to point B—with and without obstacles or using a maze pattern—could be done to develop understandings of multiple solutions to problems and could be turned into a *strategy* activity. A blank mat could also be used and children with two Bee-Bots starting on opposite sides of the mat would have to strategize to avoid having the Bee-Bots hit each other. (Math, Science)

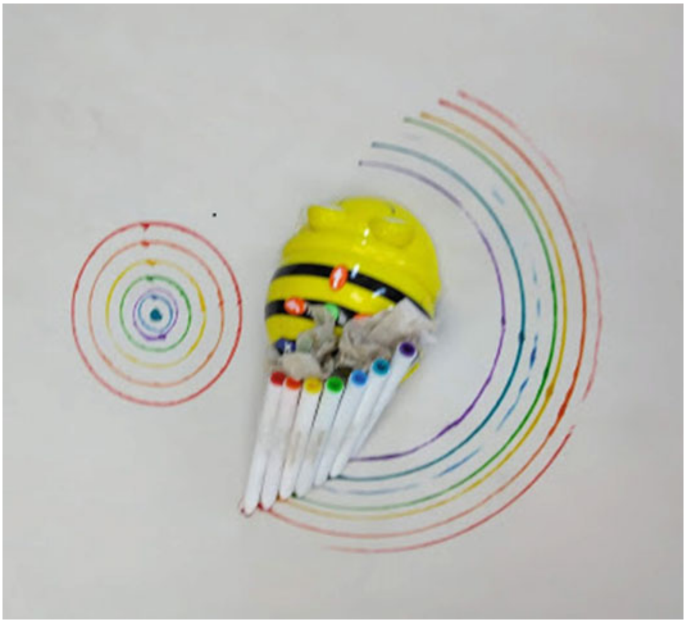

Fig. 9.3 Bee-Bot with Pens attached

8. Implicit in many of the above is the idea of “*algorithms*” and “*patterning*”. (Coding)
9. Implicit in many of the above are the idea of “*vectors*”. In effect, the idea of combining the information of distance and direction, whether in 1 or 2 dimensions, is a preliminary to the understanding of vectors. (Math)
10. Implicit in many of the curriculum topic areas above are the science investigation concepts of *hypothesis, experiment, evidence,* and *solution.* (Science)
11. The idea that *technology can solve problems* could be introduced to more mature children as their play with the Bee-Bot advances. Simply asking them “How could you use a Bee-Bot to do something ‘useful’?” can stimulate all sorts of ideas ranging from taping a smartphone onto a Bee-Bot and sending it into another room to send video pictures back to taping pens to a Bee-Bot to draw shapes. (Science, Art, Math)
12. *Experiments* could be done with the Bee-Bot by altering the high friction nature of its rubber wheels by putting clear or matte cellotape on them. This would reduce the *friction* and the Bee-Bot could then be tested on different surfaces for slipping, or on different slopes. (Science)

From what we have listed above, and we don’t doubt there are other concepts in these and other topics we have missed discussing, it is clear to us that using Bee-Bots with preschool children can lead to the development of foundational thinking in many subject areas that can later be advanced in formal schooling, and that this would happen whether it was done through free play, modeling, through mediated/guided activity (including by the implicit manipulation of resources and the environment) with the Bee-Bot, or even through episodic direct instruction.

9.6 Conclusion and Recommendations

The learning and curriculum guidelines in the various jurisdictions across Canada are designed with enough flexibility to allow technology learning tools such as the Bee-Bot to serve an important use in childcare learning settings. Our all-too-brief observations of students playing with Bee-Bots suggests that they would be enthusiastically adopted in the preschool learning environment and that they could serve as an effective approach to preparing the children for subjects and topics they will encounter in later grades.

With technology such as the Bee-Bot there is evidence that if children use it on their own, they may not learn to use it well (Preradović et al., 2017) and that using technology alongside more experienced peers or adults leads to improved learning outcomes (McCarrick & Li, 2007). The apparent need for more guided/modeled play with STEM technologies in preschool settings suggests that there will need to be a more effective integration of STEM into professional development models for those years. There is, we believe there is a need for professional development that more explicitly focuses on STEM and topics embedded in STEM (Brenneman et al., 2019), especially given the weak background of early childhood educators in science and mathematics (Gerde et al., 2018; Piasta et al., 2014) and technology (Jack & Higgins, 2019).

Given the increase in direct instruction in early childhood learning noted by some (such as Hewes, 2006) it is likely that professional development specifically with technology learning tools such as Bee-Bots may be necessary. Given the requirement in many provinces for ongoing professional development in preschool educators this would not seem to be a challenge. However, since the majority of early childcare settings in most parts of Canada are private businesses (because they are not part of the formal schooling setting in most jurisdictions), convincing childcare owners to make financial outlays for floor robots such as the Bee-Bot will be difficult. On the other hand, the recent increase in the number of pre-Kindergarten programs, such as recently occurred in Nova Scotia, offers the opportunity for governments to provide technology such as Bee-Bots in early childhood education programs before children enter formal schooling in Kindergarten and grade 1.

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Part II
Policies and Training for Formal Education Environments

Chapter 10
Sweden, Australia, and Belgium: STEM Comparisons in Early Childhood

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Abstract Internationally, there has been an ongoing focus by governments through their educational policies to address declining interest in Science, Technology, Engineering and Mathematics (STEM). This increasing need for knowledge and understanding of STEM provides an impetus for all educational systems to re-visit their actions around STEM learning and engagement. A more comprehensive understanding of early childhood STEM education provision is needed so that an informed, effective, and appropriate development of early childhood STEM pedagogical standards and resources occurs. This chapter provides research to understand what cultural influences are brought into play as teachers work in STEM education, what they do when teaching STEM and the factors which influence their decision making. Examples from three countries, Sweden, Australia, and Belgium, are explored using document analysis and qualitative data to formulate their cases. The three cases studies were considered from the perspective of education policy, provision of teacher education, and teaching practice. Examination of the practices that are currently in place in Sweden, Australia and Belgium provide information that the policy and

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cultural background of each country contribute to strong similarities and but also relatively small differences in teacher pedagogy.

Keywords Early childhood · Policy · Curriculum · Cultural influences · Pedagogy

10.1 Introduction

Science, Technology, Engineering and Mathematics (STEM) is at the forefront of both government and educational policies at an international level. With a current recognition of the declining interest in these areas, yet the increasing need for knowledge and understanding of STEM, there is an impetus for all educational systems to re-visit their actions around STEM learning and engagement. Young children's understanding of the world around them is one of the strongest predictors of their later science, mathematics, and literacy learning (Grissmer et al., 2010), yet many young children have few opportunities to engage in STEM learning (Early et al., 2010; Greenfield et al., 2009). STEM learning needs to occur in early childhood is considered internationally to mean children from birth to eight years of age.

Research into early childhood STEM is limited (see, for example, Campbell et al., 2018; Tippett & Milford, 2017). EC STEM research is not widely distributed, nor well integrated into existing programs at early childhood centres such as preschools. Important areas which need further investigation if we are to achieve a goal of effective practice in early childhood STEM include research that identifies the children's STEM capabilities and teaching practices or experiences that enhance children's learning in and across the STEM areas.

To support the development of STEM understandings in early childhood, we need to understand what is currently happening in early childhood centres. We cannot consider how to better prepare educators if we do not know what they do. We cannot develop resources or standards without a much better understanding of what is happening in our early childhood centers and preschools in regard to children's STEM learning and teachers' STEM pedagogy. Our investigations across the three countries centred on what early childhood teachers do to teach STEM, what strategies they used, how they enhanced children's existing understandings and how they developed their own professional learning. This chapter uses three Case Studies from Sweden, Australia, and Belgium to investigate existing STEM learning experiences and interrogate these experiences in terms of their ability to help children develop meaningful STEM understandings.

10.2 Selection of Cases

This chapter's authors, from Sweden, Australia and Belgium, were attending a large European early childhood conference of approximately 2500 delegates and theirs were the only specific STEM presentations. At each of their presentations, the questions raised led us to believe that synergies existed across the different research studies. Our curiosity was piqued as we sought to better understand each other's research. A meeting to discuss the different research results and to decide whether the similarities or differences were valuable to report took place. All studies approached the research aware that large-scale research in STEM in early childhood was not well reported. We wanted to draw together three different sets of data and examine the complementarity of each data set. There was an understanding that the three studies were seeking answers to broad questions rather than proposing theoretical positions. Immediately, synergies were apparent as the questions posed to early childhood teachers were similar. We hoped that this would be of interest to other international contexts seeking to understand this issue and that our study in a field, which remains under-researched, would provide others a baseline to apply to their own situation.

Sweden, Australia and Belgium provide interesting cases to study. They exhibit a range of similarities and differences. Culturally, all countries are regarded as 'individualistic' (Hofstede, 2021) that is, each individual and their needs are prioritised over the entire group or its needs. Individualistic cultures are oriented around the self, being independent (Hofstede, 2021). This relates strongly to the ideas surrounding the development of each individual in the education system and the way that education strategies relate to children as learners. Despite differences in language, there are similarities with each government's policy focus on STEM, and STEM education. We examined and found clear consistencies between key measures in education such as TIMSS (Sweden mathematics 510/science 540; Australia 517/524; and Belgium 546/512) and PISA (Sweden 25-495, Australia 21-502.2 and Belgium 20-502). These speak to not only the similarity between each country but also it allowed us to interrogate more closely what potential differences exist.

10.3 Country Contexts

To understand each of the three Case Studies in Sweden, Australia and Belgium, some background is provided in relation to the place of early childhood in national curriculum, how policy directs local provision, and teacher qualifications/education, sourced through policy documents and websites in each country.

SWEDEN
EC in national curriculum—The National Agency for Education is the central national administrative authority for the school system. Preschool is the first stage in the *Swedish educational* system. Preschool education is governed by the Education Act and the national curriculum specified by the Swedish National Agency. The national curriculum describes the preschool values, goals to strive for and educational tasks for the preschool staff. It is voluntary and includes educational activities for children aged one to five years old. At age six children attend mandatory preschool class. After one year in preschool class, the children continue through a nine-year compulsory school system

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Policy directs local provision—Teaching approaches depend on local culture, resources and the teacher's selected curriculum goals. Preschool is intended to lay the foundation for lifelong learning and should, according to the national curriculum, be fun and interesting for all. Children should have the opportunity to learn through play, to create and to explore on their own, in groups or together with adults. The preschool teachers are responsible for education, and together with the other staff, the preschool should promote the children's development and learning. Preschool teaching can be indoor or outdoor. The National Curriculum emphasizes that time spent outdoors should provide opportunities for play and other activities, both in planned and natural environments (National Agency 2016, p. 7)
Teacher qualifications/education—Preschool teacher undertake three and a half years of full-time study at university level with a bachelor's degree. There is one education program for all preschool teachers with local differences across universities. The education includes courses in science, technology and mathematics, besides other knowledge areas. During their education degree, students undertake a 20-week internship in preschool divided into three periods supervised by *local teacher educator* and university academics. Not all preschool *staff* are trained teachers. The National Agency for Education ensures that Swedish education maintains a good standard of quality and achieves this with the help of national school development programs and in-service training of the staff. The agency issues diplomas of certification to preschool teachers. The National Agency for Education prepares knowledge requirements and general recommendations. They are responsible for official statistics in the area of education and conduct national follow-ups and evaluations. In-service teachers have opportunities to attend other courses at university level for example five-week courses. These courses can be assignment courses ordered by the National Agency of Education and can include courses in science, mathematics, and technology or in language and multilingualism. The municipalities also support the preschool teacher's professional learning and offer opportunities to attend lectures in different topics
AUSTRALIA
EC in national curriculum—Education is both a federal and a state issue. The federal government provides funding to the states, but the states must also use their own budgets to fund preschools. Early childhood education, birth to five years old, is not compulsory. Preschool education (frequently called kindergarten) occurs in the year prior to formal primary education and is delivered by both childcare centres (privately owned and managed) and government preschool centres. Children are nominally four to five years of age during preschool. Preschool programs are funded by government for 15 h each week. Children younger than aged four to five can attend a three-year-old 'kinder' but this is privately funded by parents. *The Early Years Learning Framework* (EYLF, DEEWR 2009), are guidelines that teachers can access, however, there is no mandated curriculum to be followed. The Framework is designed to outfit teachers with common language about children's learning and stipulates five learning outcomes for young children around identity; connected to their world; wellbeing; confident and involved learners; effective communicators
Policy directs local provision—The EYLF learning outcomes provide a broad direction. Autonomy is provided to the teacher to design curriculum specific to the local community and specific setting beliefs and policy. The preschool day is usually divided into short segments with time spent both inside with more structured materials and outside with most preschools having an outside area which is designed to be as natural as possible, but will also contain features such as a digging area (sand pit), grassed area (for movement), water troughs and outside toys. Many kindergartens now offer three to five hours in an outside 'bush' or natural environment each week

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Teacher qualifications/education—Early childhood teachers must complete a four-year university undergraduate bachelor's degree. This is usually a bachelor's degree in early childhood studies or early years in which STEM is often represented in pedagogical discipline studies of science, technology, mathematics. In recent years, the bachelor's degree has been adapted to provide educational coverage for children from birth to age 12 (early childhood and primary teaching). The label of 'teacher' differentiates a four-year educated person from someone who qualifies with a three-year diploma (Technical and Further Education Institute—TAFE) or a two-year certificate (TAFE). These lesser qualifications designate a trained person as an 'educator'. Trainee teachers and educators spend time in preschool setting as interns for approximately 80 days. In preschools, a qualified teacher will lead the four- to five-year-old program, while trained educators will work with the birth to three-year-old children. There are minimal additional training sessions or professional learning opportunities in the STEM areas for early childhood educators or teachers to attend
BELGIUM
EC in national curriculum—Belgium is a federal state, composed of three communities (Flemish, French and German-speaking communities) and three regions (Flemish Region, the Brussels-Capital Region, and the Walloon Region). The power to make decisions no longer belongs exclusively to the federal government. The Flemish, French and German-speaking Community are autonomous in the field of education overseen by the federal government. The Flemish Government is fully responsible for the organization of education in Flanders across primary education (including preschool), secondary education and higher education. Preschool education for children from two and a half to six years, is not compulsory. At the age of six, a child usually moves to primary school, which is compulsory and undergoes six years of study, obtaining their first diploma: the certificate of primary education. This certificate enables the transition to secondary education There are six learning areas in preschool education: (1) physical education; (2) musical education; (3) Dutch language; (4) people and society; (5) science and technology; (6) mathematical initiation. Development goals for preschool education are knowledge, insight, skills and attitudes. With these development goals, the Flemish government determines the social mission of every school
Policy directs local provision—The school and the parents know the required minimum standards. Each school and teacher can freely design their own curriculum content. The preschool teachers place the children in powerful and rich learning environments where the children take their own learning into their own hands. Children have opportunities to develop competencies in situations that are realistic for them, learning from their environment or during the exploration of another person's world. Teachers focus on cognitive, motor and social-emotional aspects and challenge children to actively learn, to solve problems collaboratively, to organise themselves, and to explain their own methods
Teacher qualifications/education—Education for preschool teachers is conducted during three years of full-time studies at a university college (Professional bachelor's degree). Preschool teachers obtain a degree of Bachelor of Education: Preschool (Pre-primary)

10.4 Comparing the Research Designs

The research designs of all three studies were based on collecting qualitative data, relying on collection methods such as surveys and in some cases teacher and educator observations and interviews. The aim of each study was similar in terms of locating knowledge about STEM practices in early childhood. The three research studies were conducted in 2016 in Sweden and Australia, and in 2017 in Belgium. See Table 10.1 for an overview of data collection methods.

Sweden developed a research design that combined different ways of constructing data over time. The survey collected demographic data and information regarding STEM knowledge and curriculum goals. STEM pedagogy/didactics and the subsequent analysis pointed to the need to deepen knowledge of preschool teachers' work with STEM areas in their child groups. Interviews were informed by the survey results. The survey and interview questions were underpinned by key ideas that included *preschool teachers' knowledge* of STEM education and teaching objectives/goals as well as *pedagogical content knowledge* focusing on developing children's learning in STEM areas. The interview, questions considered topics including how teachers challenge children to develop mathematical (scientific and technological) ability and how teachers learn from children's previous knowledge. Other questions considered children's feedback and the use of children's own questions and the teachers' perceived challenges in their teaching.

Researchers in the Australian study undertook site visits to observe instances of STEM teaching and learning. Four preschool settings were visited weekly for six weeks and observational data recorded visually through electronic means (ipads) and through researcher journal notes. The effectiveness of preschool teachers' early childhood STEM pedagogy and how teachers engage children's learning in STEM were considered. The four sites provided opportunities for comparison. In 2016, in addition to the research visits to preschools (4–5 years old), an online survey was conducted with teachers from three different Australian states. Despite widespread distribution, only 26 responses were received. The questions of the survey were underpinned by three key ideas: *teachers' knowledge* of STEM as a learning area

Table 10.1 Overview of data collection methods used

	Aim	Survey	Observation	Interviews
Sweden	to build knowledge of preschool teachers' teaching, content knowledge and pedagogical content knowledge	Yes (300 teachers)		Yes (10 teachers)
Australia	to examine how preschool teachers undertake early childhood STEM pedagogy and teaching practice and how teachers engage children's learning in STEM	Yes (26 teachers)	Yes (40 visits)	
Belgium	to examine preschool teachers' familiarity with STEM education, focussing on teachers' knowledge about the STEM domain and pedagogy, planning and organizing STEM lessons, and identifying teachers' needs for support in relation to STEM	Yes (46 teachers)		

and pedagogy, teachers' beliefs regarding *children's learning* through engagement in STEM, and teachers' *planning and programming* practices in relation to STEM.

The Belgium researchers were preparing a STEM education professional learning program for preschool teachers. To inform the development of their program, they sought background information on the extent of familiarity that Belgian preschool teachers had with STEM education. They planned their survey questions around teachers' knowledge about the STEM domain and pedagogy, their planning and organization of STEM lessons, and to identify teachers' needs for support in relation to STEM.

10.5 What the Teachers Were Saying

From the three different countries, teachers' perceptions were gained in relation to STEM teaching, content knowledge, pedagogical content knowledge, planning and children's engagement. The following sections give an overview of what teachers said in each of the jurisdictions.

10.5.1 Sweden

In Sweden, the study shows that preschool teachers highly value having knowledge about common core values as described in the Swedish national curriculum for preschool. Common core values are, for example, values as democratic, norms and ethics. This is demonstrated in the interviews where the preschool teachers value knowledge of the children's interest as important starting points in the choice of content and work methods during teaching, and that they value their own knowledge of being able to use the children's interest and experience in teaching as significant.

> You catch the children's interest in the moment; you lie on the "car mat" on the floor with and play with a child "here the car rolls fast on the floor, but slowly here on the car mat, why is it like that"?

Preschool teachers based the teaching on the children's interest and experience in mathematics and science but indicated that this was less common for technology teaching.

> When we started using technology, there were many colleagues who were uncertain about how they would do. Then I found some books on the internet and asked the boss to order books for us. Then we could talk about how we would do and give examples, go technical hunting and some such stuff.

In the interviews, the preschool teachers discussed the importance of the activities being fun for children and being carried out according to children's wishes. According to the preschool teachers, this means that the teaching can take place in different contexts and by different methods, as governed by children's requirements. One of the preschool teachers describes that together with children, they look for simple technologies exhibited in the everyday object.

> We walk around the department and look at everyday technology, we look at the pedal bucket, how to open and close it, how to open and close a door and on the boot.

The teachers say that it is therefore important to vary the environment and context of teaching in order to inspire and challenge the children in these subject areas.

Preschool teachers describe their knowledge, and awareness of the curriculum goals when they teach. However, they do not always have the time required to teach based on the curriculum. Pre-prepared teaching materials, such as the NTA (Naturvetenskap och teknik för alla, 2018) and Green Flag (Stiftelsen Håll Sverige rent, 2018), served as support during planning of teaching. By using pre-prepared materials, preschool teachers indicated that they can work with topics such as water, air, light and sound, which leads to the incorporation of chemistry and physics teaching.

> We work with Green Flag and how can water sounds. This means that the children need to explore water, connected to the senses, splashes, dripping or dripping.

The study revealed preschool teachers' beliefs in their ability to formulate objectives for teaching in mathematics and science however they consider their ability to formulate objectives for teaching in technology requires further development. The curriculum focuses primarily on two objectives in technology: give children opportunities to "develop their ability to identify technology in everyday life and explore how simple technology works"; to develop the children's "ability to build, create and construct using different techniques, materials and tools" (National Agency for Education, 2016, p. 10). Preschool teachers have identified a need to develop their ability within teaching, in order to let the children develop their abilities and understanding in technology.

Documentation is an important part of teaching. The documentation can be directed to the children and can be used by the children, for example, for reflection. The children's interest is described as a guiding principle. The preschool teachers also express a willingness to have teaching practice that allows the children to participate and influence the content and form of the activities. This means that the preschool teachers work in a systematic way in order to find out what the children are interested in and how they can continue to work with those areas.

> The children ask questions, for example why does the apple shell disappear first [before other material]? And then we talk about it; that there is so much water in the apple shell and that it is an organic material.

Play and games are an important part of the children's learning in mathematics, science and technology. The play creates opportunities for the preschool teachers to evaluate and see what concepts and notions the children use.

> And then in the free play when the children cook, I saw the other day that a child put a baby doll at each chair and a plate and then one sees "one to one principle".

The analysis of the interviews shows that preschool teachers use both free and the planned play as opportunities for the children to develop an understanding of mathematics, science and technology.

10.5.2 Australia

In the Australian study, across the 200 plus observations noted, there were many different instances of STEM, both as discipline experiences but also as integrated STEM. These were documented using an observation protocol, which recorded the specific experiences, researcher interpretation, educator comment (when available), and other relevant factors important to the play experience. However, what was also noted in the researchers' observation was that teacher scaffolding varied, with some teachers fully involved in children's STEM play experiences, through to situations where the teacher would stand back and watch—unless specifically invited by the child to join in. The support provided to children's STEM play and the preparation of STEM activities in the pre-school was so varied that it was difficult to determine the factors, which underpinned the differences. Teacher pedagogical beliefs played a large part in the quantity and quality of STEM in early childhood centres (see Table 10.2).

The teachers' responses to the survey indicated that STEM was not a term that many of them regularly used or felt they understood well. Some teachers did have a broader understanding of STEM.

Table 10.2 Selection of observed STEM activities

STEM—integrated activity	Science concepts	Technology concepts	Mathematics concepts	STEM skills and processes
Children building 'cubby houses' using sticks and branches	Forces	Investigate materials, design, construct and evaluate cubby (fit for purpose, aesthetics)	Measuring the branches and sticks	Problem-solving estimation and approximation
Weather–undertaking inside discussion, moving outside to observe the weather	Observing –clouds, sky, rain, rainbows (shape, colour, size)	Children creating clouds, rainbows and rain as a room exhibit	Measuring rainfall	Observation measurement, recognising difference in size, shape
Whole centre theme on medicine and the human body	skeletons, human body model,		Measuring bones and aligning them to a template. Measuring body parts comparative	Establishing and justifying sorting criteria

It is an integrated approach to teaching Science, Technology, Engineering and Maths.

When discussing their teaching practices, many teachers discussed distinct disciplinary-related practices such as 'inquiry approaches' associated with science and developmental learning appropriate to mathematics.

…science intentional teaching activities from time to time and more often incidental learning activities. Using a SmartBoard. Providing activities that support children's engineering/mathematical learning.

When asked to describe how they enhanced children's STEM learning, the responses ranged across a number of strategies that were both generic (group learning, teacher-led) but also those considered STEM (demonstrations followed by children experimenting, guided interaction, inquiry-based activities, questioning) (Fig. 10.1).

I apply the following practices - Inquiry, questioning, provoking and challenging children's ideas, intentionally setting up learning experiences with the purpose to explore a particular idea, scaffolding and suggesting children to explore and discover.

All teachers indicated that learning needed to start with children's interests and prior understanding. Teachers listen to what children say and observe what they do. They can then plan and build children's understanding from there (Fig. 10.2).

I do this by placing priority on this learning, talking to children about their own learning in this area and acknowledging that everyday experiences can form STEM learning.

Children's engagement and attitudes to STEM were considered very important with teachers indicating their belief that exposure to the STEM disciplines were important for children's later learning in life.

Fig. 10.1 Teacher-led activity where children were investigating sea animals (sea dragon)

Fig. 10.2 Intentional teaching of weather and observing clouds

> I'm not sure I would say I'm 'strong' in the STEM area but I try to offer different activities that lend themselves to the Stem concept and build on them from there. I try to be interested and model different behaviours with the activities to promote interest.

Much of the STEM learning was planned and documented with the inclusion of both integrated and specific discipline-focussed activities prepared for the children on a regular basis. These were labelled as science, technologies, construction, mathematics or integrated activities, rather than STEM. All teachers commented that they did include STEM in their program.

> Being intentional and specific with explanations and discussions. Really thinking about the language that we use and demonstrating skills where appropriate.

The teachers acknowledged that planning was difficult, and this seemed contradictory to the idea of child-instigated learning through play.

> Often unsure that I am doing enough in these areas. Often find some staff overlook these areas or think it must be a very structured lesson or a whole group being shown an experiment.

Teachers indicated that additional materials, further professional learning in STEM and greater parent support were amongst the resources they would like to enhance. One of the most significant forms to support STEM learning was listed as *other knowledgeable adults* as well as a particular setting such as bush or natural settings.

> Adults with strong interest in the outdoors and in the environment, lots of outdoor play, multiples of equipment to promote experimenting and discovering, building and trying out new things". "Perhaps further PD opportunities to expand my knowledge as a teacher to be able to know how best to take these topics further.

10.5.3 Belgium

In 2017, a survey was completed by 43 Belgian preschool teachers to examine preschool teachers' familiarity with STEM education. It focused on teachers' *knowledge* about STEM and *pedagogy*, *planning* and *organizing* STEM lessons, and identify teachers' *needs* for *support* in relation to STEM. Data indicated many similarities in the answers of the preschool teachers. There were clear differences in the description of STEM in their own words and it was determined that the meaning of STEM education is not unambiguous. The preschool teachers indicated that they try to plan STEM activities within their daily planning. Observing children's play, listening and talking to children, is crucial to respond to the child's interests. Preschool teachers highlighted that they needed further professional support in order to be able to achieve good STEM education in their daily practice.

Despite the availability of the curriculum documents and the STEM Framework, the analysis of the survey data showed that for preschool teachers 'STEM' is not a frequently used concept. Most teachers referred to domains, mainly science and technology. The integrated work on science, technology, engineering, and mathematics within a STEM activity is mentioned in a few responses. In the definition of 'STEM', preschool teachers often referred to research and design skills that children use in STEM activities: experimenting, discovering, problem-solving, playful experiences. They link activities with computational thinking.

In the survey responses, preschool teachers described that they mainly start from the observations of children's play for the development of STEM activities: the interests of the child form the basis for the choice of teaching methods. Teaching methods cited for STEM activities include asking questions leading to research and design, provoking discussion, and group work. Preschool teachers made a distinction between planned activities and unplanned activities. Working from the interests of the child is important as it provides context -for example, arousing curiosity whereby the child is challenged in a playful way to think for himself, to experiment, to ask questions and to use 'real' material. The offer must be attractive to the children (connection with their environment). These results are also in line with the goals of the STEM Framework where 'STEM wants to learn by means of *real-life* experiences and socially relevant challenges' (Departement Onderwijs en Vorming, 2015, p. 15).

The survey also indicated that preschool teachers could distinguish between, and strive to carry out, planned activities and unplanned activities within a theme: responding to the interests of the children plays an important role here. Preschool teachers indicated that their own knowledge, skills and experiences within STEM education are limited which highlighted that responding to the interests of the children is not easy with every theme. Daring to let go of the children (allowing them autonomy) is also seen as difficult. The demand for professionalization around STEM is high with some stating that there is a 'need' for a handbook with concrete examples. The demand for extra materials and budget to realize STEM education in preschool is also strongly reflected in the surveys.

10.5.4 Discussion of the Comparisons Across the Countries

In comparing the various components for each country against the nominated themes arising from the Swedish study, we found strong similarities and some minor differences. In terms of the policy directions of each country, all countries had policies indicating the importance of education in early childhood, However, Australia did not incorporate STEM learning in the national curriculum.

Teacher practice at the local level tended to be similar, but with some clear differences in the level of detail. For example, while Swedish teachers mentioned linking curriculum goals to the activities, Australian and Belgium teachers did not. This indicates a possible disconnect between the value of learning goals and the planning of activities. The other major difference that was clear in the data from teachers was that documentation of planned activities appeared to be valued by the Swedish teachers, but was not obvious from the Australian or Belgium teachers. There is no data to suggest why this might be, as all curriculum documents from the three participating countries do highlight the need for planning and documentation.

Table 10.3 provides an overview of the results of the comparisons.

Table 10.3 Comparisons across the countries

Overview	Sweden—nominated themes	Australian case—supports Swedish case?	Belgium case—supports Swedish case?
National policy and importance	Education is a national issue	Yes	Yes
	Early childhood is in the national curriculum	Yes, but STEM is not	Yes
	Preschool is mandatory	Yes	Yes
Teacher practice at the local level	Teachers use thematic areas	Yes	Yes
	Teaching opportunities—spontaneous and random	Yes	Yes
	Goals from the curriculum are linked to the activity afterwards	Not specifically mentioned	Not specifically mentioned
	Teachers use planned activities and children's interest as important starting points	Yes	Yes
	Teachers value activities as fun and being carried out according to children's wishes	Yes	Yes
	Teachers vary the environment and context of teaching	Yes	Not specifically mentioned
	Teachers value documentation as an important part of teaching	Not specifically mentioned	Not specifically mentioned

10.6 Conclusion

For the teachers in Sweden, Australia and Belgium involved in these studies, there is a strong belief in the autonomy of the child in directing their own learning and in the need to work through children's own play inquiries and interests. Teachers provide learning both through planned and unplanned activities and experiences. However, culturally, one country (Sweden) provided a more prescriptive curriculum document for teachers which enables STEM pedagogy to be more targeted to national requirements. In the Swedish national curriculum document, there appeared to be a stronger focus on 'learning' whereas the other two countries' curriculum documents had a more holistic approach to whole child development.

In relation to qualifications, all countries provided STEM content knowledge in their early childhood degrees. However, this did not translate to similar findings in the teachers' levels of confidence with their own STEM knowledge. The reasons for this are unclear, but may reflect the support for teachers through, either the didactic strength of curriculum documents (e.g. Sweden) or the current Australian State and National government focus on providing additional STEM support in preschools (Australian Government, 2015).

Most of the teachers' discussions highlighted a disciplinary approach to planned STEM activities rather than an integrated approach which could be attributable to the discipline-based teaching teachers received throughout their degree. Integrated STEM approaches are still in their infancy in many countries. Considering that generally children's learning is holistic, a disciplinary approach sits at odds with young children's learning in general. However, as the majority of teachers' time in guiding young children's learning is through scaffolding at the point of need, perhaps this is not a big issue.

Overall, the research findings indicated that the teachers' roles in presenting STEM to the children were very similar and were similarly represented in their discussions. In terms of cross-country comparisons, the evaluation of the three research cases revealed a stronger thread of similarity than difference. The international field of early childhood STEM education providers appear to be taking a comparable pathway forward.

10.7 Recommendations

The analysis above highlights that teacher confidence varies across the countries, despite what appears to be comprehensive cover of STEM in qualifications. Further research is required to clarify this difference in teachers' perceptions of their STEM knowledge. Similarly, the data highlighted the disciplinary nature of STEM provision at the early childhood centres which is at odds with the holistic nature of children's learning through play. This points to a need to better understand how an integrated STEM approach might be provided. What specific training do teachers need? Again further research would clarify future professional learning needs of teachers. Finally, as STEM gains a greater foothold in early childhood curriculum through both planned and unplanned activities, there is a greater need to understand how this is supported by government policies in early learning as well as how it can be implemented successfully in early learning centres.

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Chapter 11
Perspectives on the Finnish Early Years STEAM Education: Reflecting on the Avant-Garde

Jaakko Hilppö, Jenni Vartiainen, and Pasi Silander

Abstract The skills needed to live in our current societies are rapidly changing. How will we provide children with the skills they will need in the future? While early years education has been traditionally strong in supporting twenty-first century skills like creativity, collaboration and problem-solving within play, global crises around the ecological, social and economic sustainability of our societies challenge current practices and call on us as researchers and educators to rethink how these and other skills, like computational thinking, could be advanced in early childhood education via science, technology, engineering, arts and mathematics (STEAM) education.

Over recent years, the Finnish educational system has enjoyed intense national and international attention, the early childhood education and care (ECEC) sector along with it. This has resulted in multiple descriptions and attempts to characterize Finnish education's main differences from other national systems. Finnish early years education has been heralded for its holistic orientation to children's care and education, as well as its focus on playful learning approaches and participatory culture. However, despite these positive characterizations and the arguably great potential of the Finnish pre-primary education for offering children with rich opportunities to engage in STEAM learning, early childhood educators are still cautious in implementing STEAM and phenomenon-based learning.

In this chapter, we present three distinctive approaches to early STEAM education developed in Finland, namely (1) phenomenon-based learning, (2) children's makerspaces and (3) children's projects. In addition, we also discuss how these approaches build on the current form of Finnish ECEC and draw out suggestions on how these

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approaches could potentially address the above concerns regarding Finnish early years STEAM education.

Keywords Early childhood education · STEM · Phenomenon-based learning · Twenty-first century skills · STEAM

11.1 The Finnish Early years Education as a Context for children's STEAM Education and Twenty-First Century Skills

Over recent years, the Finnish educational system has enjoyed intense national and international attention, and the Early Childhood Education and Care (ECEC) sector along with it. This has resulted in multiple descriptions and attempts to characterize its main differences from other national systems (e.g., Einarsdottir et al., 2015; Hujala et al., 2009). However, in her recent review Kumpulainen (2018) argues that the Finnish system does not have any one element that makes it unique. Rather, the merits of the Finnish ECEC lie in several intertwined values that permeate the various ECEC services and the educational system as a whole. According to Kumpulainen, these values are (1) the system's principled nature, i.e., the way in which education and care are embedded within the Nordic social welfare state model and its legislation, (2) mutual trust between families, the government, educators and children, (3) child-centered pedagogics and (4) the opportunity to personalize and build individualized support for children's learning and development. Although these values work in concert, we believe that the last two, child-centered pedagogics and opportunities for personalization, are most relevant from the perspective of STEAM education and fostering twenty-first century skills. We will elaborate this argument in the next few paragraphs.

However, before doing this, we need to first outline our perspective into STEAM education. For us, STEAM education connotes a pedagogical approach that integrates content and skills specific to science, technology, engineering, arts and mathematics (Martín-Páez et al., 2019). STEAM education connects each component into a meaningful combination of disciplines integrated into the one educational experience (Martín-Páez et al., 2019). By merging the STEAM disciplines into a seamless entity, teachers can provide children with possibilities to build their understanding of authentic scientific phenomena as they emerge in a child's life. STEAM offers a scene in which children can work with interdisciplinary problem-solving tasks and innovations from their own starting points. Hence, STEAM shouldn't be treated as a pedagogical approach that combines the disciplines but rather as a meta-discipline created from them (Kaufman et al., 2003). Consequently, STEAM becomes more than a sum of its factors. Meta-discipline thinking opens up STEAM education to implement practices that develop children's twenty-first century skills, both the more commonly recognized, like creativity and collaboration, and the new, like computational thinking (Denning & Tedre, 2019; Wing, 2006). Through this STEAM education can support understanding the role of digitalization and Artificial Intelligence (AI) in everyday life in our modern societies. Moreover, STEAM education adapts inquiry-based learning practices (Minner et al., 2010) which require openness from the learning environments and tasks. We also think that STEAM education should be nested in authentic problems or tasks that arise from children's everyday observations or wonderings. Importantly, in early childhood education settings, STEAM education doesn't necessarily require integration of all disciplines. Rather, following Tippett and Milford (2017), we think that the integration of any two of the disciplines can be counted as STEAM education in so far as the aspects of authenticity, children's agency and inquiry-based practices are present.

The child-centered nature of Finnish ECEC means that it is poised to support this type of STEAM education. In the opening statements of the current National Core Curriculum one of the main goals of ECEC is outlines as "*to promote children's holistic growth, development and learning in collaboration with their guardians*" and that "*Knowledge and skills acquired in early childhood education and care strengthen children's participation and active agency in the society*" (Finnish National Agency for Education, 2016, p. 12). Later, when discussing learning in ECEC settings more specifically, the curriculum states that "*In early childhood education and care, the previous experiences of children, their interests, and their competencies are the starting point for learning*" and that the curriculums' "*conception of learning is also based on a view of the child's active agency*" (Finnish National Agency for Education, 2016, p. 18). In practice, this emphasis has meant that children are invited to participate in creating and assessing activities with the early childhood educators and that their interests and lifeworlds are taken as a starting point for the activities (e.g., Alasuutari et al., 2014; Kangas, 2016). While these educational policies and guidelines have not always been translated into professional practices as such (Kangas & Lastikka, 2019; also Paananen, 2017), the child-centered nature of Finnish ECEC means that children have both the opportunity and the support they might need for both STEAM learning and developing their STEAM interests.

This opportunity and support is further accentuated by the number of structural elements aimed at securing individualized care and support for learning and development. In addition to families having the several options to choose between the type of care best for their child, Kumpulainen (2018) highlights the individualized education plan (IEP) negotiated between the parents, the child and the early childhood educators as an important tool in this regard. The goal of the IEP is to act as a formative bridge between the child's current interests, their possible developmental needs and the ECEC curriculum and help tailor the pedagogical practices for each child (Finnish National Agency for Education, 2016). Again, while the IEPs are not always considered in everyday practice and can become stagnant documents (Heiskanen, 2019; Paananen & Lipponen, 2018), they do offer a substantial opportunity to bridge children's lifeworlds and deepen the connections between home and pre-primary education. In relation to STEAM education, this means that children's interests in STEAM phenomena can more easily travel between kindergarten and their home.

In addition to these two central values, there are also other contributing aspects that make Finnish pre-primary education a formative setting for STEAM education. The Finnish pre-primary education, like in other countries, is situated between early education and care services and elementary education, as such a transitional institution itself, and arguably a mix between the care and play oriented kindergarten groups for 0–5-year-olds and primary education with its emphasis on formal instruction. For example, approximately 700 h per year are used for a variety of pre-primary activities, which breaks down to four hours per day (Kumpulainen, 2018). Although only this part of the day is mandatory for all 6-year-olds, most of them attend for the full day. In addition, in most cases pre-primary education groups are situated in the kindergarten's facilities (Kumpulainen, 2018). This means that the schedule and daily rhythm has room for guided STEAM exploration as well as self-generated activities around STEAM.

11.2 Novel Finnish Approaches to Early STEAM Education

Next, we present three distinctive approaches to early STEAM education developed in Finland, namely (1) phenomenon-based learning, (2) children's makerspaces and (3) children's projects. In addition to highlighting new ways to engage in STEAM education, these approaches importantly also show the way in which the two core values of the Finnish early education and care system we discussed above make possible the development and implementation of multiple mutually supportive pedagogical designs aimed at supporting STEAM interests and learning (Fig. 11.1).

11.2.1 Phenomenon Based Learning as a Holistic Approach to STEAM

Phenomenon based teaching and learning uses the natural curiosity of children to learn in a holistic and authentic context. It is important for learning twenty-first century skills like critical thinking, creativity, communication as well as computational thinking. Phenomenon-based learning can be described as multidisciplinary inquiry learning in which teaching and learning are based on holistic and authentic topics—not on traditional decontextualized exercises. The key dimensions of phenomenon-based learning are:

- Holisticness: The topics and concepts to be learned are chosen for their relevance in the real world, and a 360° perspective is offered through the integration of traditional school subjects.

Fig. 11.1 Interest towards STEAM starts from early on (Kide Science)

- Authenticity: The methods, tools, materials, and cognitive practices used in learning situations should correspond to ones in the real world: for example, in professional life.
- Contextuality: Learners learn new things in their natural context and learn to move fluidly between contextualization and abstraction.
- Problem-based inquiry learning: Learning and collaborative knowledge building are based on the questions and problems posed by learners, and solutions are created by them as well, allowing them to take an active role in designing the curriculum.
- Learning as a nonlinear process: Learning is seen as a nonlinear process, which is activated, guided, and facilitated by open learning challenges and supporting structures.

The basis of phenomenon-based teaching and learning can be found in constructivism, which sees children as active builders and creators of artifacts. Knowledge is constructed as a result of problem-solving and creative production through the integration of little pieces into a comprehensive whole according to the situational needs and the information available at the time. When phenomenon-based learning occurs in a collaborative setting (when the children work together), it supports the socio-constructivist and socio-cultural learning theories (see, e.g., Vygotsky, 1978), in which knowledge is not just an internal element of an individual. Instead, knowledge is formed in a social context. Socio-cultural learning theories focus on cultural artifacts (e.g., systems of symbols, such as language, and different kinds of thinking tools). These artifacts are basic elements in computational thinking and need to understand digitalization and artificial intelligence (AI).

Phenomenon-based learning begins with the shared observation of holistic, genuine real-world phenomena in the learning community. The phenomena are studied as complete entities in their real context e.g., in the forms of plays, games or maker projects. In phenomenon-based learning, understanding and studying the phenomenon starts by asking a question or posing a problem (e.g., why does a spider have eight legs?). At its best, phenomenon-based learning is cyclic inquiry learning, where children ask questions or wonder about a phenomenon that interests them and then discover answers and find solutions together. The problems and questions are posed by children together, they are things the children are genuinely curious about. Children can create their own artifacts like drawings, stories or animations or construct Lego robots. Digital gaming, simulations and virtual worlds may also be used as a tool to build shared artifacts.

In the learning process, new knowledge and skills are applied to the phenomenon at hand, which means that new knowledge and skills have immediate utility in the learning situation. This can be well implemented in STEAM projects involving design process, reflection and reasoning done by children. Even complex phenomena, like machine learning (ML) can be studied in ECEC e.g., by the activity when children are providing data sets and exploring ML by teaching computer to recognize emotions by showing facial expressions and gestures to a computer (Vartiainen et al., 2020). The skills learned in the process were not only related to computational thinking but also to socio-emotional skills.

Overall, phenomenon-based learning is suited particularly well to fostering twenty-first century skills, knowledge creation and computational thinking. This is in part due to its epistemological differences in relation to more traditional instructional approaches. Table 11.1 characterizes these differences and contrasts phenomenon-based learning to traditional surface learning and deep learning.

Table 11.1 The epistemic approach for learning the traditional and twenty-first century skills (Adopted from Silander et al. (in press) in STEAM projects

	Surface learning	Deep learning	Phenomenon-based learning
Goal	Recalling facts	Understanding	Creating new solutions
Outcome	Capability to apply information only in a narrow context, if at all	Capability to apply knowledge in various situations	Capability to create new solutions for various new situations
Methods	Information acquisition	Collaborative knowledge building	Co-creation and co-innovation
Focus	Facts	Knowledge	Thinking skills and strategies as well as innovation practices

11.2.2 Makerspaces in Early STEAM Education: Melding STEAM into Children's Culture

In this section, we will present an approach to early STEAM education that nests STEAM practices into the context of makerspace in kindergarten (Vartiainen & Kumpulainen, 2020). Makerspace approach to STEAM education shares the holistic, cooperative, and authentic approach to STEAM as phenomenon-based learning described in the previous example. In addition, it embraces creative, aesthetic and imagination-driven pedagogical principles. Makerspaces are introduced as environments that enable creative and collaborative problem-solving. Makerspaces have been studied as a venue for children to engage in authentic tasks that naturally invite children to solve problems that arise from their cultural spheres by applying STEAM skills and knowledge (e.g., Bevan et al., 2016; Kumpulainen et al., 2019). STEAM education in makerspaces has been studied mostly among primary or secondary school children, while early childhood education has gained little attention, even if the learner-driven nature of makerspaces have great potential to serve early STEAM education. Vartiainen and Kumpulainen (2020) implemented a Poetry Science project within early childhood education that combined STEAM education with maker activities. Their project underscored the approach to early STEAM that brings in contexts and cultural practices that are closely related to children's life worlds and culture. Mixing cultural practices of STEAM into children's culture happens by penetrating the problem-solving process and making with imagination, play, stories and poems. We will reflect on the work of Vartiainen and Kumpulainen (2020) and highlight the aspects of the project that aim to strengthen child-centeredness and personalization by looking at how children translate STEAM into their own cultural practices.

The project included a maker activity in which children were motivated by stories, poems and play to experiment properties of air resistance and to construct parachutes to help objects fall at a slower pace. The Poetry Science project was located in a Finnish ECE center and included 28 children aged 3–5 years old and their teachers. The problem-solving task was introduced to children by a puppet play and a related poem (Fig. 11.2).

> The teacher and the children sit on a floor. The teacher operates a dragon puppet called Hurricane. Hurricane tells children about a wacky incident she witnessed the other day. She has met two funny fish that were planning to set their home into the tree. But the fishes had a serious problem: They can't fly so they are not able to get to the tree. Hurricane says she wrote a poem about the fish, and she reads it aloud to the children:
>
> The children get excited and they suggest various ways the fish could get to the tree: They need to borrow wings from a flying fish! They could use a rocket! I've been in an airplane, someone suddenly remembers. The teacher nudges the children's thinking by asking what if fish could somehow get to the tree: How could they get down in a safe way? The children's ideas start bursting right away: They need a trampoline, they could use a slide, they could use a hot air balloon, they need a parachute! Children get excited about the idea of using parachutes and they start sharing their previous experiences about parachutes. The teacher grabs onto the idea of parachutes and scaffolds the children's thinking towards setting the aim for problem-solving. What do you say, should we build parachutes for the fish? What properties should parachutes have to slow down the falling?

Fig. 11.2 Flying fish poetry science card (MOI—Joy of Learning Multiliteracy development project)

In the example, the aim of problem-solving is generated from the shared playful moment. As in phenomenon-based learning, this approach follows inquiry-based strategies and setting the leading question or aim is important. Questions should be such that children find them meaningful and to support child-centeredness the questions should arise from children's suggestions. The makerspace activity is based on the pedagogical approach applied from guided inquiry meaning that some decisions in the inquiry process are defined by a teacher and some by children (Abrams et al., 2007). The context of the story and poem steers the possible aims of a problem-solving so that the teacher can anticipate the spectrum of outcomes and hence control the complexity of inquiry. Still, the aim is generated by a child-centered basis. The example underscores that children's own ideas and interests can be summoned from playful situations by the teacher's responsive scaffolding. The children's life-worlds and previous experiences are connected to the STEAM phenomena when children are allowed to reflect on puppet play by using their imagination and suggesting ideas. This creates a culturally meaningful space for children's joint meaning-making.

The next phase in the makerspace approach is to define how the question can be addressed.

> The teacher has prepared materials the children can use to experiment with air resistance and what effect the surface area has on it. The teacher let children freely explore different sized and shaped recycled newspaper pieces. Children start throwing pieces of newspaper into the air. They laugh and enjoy watching the newspapers falling. As children make observations that some of the pieces come down later than others, the teacher starts wondering what differences can be identified with quickly landing pieces and with slowly falling pieces. The teacher gives the children room to experiment and play with pieces, but she is constantly observing and listening to the children's initiatives and ideas that could lead the inquiry process towards addressing the problem-solving question. When the children compare different sized and shaped newspaper pieces, the teacher scaffolds the children's thinking by referring to the story: Can we use that piece of information to help the fish? The working continues and the teacher subtly scaffolds children's process towards making parachutes. At first, children concentrate on making observations about the parachutes: they drop parachutes from different heights, they run, slide and rush with them and drop parachutes upside down. Little by little, more playful aspects emerge in the children's meaning-making process and eventually it has taken the role of imagination-driven play with self-made parachutes.

The inquiry strategy implemented here is open in the sense of the methods and result (Abrams et al., 2007). The teacher has defined the materials but not limited them. If the children want, they can bring in other materials from the environment as well. By referring to the story, the teacher returns experimentation to the children's culture. By doing that, children can express their observations and inferences through the familiar context with their own narrative ways. Eventually, the children build their own parachutes. They tested and observed how parachutes acted under different manipulations. While experimenting with parachutes, the children's engagement started sliding seamlessly towards playing with parachutes. In the example presented here, the play merged the children's scientific observations, problem-solving, earlier experiences that the poem evoked and children's self-directed imagination-driven play. Although, the meaning-making took the form of a play, earlier observations had a remarkable role in defining how the play proceeded. Hence, children used results from their experimenting as the rules of the play (Vygotsky, 1967). This emerged unity is the sphere in which the children's STEAM practices become meaningful for children.

11.2.3 Children's Projects: Helping STEAM Interests Grow

Much like these two approaches, the idea of children's projects is aimed at cultivating children's interests and learning in STEAM. However, in contrast to them, the main pedagogical idea behind children's projects is to support and help the children to follow their emerging interests beyond the initial pedagogical designs or other sources that might have sparked their interests. This way the focus on children's project as a pedagogical approach is less on how STEAM interests can be introduced to children in early childhood education and more on how the development of already sparked interests can be accommodated and fostered. Building on principles of agency-based pedagogy (Rajala, 2016) central features of this support include dialogical relationships between children and early childhood educators that are characterized by trust and the adults' continued interest in and appreciation of the children's learning process.

But what are these "children's projects"? Hilppö (2017) characterizes children's projects tentatively as child-initiated and child-lead activities that are centered around a particular theme or the production of an artifact. Such projects, like children's interest in STEAM (Renninger et al., 2015), can be initially sparked by many things or situations. For example, playing with water in puddles in the playground, visiting a dinosaur exhibition or doing a fun science experiment with the teacher can awaken the children's interests and lead them to explore these interests more by themselves (Anderhag et al., 2016; Chesworth, 2019; Crowley et al., 2015). Similarly, such projects can emerge from sustained engagement with toys or technological devices, during which their curiosity and a sense of agency, I want to know what's inside, and I can open it, pushes the children into the opportunities they see as opening for them. These moments mark pivotal turning points in interest development as the children move beyond what has initially supported their interests and start creating new learning opportunities for themselves (Hidi & Renninger, 2006) (Fig. 11.3).

Fig. 11.3 Support by adults is important in retaining the children's sparked situational interest (Kide Science)

Next we provide a short narrative vignette of a children's project in a Finnish kindergarten that centered around bats. The observations on which the vignette is based on were collected by a pre-service teacher during a practicum period in a public municipal kindergarten in the north of Finland. The narrative is told from the perspective of the observing pre-service teacher.

> Most of the children in the kindergarten group I observed were very enthusiastic about bats. Bats were frequently part of their plays and the children had drawn a considerable number of pictures that displayed various kinds of bats, some coloring book pictures, or others drawn by the children themselves. They had even created a small performance about bats for the rest of the group. The whole thing had been started by a girl who had gotten excited about bats when seeing the movie Hotel Transylvania. According to her, the project was about exploring bats but also about exploring what she found scary about vampires. She told me that because of the project many of her friends come to her with questions about bats and that she likes this. The teacher of the kindergarten group saw The Bat project as educationally valuable. She told me that she and the children had read and learned a lot about bats, their habitats and their lifecycle. Although learning about bats was not part of the groups' official curriculum, the project had also offered the children a significant chance for self-directed learning. The opportunity to introduce a new activity as part of the kindergarten day as well as how they want to proceed with it and how to divide the work between themselves, were important learning moments for the children according to their teacher.

What is particularly significant in the above example in relation to STEAM and STEAM learning, is the way in which the project functioned as a site for exploring bats and our current knowledge about them. While this was not the only aspect the children engaged with, it nonetheless suggests that when we support children in following their STEAM (or other!) interests, this can lead the children to substantial learning opportunities which they themselves also seem to recognize. From a Deweyan perspective (Dewey, 1910; e.g., Miettinen, 2000), the Bat project could then be seen as a naturally emerging and collaborative inquiry process between the children and the teacher which entails encountering, engaging with and using disciplinary knowledge to advance, and as part of, the project (see also Hilppö et al., 2020; Hilppö & Stevens, 2021). More importantly, the Bat project also served as a site for multidisciplinarity and integrated the arts as a meaningful way to explore bats further.

11.3 Conclusions

Despite the conditions for engaging in STEAM education in Finnish ECEC arguably being favorable, early childhood educators are still cautious about implementing STEAM and inquiry-based practices with the kindergarten groups (Repo et al., 2019). Educators report that their own negative attitudes and low feelings of competence in the STEAM disciplines, unsuitable working environments, lack of equipment and materials as well as the heterogeneity of the children are significantly impeding them from engaging children more in STEAM education. Together and by themselves, each of these reported problems are formidable obstacles that hinder advancing early years

STEAM education Finland. In this section, we will briefly explore how the presented novel STEAM education approaches could address these obstacles.

Teachers' low feelings of competence about STEAM education could be tackled in at least two ways with the approaches presented. First, they offer teachers tools to reduce the complexity of the inquiry process and second, they shift the role of the teacher from being a leader of the process to a co-explorer with the children. The makerspace approach demonstrated how play and stories can be used as a scaffold to reduce the complexity of inquiry-based STEAM activities. Such a reduction might mitigate teachers' insecurities about their STEAM skills and knowledge that stem from situations, imagine or experienced, where children ask or need assistance with something that is beyond their current knowledge and know-how. By using play and stories as naturally framed contexts for STEAM education, teachers can guide the question-generation phase and thus can also be more prepared to offer children proper cognitive and procedural scaffold and materials. With the children's projects approach, the shift in the teachers' role to a more co-explorer position is more extensive. While the children's emerging interests and activities can challenge the teacher's STEAM substance knowledge, allowing the children to lead the project tasks the teachers more with helping out with the project, pointing to possible helpful resources and offering suggestions than knowing something about the substance of the project.

According to Repo et al. (2019), Finnish ECEC teachers also feel that the existing learning environments and materials are not sufficient for STEAM education. The approaches presented above address this concern with a change of perspective on what eventually constitutes early years STEAM education. Traditionally STEAM education is regarded from a procedural and discursive practices perspective that has been adapted from how science, technology, engineering and mathematics are conducted in the working life (Martín-Páez et al., 2019). Consequently, STEAM learning environments are seen as requiring materials, tools and discursive practices similar to science laboratory environments or discourses that build up from scientific concepts. The makerspace approach demonstrates how play and stories act as cultural bridges between children's life-worlds and the world of STEAM. In the approach, problem-solving is looked at from the viewpoint of children's culture and hence the learning environments, materials and discourses are defined by the children's cultural practices. Therefore, STEAM education can happen where children naturally spend their time with equipment and tools that are familiar to them. Driving questions of inquiry emerge from the children's observations and wonderings. Observations and results are discussed within the frame of children's culture and therefore the results become meaningful for children. With the children's project approach, we demonstrated how children and a teacher through a collaborative inquiry process used disciplinary knowledge to advance their multidisciplinary project. While traditionally children's interests are harnessed to enhance learning of STEAM practices, with the children's projects approach STEAM practices serve as tools to foster children's emerging interests. To sum up, early years STEAM education does not necessarily always require lofty or expensive materials. Much can be done with "finding" STEAM in children's own cultural spheres and lifeworlds and cultivating these aspects with materials and practices available in each kindergarten. While we think that the teachers' concerns regarding how the kindergartens they work in are equipped for STEAM education should not be overlooked (rather the opposite!), we would also like to caution against seeing STEAM education as being fundamentally made up by the tools scientists use. Tools are an important part of STEAM and STEAM education, but an overemphasis on them runs the risk of pushing children into the world of STEAM without generating a more authentic understanding of what they are needed for.

Lastly, the teachers in the study by Repo et al. (2019) highlighted that the heterogeneity of their kindergarteners in terms of existing skills and competencies is impeding the teachers from engaging in STEAM education with them. From our perspective, this heterogeneity is less of an issue with both the makerspace and the children's projects approach. With the makerspace approach, the joint stories, poems and plays offer various entry points into the inquiry process and also suggest alternative ways of exploring the underlying phenomena. Hence, with the makerspace approach there is no "one right way" to engage in the making process but rather there is the opportunity for variety and personalization based on each child's own skills and interests. With more established and longer cultivation of makerspaces in kindergarten, one could easily imagine such opportunities being even further accentuated. As a mature and stable practice, a makerspace can host multiple maker activities simultaneously, much like in Montessori kindergartens. In these learning environments, the pedagogical structure of the various maker activities gives teachers more time to focus on each child and their particular learning needs. In turn, with the children's projects approach differences in terms of children's STEAM skills and knowledge is possibly even less central. With the projects building on each child's own interests and advancing much on their terms, the projects act as an arguable zone of proximal development (Vygotsky, 1978; or learning, see Chaiklin, 2003). As such, the projects call the children to put into play both what they know and can in the service of the project and also to learn and develop their skills further as part of it. In this way, their current skills, divergent between themselves or not, create the conditions for their own advancement in the context of the project.

Overall, while there are obstacles that significantly impede a more widespread adoption and implementation of STEAM education in Finnish ECEC, the avant-garde approaches we have outlined in this chapter offer some interesting options and avenues for addressing them. Whether and how these are realized in the various kindergartens across Finland is something we look forward to uncovering in future studies.

11.4 Recommendations

There are currently several books which present and discuss the positive aspects of the Finnish educational system and the recommendations educators around the world could take (e.g., Niemi et al., 2016; Sahlberg, 2011). However, what must be kept in mind when thinking about possible lessons learned for the international community is that the educational system in Finland, and the ECEC sector along with it, are embedded within and connected to a broader Nordic welfare state model and its other aspects. Thus, with any educational innovation, be it Finnish or other, it is important to understand that a mere facsimile of the innovative practices might not be enough to reproduce their effects (Morel et al., 2019). Rather, a more fruitful approach would be to see each innovation or recommendation as part of a larger parcel, to see both the figure and the ground that makes the figure stand out.

To this end, we hope that what we have provided illustrates well how the avant-garde approaches outlined above rest on and further build the more encompassing context of Finnish ECEC, how the innovative practices figure against a particular background. Moreover, we also hope that the examples we have given function in the future as *prototypical narratives* (Nissen, 2015), examples which embody the espoused axiological commitments and theoretical perspectives in descriptions of lived practices, instead of tick-the-box checklists. In this sense, we hope that our narratives have shown the overall importance of play and playful orientation to STEAM education in the early years and how this can support children's meaning making and the meaningfulness of STEAM to the children themselves. Moreover, we hope that our examples have been inspirational and have opened up new ideas and thinking regarding STEAM education in its readers. If so, we want to recommend and encourage each of you to take the next step. We eagerly look forward to what we can learn from you.

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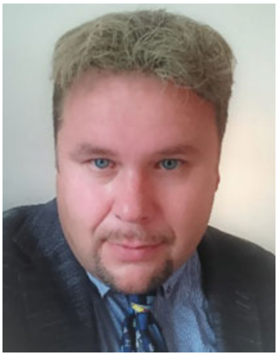

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Chapter 12
Play-Based Learning as a Natural Teaching Strategy in the Jamaican Preschool Environment

Karlene DeGrasse-Deslandes and Nicole Morgan

Abstract The interpretation and implementation of play in the Jamaican preschool has evolved over the years. The benefits of play are usually highlighted but the teaching of academic skills, rather than developing the preschooler's natural exploration of their environments, has been given precedence. Four to five decades ago children were told, "just go outside and play" which resulted in children playing outdoor games such as baseball, dandy-shandy, marbles, cricket, football, jacks or creating their own games. Preschoolers today are not being given the educational experiences and opportunities to be natural explorers and investigators as incorporating play through their daily activities is not being fully actualized. In the last decade, national initiatives have encouraged the implementation of play-based learning. This chapter reviews the challenges being experienced by early childhood practitioners (ECPs) in using more play-based learning techniques to encourage STEM in the early childhood environment. The value and purpose of play in the Jamaica Early Childhood Curriculum continues to be the source of much debate. The authors' questions are based on ECPs having clear understanding of play and its role in children's development. Should there be such policies as "no work sheets and textbooks" in the preschool classroom to place more emphasis on STEM education?

Keywords Play · Play-based learning · Preschool · Early childhood practitioners · STEM

12.1 Introduction

Play in the early years has been of significance to many scholars, child development therapists, child psychologists and educators for decades. Among the first to link play with cognitive development in children was Piaget in 1962, and later Vygotsky

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in 1978. A child's early years, the period between zero to eight years of age, are widely accepted as the most critical period for significant development to take place. Based on the work of Rousseau, Froebel and Dewey, play is seen as an important vehicle for preschool children to develop self-regulation; promote language development; promote cognition; and social competence. Feinberg (2010) stated that play gives children the opportunity to develop physical competence and enjoyment of the outdoors, understand and make sense of their world, interact with others, express and control emotions, develop their symbolic and problem-solving abilities, and practice emerging skills.

If this period is effectively managed, children will experience cognitive, socio-emotional, language, motor-development, and overall better performance as they advance on the education continuum, with an enthusiasm for lifelong learning (World Bank Report, 2018). The mounting research implies that children were no longer being viewed as miniature adults as indicated from the research of children which emerged in fifteenth century Europe (Barrow & Ince, 2008). Davies (1997) describes the early years as the most remarkable period of growth and development in the lives of children.

In play, children begin to construct an understanding of their world and an understanding of how people interact, consequently they thrive best in learning environments that have a culture that initiates playful learning. Therefore, play serves a critical role in children's development. In reviewing the numerous studies on play it is our conclusion that play contributes to the development of vocabulary, language comprehension, attention span, imagination, concentration, impulse control, curiosity, problem-solving strategies, cooperation, empathy, and group participation (Smilansky & Shefatya, 1990). Basic science and math, along with engineering ideas in action, allow children to experience and learn on their own terms.

12.2 Play-Based Learning in Jamaica

In Jamaica, attempts to integrate more play within the early childhood learning environment has been a difficult task. Bodrova and Leong (2003) stated that educators have always considered play as an essential in early childhood classrooms but due to increasing demands for teachers' accountability and measurable outcomes for young children, some early childhood programs tend to prefer early learning to be more academic content focused, hence the use of text books and work sheets with children as young as three years old. Early childhood practitioners tend to focus more on the development of children's cognitive skills rather than applying play principles and practices to offer children adequate opportunities to learn through play. There has been a plethora of books published recently by early childhood educationalists and developmental psychologists setting out the value of play for children's learning and development. At the same time, however, these publications consistently document the difficulties early years' practitioners have in developing effective practice to support children's learning through play, largely exacerbated by pressures to 'cover' the prescribed curriculum, meet government-imposed standards (Whitebread et al., 2012).

The history of early childhood development in Jamaica, has its roots in slavery, with children being treated as additional labour on the plantation prior to, and long after the abolition of slavery. In the years following slavery and emancipation, Jamaican early childhood programmes often facilitated by untrained teachers who had limited knowledge of children's learning needs and pedagogical strategies provided custodial care which focused only on the children's academic, reading, arithmetic and writing. However, there was significant development in the early childhood sector through projects such as the Bernard Van Leer Foundation. The late Dudley R. B. Grant led the Project for Early Childhood Education (PECE), which was designed to improve teacher quality through ongoing in-service teacher training, improve and formalize the basic school system and curriculum development with appropriate teaching and learning materials for teachers and children (Davies, 1997).

However, as international and local research grew, Jamaica's emphasis on developing an appropriate early childhood system strengthened. Projects in recent decades such as the review of the early childhood sector in 2000 by the Planning Institute of Jamaica, and in 2004 the Profiles Project (Samms-Vaughan, 2004) a landmark longitudinal research examined the status of early childhood development in Jamaica. The increased exposure to the plight in the education of the Jamaican child created the environment where the legal and social provision for their welfare, especially their health and education were increasingly prioritized and hence the focus of national debates.

The Jamaican Early Childhood Curriculum for children Birth to Five is comprised of four documents. The Conceptual Framework is one of the four documents that outlines the purpose, rational and philosophical principles of the curriculum. The first guiding principle is that children learn through play and interaction with the environment. It was also highlighted that play is the main vehicle through which children integrate knowledge in a meaningful way, learn self-expression and a gain a sense of competence (Jamaica Early Childhood Curriculum, 2008). From a national level, play has been promoted as important. Most recent, the Early Childhood Commission, has developed a national programme to reengage and re-culture early childhood stakeholders of the importance of play in the early years. The Early Childhood Commission (ECC) is an Agency of the Ministry of Education, Youth and Information and is the regulatory body with the legislated responsibility for the early childhood sector in Jamaica. Based on the most recent ECC census (2020), there are approximately 2,600 early childhood institutions (ECIs), over 120,000 children and over 12,000 practitioners. The activities that are initiated by the ECC are aimed at ensuring that our children have the best opportunity to achieve the most positive outcomes. One of the outcome for this national programme, is to ensure that more play-based learning with the inclusion of STEM is better integrated in the daily programmes of early childhood institutions and home.

As the overseeing agency of the Jamaican early childhood sector, the ECC is presently reviewing the Early Childhood Development Policy and one of the priority area is to outline the guidelines of play-based learning and Science, Technology, Engineering and Mathematics (STEM) at the early childhood level. The intent is to bridge the gap between the theory and practice of play. Also, the ECC is also reviewing the current curriculum to make it more play based with the inclusion of STEM.

12.3 Early Childhood Education in Jamaica

At present, over 90% of our Jamaican children within the early childhood age cohort attends an early childhood institution (ECI). Approximately 18% of these schools are owned by the government, while the rest are public/private partnerships or privately owned. The sector comprised of community and church owned and operated basic schools, daycare centers, privately own and operated preparatory schools and government infant schools and infant departments in primary schools. Several basic schools albeit not owned by the government, benefitted from government grants and subsidies for teacher's salaries, teaching and learning material and, nutritional provision through public/private partnerships.

In 1976, the criteria to receive government grants and subsidy was set by the then Ministry of Education Youth and Culture (MoEYC), currently the Ministry of Education Youth and Information (MoEYI), and basic schools that satisfied the minimum requirements were awarded recognition status and received government subsidies. The salary subsidy for teachers was linked to the national minimum wages and was paid to recognized basic schools by the MoEYC in collaboration with the community or the church. Regardless of facility type all schools were eligible for instructional supervision from the MoEYC. Parents of children in basic schools pay minimum fees, and this payment contributes to the teachers' total salary as well as the schools' maintenance and operations.

Service in the sector was delivered by early childhood practitioners (ECPs), trained teacher (degree or diploma) and caregivers. MoEYC provided instructional supervision through its cadre of early childhood education officers. ECPs were trained to a minimum of Level 1 training Early Childhood Development and Care, provided through the National Council for Technical and Vocational Education and Training (NCTVET) which led to participants receiving certification. Principals and teachers were educated at teacher training institutions where participants obtained a degree or a diploma in early childhood education—a marked indication of the inequality of qualification within the early childhood sector.

Established in 2003, the Early Childhood Commission (ECC) was charged with coordinating all early childhood development activities and development of the Standards for the Operation, Management and Administration of Early Childhood Institutions, a major legislated function being the monitoring and regulation of all early childhood institutions with children 0–6 years. As an Agency of the Ministry of

Education, Youth and Information (MoEYI), changed from MoEYC in 2015, the ECC had to ensure the fulfillment of children's health, safety and developmental needs. In the years immediately following the passage of the legislation, as the ECC began the activities necessary to reduce the fragmentation within the early childhood sector legal problems developed for most stakeholders. This led to the design and implementation of a comprehensive Jamaica Early Childhood Curriculum that catered to children aged birth to five.

It is the authors belief that play is a critical element in child development and simple games such as baseball and dandy-shandy are more important to the development of a child's brain than as means of passing time as it is often used in many ECIs. It is also the authors belief that when opportunities are provided for play, children enjoy learning and concepts are better understood which will ultimately develop children's readiness skills. Culture and traditions are important considerations when promoting natural play for young children. Early years practitioners can promote STEM at home by encouraging parents and caregivers to use math and science concepts in everyday activities. Engineering ideas intuitively result through play, thus providing opportunities in the early years' environment to work in teams using open-ended, easy to follow instructions, blocks, and easy to assemble parts; the testing of ideas and design processes will inevitably introduce young children to solving problems and building things (Cheng, 2008).

From conception and throughout early development, children, learning through play starts with parents and/or caregivers as they engage and respond to the child. Studies has determined that approximately 80% of children's brain development is completed by age three and 90% by age 5, while play is not the only way children learn, early childhood games are vital to laying the foundations for formal education in these early years of children development.

In Jamaica play is heavily influenced by culture, allowing for boundaries and rules to be set by parents and school personnel (Kinkead-Clark, 2019). These individuals determine the nature and context of how children should engage in play, impacting how play is interpreted and implemented and indeed how play evolved in Jamaican preschools.

In the Jamaican early childhood institutions, the benefits of play are usually highlighted however, the teaching of academic skills rather than developing the preschooler's natural exploration of their environments took precedence. Over the years, children were told, "just go outside and play" which resulted in children playing other outdoor games such as marbles, cricket, football, jacks or creating their own games. Preschoolers today are not being given the educational experiences and opportunities to be natural explorers and investigators as incorporating play in their daily activities is not being fully actualized. Traditionally play was never seen as an essential element in the teaching and learning environment, rather play was viewed as a meaningless activity that could not enhance the learning capacity of young children. According to Yogman et al. (2018), "Play is not frivolous: it enhances brain structure and function and promotes executive function (i.e., the process of learning, rather than learning the content), which allow us to pursue goals and ignore distractions." Play forms an intrinsic part of our culture and social activities where children learn the Jamaican culture and norms through different types of games.

In the last two decades especially since the development of the early childhood curriculum, the implementation of play-based learning in the early childhood learning environment has increased significantly. Child initiated and guided play is being realized as an essential element in how young children learn the skills needed to develop as the implementation of the curriculum is now observed in a number if the ECIs with significant success. The early childhood curriculum reinforces the role of play-based learning in the early childhood classroom through the "Conceptual Framework" which is one of the accompanying documents of the curriculum. The objective of the framework is to outline the purpose, rationale and guiding philosophical principles of the curriculum and the developmental goals and learning outcomes desired for Jamaican children (Jamaica Early Childhood Curriculum, 2008).

Play is often defined as activity done for its own sake, characterized by means rather than ends (the process is more important than any end point or goal), flexibility (objects are put in new combinations or roles are acted out in new ways), and positive affect (children often smile, laugh, and say they enjoy it). These criteria contrast play with exploration (focused investigation as a child gets more familiar with a new toy or environment, that may then lead into play), work (which has a definite goal), and games (more organized activities in which there is some goal, typically winning the game) (Smith & Pellegrini, 2013). In the Jamaican early childhood classrooms, children are engaged in some form of play which are free play or guided play. The findings suggest that both free play and guided play are indeed linked to social and academic development (Hirsh-Pasek & Golinkoff, 2008). 90% of early childhood practitioners stated that they provide play opportunities daily. Of the 90% early childhood practitioners, 57% provides between 1 and 3 h of play experiences daily for the children. The types of play provided are free and guided play.

Free play is referred to unstructured play where children freely choose from resources both indoor and outdoor. Free play is described in Play England (Santer et al., 2007) as children choosing what they want to do, how they want to do it and when to stop and try something else. Free play has no external goals set by adults and has no adult-imposed curriculum. Although adults usually provide the space and resources for free play and might be involved, the child takes the lead, and the adults respond to cues from the child. The early childhood institution daily schedule is a structured outline of activities that incorporate the different categories of play. Early childhood practitioners are encouraged to organize their daily activities to ensure play is a central component of the learning environment. Free play activities are usually encouraged in the morning upon children's arrival at school and afternoon when children wait to be picked up by their parent or guardian. The use of the learning centres is highly recommended, so as early as children arrive at school, they are encouraged to play freely with learning materials which are usually from the learning centres. The learning materials are organized according to the five (5) learning centres namely: Language and Reading; Manipulatives and Cognitive; Art and Sensory; Dramatic Play and Nature and Science. Throughout the day the practitioners' role is to provide the learning materials and learning opportunities for children to engage in STEM play. During this period, children will converse and play with their classmates while interacting with toys and learning materials.

Guided play is usually directed by the practitioner where he/she provides specific learning resources for the children to interact with or explore. Guided play refers to learning experiences that combine the child-directed nature of free play with a focus on learning outcomes and adult mentorship. Guided play can take two forms one in which the adults design the learning environment to highlight a learning goal while ensuring that children have autonomy to explore within that setting. Two, adults will observe child-directed activities and make comments, encourage children to question, or extend children's interests (Weisberg et al., 2016). Guided play is highly promoted in the Jamaican early childhood classroom. According to the daily schedule of an early childhood classroom, practitioners guide and facilitate the children in their learning by providing specific play activities that the children will engage in. The practitioners' roles are to prepare the learning space with the desired resources to either teach or reinforce a concept. The children's roles are to follow the guidance from the practitioners in order to learn the desired concept/s intended by the practitioner. For example, the practitioner will create the learning environment by providing all learning resources such as peas, cups, water, for children to plant and observe. The teacher may allow them to role play a farmer from whom they purchase peas for planting. Over a period of time, they would observe its growth. The practitioner will use open ended questions to discuss and guide children's thinking in order to develop a particular skill or concept.

Implementation of play in daily activities is a recommendation of the Early Childhood Commission (ECC), and as one of the guiding principles in the conceptual framework it emphasizes its belief in the importance of children learning through play. However, despite the curriculum change, some early childhood programmes still struggle to balance academic focused outcome and play-based learning. For some early childhood practitioners, the benefits of play to the development of the child is not easily understood or assessed and therefore provides a challenge for them to explain its benefit to parents who are often more focused on academic achievement. They are also challenged by how to prepare the environment and the time required to prepare the materials to ensure the appropriate resources are available for guided or free play activities. As teachers struggle to incorporate play, they also struggle to incorporate STEM in everyday activities. Teachers strongly believe that to incorporate play and STEM in everyday activities, requires more work and/or more equipment than purely academic activities.

Understanding that the amplified brain development happens as children play, it is necessary within education systems such as that which exists in Jamaica to have a policy that ensures that children are afforded the opportunities of this type of development. While children play, they are developing their language skills and expanding their vocabulary as they talk about the activity. It provides for each child the opportunity to build their understanding of the new concepts that emerge. Such interactions allow the brain to be stimulated and allow children to develop cognitive abilities as they explore the world, their memory, perception, problem-solving and thinking skills are developed. Children also learn how to socialize as there is an immense amount of negotiation and compromise that is involved as they take turns, follow rules, resolve conflict, learn to compromise, understand things from another's point of view, and show compassion and understanding. This leads to emotional development as children engage in role play and therefore learn to express their feelings and make sense of the world. This is the time they begin to develop emotional intelligence that allows the opportunities for them to channel their anxious and angry feeling in positive ways. Not to be left out is the development of the child's fine and gross motor skills, the building of large and small muscles that happens during physical play. The play experience is enhanced by the inclusion of STEM activities. In 2015 and 2017, research conducted in four preschools overseas concluded that STEM activities provide rich experiences for children as they explore their interests and increase their confidence in their abilities to learn (Campbell et al., 2018).

12.4 Children Engagement in Play-Based Activities

Despite, that some early childhood practitioners found it easier to implement worksheets in their daily routine, others implemented a play-based learning. Even during the COVID-19 pandemic, the early childhood practitioners encouraged play-based learning at home. Early childhood practitioners endeavoured to create stimulating learning environment to provide the opportunities for children to play. Below are pictures of children engaged in play-based learning (Figs. 12.1, 12.2, 12.3, 12.4, and 12.5).

Fig. 12.1 Learning centres to facilitate play based and STEM learning

Fig. 12.2 Charles* interacting with learning resources from the Science and Nature Learning Centre

Fig. 12.3 Charles* busily fitting puzzle pieces together

It is our belief that the best approach to support STEM in the early childhood learning environment is to incorporate it into play activities, and therefore form an integral part of children learning. A 2017 research partnership between the Dudley Grant Memorial Trust (DMGT), and the Grace Kennedy Foundation (GKF), a local

Fig. 12.4 Davian* playing games at home with the family to fit the missing pieces of the body parts

Fig. 12.5 Alyson* poses with the guitar that her dad and her just made. They will be using the guitar to make music

STEM centre supports the promotion of hands-on, exploratory experiences in the play activities of our children through training workshops for early childhood practitioners. STEM develop a child's inquiry skills while encouraging higher-level thinking through hands-on experiences and facilitate the development of valuable twenty-first century skills of communication, collaboration, critical thinking, and creativity. By combining STEM and play children are able to discover and explore their natural environment. Children can solve real problems in fun ways while providing different ways for science, technology, engineering, and math skills to emerge during play time activities. Understanding how crucial the early years are, we have a responsibility to provide children with play-based activities to enable them to learn in a natural way all skills needed to prepare them to become lifelong learners. STEM should not be taught in isolation; to be effective it cannot be about teaching one subject at a time but integrating all areas through play activities and encouraging children to begin thinking creatively.

Teachers in the early childhood environment must transition from thinking of STEM as an abstract concept and seek to find exciting and enriching ways of incorporating it in their lessons through play. This will not be accomplished without having a direct policy that mandate teachers to integrate STEM and play in daily teaching learning activities. Over 88% of early childhood practitioners agree that there should be a policy supporting mandatory play in early childhood learning environments. Having the policy will articulate the importance of integrating STEM with play and serve as a guide to teachers in how to implement play activities the in early childhood classrooms. With over 88% in agreement with the policy, it may lead to a greater appreciation and implementation of play in early childhood learning environment.

12.5 Conclusion

The natural ability of children to explore and make sense of their environment through play embodies the essence of learning through play. Therefore, an enriched learning environment with opportunities to capture the imagination of children and hone their problem solving and self-regulatory skills, their fine and gross motor skills is the proven and preferred strategy to help early learners as they grow and develop. A great number of local and international research have presented significant proof that play-based learning is a natural strategy to teach our children in the Jamaican preschool environment and many of our practitioners have been exposed to the various approaches and the benefits that are derived from employing same, yet the traditional culture and practice of engaging our children largely remains a slow evolution. The impact of the COVID-19 pandemic has riveted the shortcomings in the progress of early childhood development worldwide but more so in Jamaica as the closure and slow reopening of our care centres has retarded the abilities of practitioners to integrate play activities in the virtual space as they interact with the early learners. The perception of learning loss at the early childhood level has propelled an urgency to abandon play-based activities to more readily accept paper-based, academic activities as a means to recover academic readiness.

Children play even in a pandemic and play becomes increasingly important to mitigate the emotional trauma on the child caused by the pandemic. This is the perfect opportunity for practitioners to transition their perceptions of STEM and play as mere abstract concepts to available and beneficial approaches that can enhance their daily routines and the development of children.

12.6 Recommendations

In order to steer the mindset of our practitioners to more wholesomely adapt the practices of intentional play and STEM integration in the play activities in early childhood learning environments, a policy shift should be considered. Redefining the policies that support early childhood development or developing a play policy that further strengthens the use of play and STEM activities in the learning environments of young children birth to five years should become a major legislative undertaking. This policy should define the abolishment of the use of text books by children, two to five years and mandate more hands-on manipulatives and purposeful play activities like outdoor games, nature walks for children and continuous documentation of observations of the practitioners as they support the young learners.

Prioritizing budgetary allocations for early childhood development is key to investing in legislated play. Therefore, increasing the state budget for the provision of age and needs appropriate resources in the approved care centres should be considered and funding maintained for long term sustatinability.

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Chapter 13
Preparing Early Years Practitioners in Mauritius

Ravhee Bholah, Rajeev Nenduradu, and Jyotsanah Thaunoo

Abstract The Republic of Mauritius is a small island state in Africa located on the southeast coast of the Indian Ocean. Its education system is largely based on the British system where early childhood development and education are organised in two separate systems; children under 3-years old are in the childcare system under the Ministry of Gender Equality and Family Welfare, while the 3–5-years old children are in the pre-primary school system under the Ministry of Education, Tertiary Education, Science and Technology. Early Childhood Education has evolved with the changing educational context over the years, shaped by both national and international educational policies including the United Nations Sustainable Development Goal 4. In 2010, the National Curriculum Framework Pre-Primary (for children 3–5 years of age) was developed with six areas of learning including Body and Environmental Awareness, and Mathematical and Logical thinking. This policy document has influenced teacher education, curriculum development and the practice of STEM. This chapter thus highlights the role of relevant educational institutions, particularly the Mauritius Institute of Education, in preparing early years practitioners. Mainstreaming STEM in the teacher education programmes, the development and provision of learning resources, use of ICT and other pedagogical supports will be explored.

Keywords Mauritius · Early Childhood Education · STEM · Policy · Practice

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13.1 Introduction

The Republic of Mauritius consists of the main island (Mauritius) and a group of small islands in the Indian Ocean, namely Rodrigues, St. Brandon, Agalega, Tromelin and the Chagos Archipelago. The island of Mauritius is situated 2000 km off the Southeast coast of the African continent. The government of Mauritius provides free education to its citizens, from the pre-primary level to the tertiary level.

The education system in the Republic of Mauritius is largely based on the British system. It consists of a system of formal education and is categorised into four main sectors: Pre-Primary or the Early Years (2 years), Primary (6 years), Secondary (5 years Secondary and 2 years Higher Secondary) and Tertiary or Higher Education (after completing Higher Secondary education) until the implementation of the Nine Year Continuous Basic Education (NYCBE) (Ministry of Education and Human Resources, Tertiary Education and Scientific Research, MOEHRTESR, 2015a). The education in Mauritius is compulsory for all children till the age of 16 (from pre-primary till the first five years at secondary level). The above-mentioned sectors are managed by the Ministry of Education, Tertiary Education, Science and Technology (MOETEST). The Ministry monitors the development and administration of state-owned pre-primary, primary and secondary schools funded by the government; but also has an advisory and supervisory role in respect of private schools. The Ministry is also responsible for Special Education Needs (SEN), and Technical and Vocational Education and Training (TVET) and has the responsibility for policy formulation and planning of education, in collaboration with other ministries, the private sector, civil society and international agencies.

The National Curriculum Framework for NYCBE documents government policy for the provision and implementation of nine years of continuous basic education. Government policy centers on the education of the child from birth, with early care followed by pre-primary education, the NYBCE concerns the nine-year cycle, that is, from age 5 to 14 (MOEHRTESR, 2015a, 2015b). The first two-years of schooling constitute pre-primary education. This is followed by six years of compulsory primary schooling, from Grade 1 to Grade 6, leading to the Primary School Achievement Certificate (PSAC) examination. Afterwards, there are three/four years of compulsory secondary education, from Grade 7 to Grade 9, leading to National Certificate Education (NCE). From this stage, students will have access to academies, and they will undergo another two years of secondary education ending with the International UK Cambridge School Certificate (SC) examination. This is then followed by another two years leading to the International UK Cambridge Higher School Certificate (HSC) examination. There is a pathway for technical education for those who do not suit an academic path (MOEHRTESR, 2015a, 2017).

13.2 Early Childhood Development and Education

In the Republic of Mauritius, the early childhood development and education is organised in two distinct systems: (i) the infant/toddler period (0–3) known as the Early Childhood Development and placed under the responsibility of the Ministry of Gender Equality and Family Welfare and (ii) Pre-Primary schooling, the 3–5-years old attending pre-schools which operate within the ambit of the MOETEST.

13.2.1 The Birth to 3-Years Old Child

The provision for the birth to three years old children operate either in the formal or informal form. The formal form comprises day-care centres which are registered with the Ministry of Gender Equality and Family Welfare. The informal form comprises home care. In 2019 there were 5000 children attending registered daycare centres according to the Ministry of Equality and Family Welfare for yearly birth of 12,913 children.

The remaining children are either looked after at home by mothers, grandparents, other members of the family or a hired caregiver. The 'Atelier Partage Parents' offers adequate and appropriate information regarding child development in general, and prevention from all forms of child violence. Parents are apprised of the support services available to respond to the various needs of parents during their different periods of parenting, ranging from pre-birthing to late adolescence through early childhood ("Ministry of Gender Equality and Family Welfare," n.d.)

13.2.2 3–5-Years Old Child

Pre-Primary schooling from the age of 3–5 is compulsory in the Republic of Mauritius. The Pre-Primary schools are run either privately or by the state. Pre-Primary education is managed by the Early Childhood Care and Education Authority (ECCEA), a parastatal body operating under the aegis of the MOETEST.

The mission of ECCEA is to provide equal access for all children to quality pre-schooling, including those at risk of delayed development and disabilities, through a child-centred and play-based approach, with the involvement of the parents. The ECCEA, formerly known as Pre School Trust Fund (set up in 1984), came into operation in June 2008. The Early Childhood Care and Education Authority Act 2007 was proclaimed on 16 June 2008.

13.3 National Curriculum Framework for Pre-primary Education

Improving quality of education has been a major preoccupation of the Ministry of Education, Tertiary Education, Science and Technology, and particularly the recognition given to pre-primary education as a pre-condition for success for each child. In response to this challenge the Mauritius Institute of Education (MIE), in collaboration with different stakeholders, developed the National Curriculum Framework Pre-Primary (NCF-PP) (3–5 years) in 2010 (MIE-ECCEA, 2010) in line with the Strategic Plan 2008–2020 of the MOETEST. It aims at providing clear guidelines to all pre-primary educators/practitioners on the provision of high-quality learning experiences for young children as from age 3.

In Mauritius, for the 3–5-years old, at Pre-Primary level the developmental objectives are attained through the six learning areas of the NCF of Pre-Primary (3–5 years) level (2010), which are also in line with international trends in Early Childhood Care and Education (Fig. 13.1). These learning areas are: Mathematical and Logical Thinking (MLT); Body and Environmental Awareness (BEA); Communication, Language and Literacy (CLL); Expressive, Creative and Aesthetic Development (ECAD); Health and Physical Development (HPD); and Personal, Social and Emotional Development (PSED) (Ministry of Education, Culture and Human Resources, MOECHR, 2010).

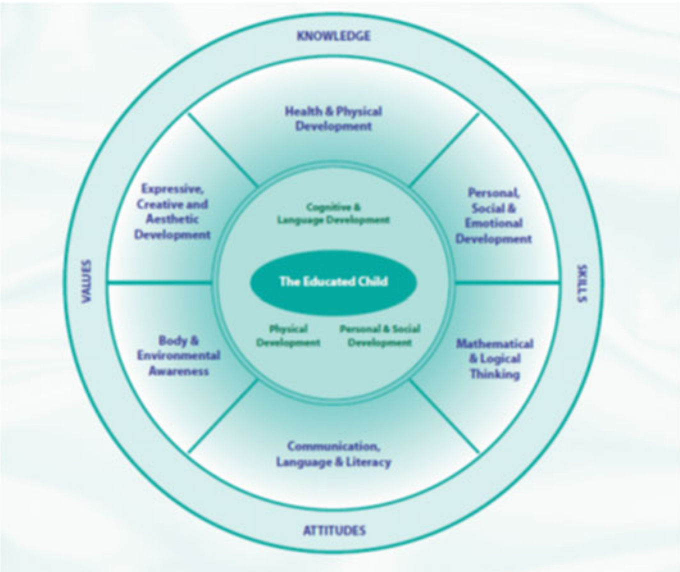

Fig. 13.1 Six Learning areas of NCF pre-primary (*Source* Ministry of Education, Culture and Human Resources [2010]. National Curriculum Framework Pre-Primary [NCF-PP] [3–5 years])

This integrated curriculum model involving all the areas of learning caters for the holistic development of the child. The activities carried out are thus organised around themes, topics, projects, and story books which are of interests to children to make learning meaningful and allow for in-depth high quality learning experiences. To assist and guide educators in planning, implementing and assessing activities using the integrated approach, a manual of activities has been designed for educators. Themes such as '**All about me**' *(my body parts/my senses, my hobby, my family/home, my pet, my school environment, my friends)*, '**My society**' *(celebrations: celebrating our independence day, water day, music day, religious festivals, traditions, child's rights & values, my neighbourhood, occupations)*, **'Natural environment'** *(my garden, world of animals, world of plants, water/lakes/rivers/sea, climate/weather, mountains and forests, natural calamities)*, '**Healthy lifestyle**' *(my health, hygiene, nutrition, safety at home, school & outdoor, sexual awareness, leisure & relaxation*), '**Creative world**' *(traditional games, drama & puppetry, painting, music & dance, crafts)*, '**Technological world**' (*means of transport: land, sea & air, types of games: electronic games; world of machines: home appliances, industrial machines, agricultural machines & electronic devices, ICT & digital world*) have been proposed in the manual (Mauritius Institute of Education, MIE, 2013). Exemplars of how to implement some themes have been given to support novice teachers' practices.

13.4 Science, Technology, Engineering and Mathematics (STEM) and Pre-primary Education

Science, Technology, Engineering and Mathematics (STEM) has been one of the driving forces for many countries towards their development, which is primarily determined by the quality of the human resources, which is dependent on the level of knowledge, skills and attitudes. It is believed that a high quality of science and technology education provides the foundation for understanding the world through specific disciplines such as Biology, Chemistry, Physics Mathematics and Earth Science/Geography. The curriculum policies worldwide thus advocate the teaching and learning of STEM in all educational contexts. The Trends Report (Forbes, 2019) emphasised that STEM is engineering the future workforce. Mauritius has not remained insensitive to the recent trends in promoting STEM education. The initiatives of the Ministry of Education to promote quality education at different levels are aligned with international norms and trends, particularly with the fourth Sustainable Development Goal (SDG 4) of UNESCO. The Strategic Plan 2008–2020 of the MOETEST policy document has thus influenced curriculum development, research, practice of STEM and teacher education in Mauritius (MOEHR, 2008).

The present NCF-PP addresses STEM including basic concepts of Science under 'Body and Environmental Awareness (BEA)' such as body parts, five senses, scientific skills, environment components and care and technological world and multimedia; and Mathematics concepts under Mathematical and Logical Thinking (MLT) such colours, shapes and sizes, measures, space orientation, numbers, volume and time. The BEA is to enable preschool learners to develop an awareness of and to promote an understanding about themselves and their surroundings while the MLT is to help learners to acquire basic mathematical skills, knowledge and attitude to make sense of the world around them (MOECHR, 2010). It should be noted that Science and Mathematics per se are not taught at the pre-primary schools in Mauritius rather STEM concepts are taught through integrated and thematic approach. For instance, while teaching the theme 'Body parts', educators have to teach **numbers** (How many eyes do you have?), **shapes** (How does your face look like? **measure** (Is your hand big or small? These mathematical concepts embedded in MLT are also linked to CLL (e.g., reading and writing the words big/small), BEA (where different parts of the body and senses are addressed), ECAD (e.g., drawing pictures of the hands, eyes and nose) and the other two learning areas (HPD and PSED) through play and hands-on activities among others.

There is also a growing importance of early STEM learning and the need for preparation for early years practitioners with appropriate pedagogy in Mauritius, that can facilitate children's emerging understanding of STEM concepts, practices, and habits of mind, while harnessing their natural curiosity and fostering developmentally appropriate STEM-infused play. Play has thus become an increasingly important area of research and recognition. In STEM, experience using cognitive and kinesthetic skills is essential in learning and understanding science in the observable everyday context (Tunnicliffe & Gkouskou, 2020).

13.5 Preparing Early Years Practitioners (Training)

Professional development is increasingly being addressed as a potential way of improving the teaching quality of early childhood education and thereby improving children's learning (Schachter, 2015). As in many countries of the world, the least qualified and untrained personnel who have received on the job training worked with the 0–5 years. However there has been a gradual evolution in terms of the profile of the staff and the training programmes provided over the years in Mauritius. Pre-primary education has been traditionally offered by private providers for over 3 decades, whereby a strong public–private partnership in the provision of pre-school education has been developed. Training for the day caregivers was provided by non-governmental organisation's (NGO) post-independence. The practices in the day care are guided by the Early Childhood Development programme guidelines handbook (0–3 years). This was developed with the collaboration of the Government of Mauritius and UNICEF to reinforce the training capacity of those who worked in the early childhood development field. This guideline emanates from the National Early Childhood Development Policy (0–3 years) which advocates the preparation of a curriculum framework (Ministry of Women's Rights, Child Development and Family Welfare, 2003) (Fig. 13.1).

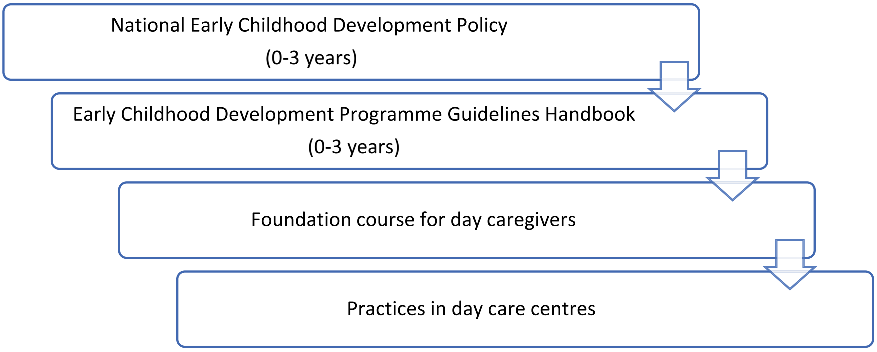

Fig. 13.2 National early childhood development policy driving practices in day-care centres

This framework is a guide to all stakeholders who care for the 0–3 aged children, particularly the carers in the day care centres as well as parents. However, most parents are not aware about this document. A pool of trainers followed a training programme and had the responsibility to train the personnel working in day-care centres. This training programme was focused on the holistic development of the child and early stimulation through play activities. This project lasted only for some years. However, training of carers is being continued by some NGO's till date. In 2009, it was found that the personnel did not have any qualification and could not be registered as a care provider. The Mauritius Institute of Education in collaboration with the Ministry of Gender designed a foundation course which gave the care givers basic knowledge and skills to care for the infant and toddlers in day care centres (Fig. 13.2).

It is noteworthy that the Mauritius Institute of Education (MIE) is a degree-awarding institution of higher learning with the mandate for Teacher Education, Curriculum Development and Educational Research, operating under the aegis of the Ministry of Education responsible for pre-primary, primary and secondary education in the Republic of Mauritius. The MIE provides both pre-service and in-service teacher education and offers a range of undergraduate and postgraduate programmes to professionalise all the education personnel, including educators, managerial cadres and those in supervisory roles. It also provides educators with opportunities for continuous professional development. It thus also provides training to carers who work in day care centres, pre-primary teachers and managers as well as supervisors of pre-primary schools.

The provision of training leading to an award certificate for the pre-primary teachers by the MIE started in 1994 leading to a **Teacher's Certificate Pre-Primar**y (Fig. 13.3). However only 325 trainees benefitted from this programme as they had the basic secondary school qualification. The remaining personnel did not have the entry requirement and a proficiency certificate had to be introduced to bridge the gap in training and give opportunities to all practising personnel to accede to the Certificate programme. The **Certificate of Proficiency in Early Childhood Education**

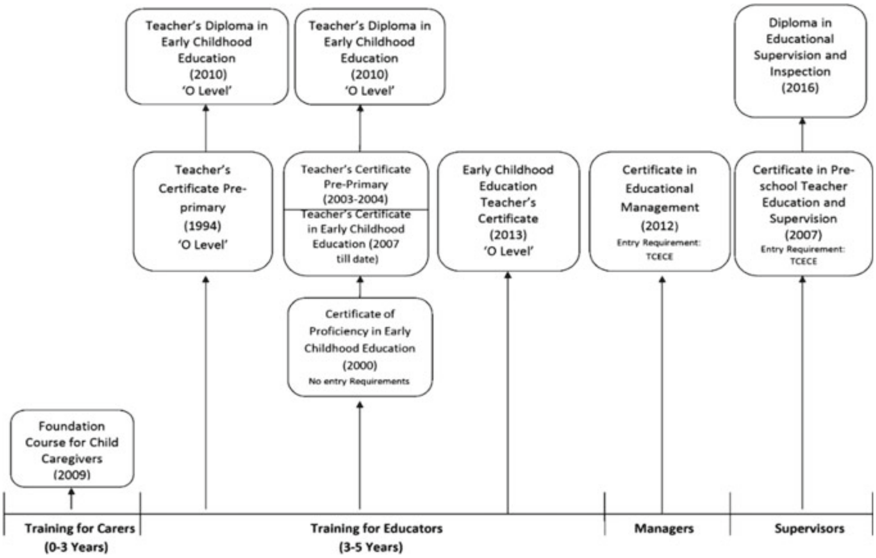

Fig. 13.3 Training programmes for early years practitioners

(CPECE) (2000) was also introduced to harmonize training which was provided by several NGOs and to cater for the needs of the sector which had personnel without basic academic qualifications. The CPECE subsequently allowed entry to a Certificate in Pre-Primary Education now called the **Teacher's Certificate in Early Childhood Education (TCECE)**. In 2010, a Diploma Programme **(TDECE)** was introduced to those who completed the Certificate programme (MIE, 2012). However, an entry requirement of 'O' level was required to be at the same level of other Diploma programme offered.

As mentioned, MIE is the main provider of ECE training programmes in Mauritius offering courses mainly up to Certificate and Diploma levels. There are two Universities- providing degree programmes and some private training institutions providing Certificate programmes awarded by the Mauritius Institute of Training and Development. This chapter thus focuses on the main ECE MIE programmes while highlighting the degree courses from other Tertiary institutions.

13.6 Early Childhood Education Programmes

13.6.1 Foundation Course—Practitioners/Care Givers Working with Children 0–3 Years

The 0–3 years guidelines focus on the holistic development of the child, the physical, cognitive, emotional, social and language development and highlights the role of parents as the first and best carers/educators of the child. The milestones for the different aspects of development help carers to identify the development of the child in each aspect and to decide what to do to help the child to grow and develop by providing developmentally appropriate experiences. The foundation course was thus focused on the development and learning of the infants and toddlers (MIE, 2015). It is organised into eight foundation areas of learning namely the self-concept, health and physical development, social development, communication, creativity, critical thinking, environmental understanding, and cultural awareness**.** For each foundation area of learning, the knowledge, skills, and attitudes that infants and toddlers need to develop are identified, the role of the educators and best practices for each area are explained. All the eight areas of learning form the basis for an integrated and child-centred approach to learning and development for young children (Ministry of Women's Rights, Child Development & Family Welfare, 2003a, 2003b).

Early years practitioners or educators are taught that Early Childhood Education with respect to STEM already starts in the womb, when the not-yet-born baby accustoms to the material world surrounding it (Irwin et al., 2007; Smith & Gasser, 2005). The training for early years practitioners is carried out in line with the programme guidelines to enable them to implement appropriate activities for all the areas of learning. Their main role is to provide a physically and emotionally safe and stimulating environment to enable children to engage actively in all activities including STEM. Though they learn how the foundation areas of learning are interrelated, this chapter focuses on the foundation areas of learning related to STEM. Critical thinking is a high order thinking that children develop when they explore the world as they can make claims on their observations and are able to justify these claims.

The early years practitioners also learn that the knowledge, skills and attitudes that children need to develop in this foundation area of learning are problem solving, decision making, observation skills and the ability to compare among others. These skills are developed when children are given opportunities to explore and experiment with different materials/resources in their surroundings. The practitioners also learn that children explore the world around them using their senses (McClure et al., 2017). They are empowered to provide children with opportunities to observe, investigate and explore their immediate environment (natural and built) as well as develop a sense of responsibility for their environment.

The practitioners are also provided with a First Aid course and workshops where they are engaged in practical activities related to childcare. The module entitled 'Child Growth, Development and Care' enables day caregivers to develop understanding of the different aspects of development and plan activities for their holistic development.

There is a spurt in growth and development during the first three years of life. Babies from birth to two years are in the sensori-motor stage of development (Berk, 2013). They start perceiving the world through their senses. The routine proposed in the guidelines for the 3–7 months, 8–12 months and 1–3 years helps carers to plan their activities. The different types of play thus form the basis of activity planning during the routine proposed in the guidelines for carers. Thus, the practitioners learn about the importance of free, mediated and guided plays during the training. Thus, the practitioners are encouraged to create a play learning environment with different play learning areas such as blocks, construction toys, water play and others. These areas help carers to provide opportunities for children to engage in free choice activities as well as mediating and guiding children's play activities. It was noted from caregivers working at day care centres that babies develop observation or gross motor skills through various free, guided and mediated play-based activities such as playing with rattles, identifying parts of the body of dolls and throwing and catching a ball. The babies are also involved in water play, sand play and blocks play. They are often given the opportunity to engage in activities such as 'walk on numbers painted with different colours on the floor' and 'listen to outdoor sounds'.

13.6.2 ECE Courses: Practitioners Working with Children 3–5 Years

As mentioned above, the MIE offers Certificate and Diploma courses for practitioners working with children 3–5 years as evidenced in the MIE programme handbooks for ECE (MIE, 2018, 2019, 2020, 2021). The courses include several modules that provide both content and pedagogical knowledge on ECE that prepares and empowers the early years practitioners to teach the six areas of learning holistically and confidently to their learners in various learning contexts. However, STEM has been prioritized in both programmes through the modules, Mathematical Thinking and Learning, Science for the Early Years (or Early Childhood) and ICT in the early years. Tables 13.1 and 13.2 show the various Science and Mathematics concepts covered at Certificate or Diploma levels. Most of these concepts are relevant to the child's everyday life as they are part of the child's immediate environment with which he/she interacts in his/her everyday life. Analysis of the ECE training programmes also reveal that, the module *entitled 'Basic skills in Information and Communication Technology'* in Certificate Teacher Education Programme covers basic component of a computer system, potential benefits of ICT, and use of ICT tools such as Graphic software, word processing, presentation software and internet.

At Diploma level, two modules are covered 'Bringing Technological Innovation into the Classroom' and 'Using ICT in teaching'. The first module covers computer literacy, information technology skills: basic skills in Paint Software, Word Processing software, spreadsheet package, presentation/multimedia package, use of internet and computer-mediated communication); while the second module 'Using

Table 13.1 Mathematics concepts covered at certificate and diploma levels

Mathematics concepts	Certificate level			Diploma level					
	Mathematical and logical thinking			Mathematical and logical Thinking I			Mathematical and logical Thinking II		
	Lessons/subconcepts	Types of activities	Types of Play	Lessons/subconcepts	Types of activities	Types of play	Lessons/subconcepts	Types of activities	Types of play
Shapes	Shapes and colours (development of spatial sense through activity-based learning)	Identification of shapes and colours in the child's environment	Guided	Work with 2D and 3D shapes	Identification of circles, triangles, squares, rectangles, cubes, cuboids, spheres in the classroom, at home and the child's surrounding Matching 2D/3D shapes with corresponding objects (both concrete and pictorial)	Mediated	Pattern recognition and continuation	Use of manipulatives in the form of circles, squares, triangles and rectangles with different colours and sizes to form patterns Construction of animals' puzzles	Mediated Guided

(continued)

Table 13.1 (continued)

Mathematics concepts	Certificate level			Diploma level					
	Mathematical and logical thinking			Mathematical and logical Thinking I			Mathematical and logical Thinking II		
	Lessons/subconcepts	Types of activities	Types of Play	Lessons/subconcepts	Types of activities	Types of play	Lessons/subconcepts	Types of activities	Types of play
Numbers	Counting-principles, stages and strategies	LEGO® and other objects • Counting all • Counting on Make an easier problem	Free Mediated Guided	Early number concepts and number sense	Use of sand tray to represent numbers followed by reproducing and writing the numerals Ordering and comparing numbers	Mediated Guided	Four fundamental arithmetic operations Solve simple problems involving arithmetic operations	Real life problems involving the four basic operations Use items/objects/people to illustrate the concept of addition, subtraction, multiplication and division	Mediated/Guided
Measurements	Size (development of spatial sense through activity-based learning)	Identification of long/short; heavy/light; big/small items	Mediated				Length Capacity Time Mass Money	Activities such as shopping corner, kitchen corner, Fruits and vegetables corner,	Mediated/Guided
Statistics							Collect, present and interpret data from the environment	Activities such as name of fruits and the number of fruits eaten per day/week are illustrated by pupils using stickers/plastic fruits Favourite colours of each pupil Birthdays of each pupil: Different months displayed on the board	Mediated

ICT in teaching' addresses integration of ICT in the teaching and learning process; use of word processor as a pedagogical tool to design activity sheets and work plans and produce teaching aids and handouts; use of spreadsheet for data handling and performance analysis, use of presentation software as a learning tool, use of graphics software to produce teaching aids and use of the internet as a learning support.

It should also be noted that there are different Art modules such as 'Expressive, creative and aesthetic development I & II' at Diploma level that help to bring the elements of values and creativity which are essential in learning both Science and Mathematics concepts. Thus, another dimension namely 'A' which is missing in STEM has also been taken into considering while preparing our educators to teach at the pre-primary level. The emphasis on STEAM is gaining a lot of importance at the international front as creativity and arts form the basis of logical, reasoning, problem solving skills as well as inquiry-based learning (Braund & Reiss, 2019). To achieve these skills and competencies, educators engage young children in mathematical thinking and learning through activities and play. Drawing from Vygotsky's theory, Hughes (2009) argued that "Children are active learners and learn best through play" (p. 13). The importance of play in a child's cognitive development and learning is undisputable (Broadhead et al., 2010). Subsequently, play in Science and Mathematics learning has also been given a lot of importance in the preparation of the educators in our teacher training programmes. Tables 13.1 and 13.2 illustrate some examples of how various types of play are commonly incorporated in the teaching and learning of Science and Mathematics.

Focus group discussions with MIE Academics and early years practitioners also revealed that besides content knowledge, the latter were also taught how STEM concepts could be addressed to pre-school learners through simple activities (including play-based) using a variety of teaching as well as learning resources and different teaching and learning strategies such as discovery method, group work, role play and game. For instance, the early years practitioners have learnt the following activities for the theme **"All About me" for *BEA***: Sequencing personal clothing by size and for ***MLT***: Sorting and matching of body parts and making puzzle. Similarly, it was noted that they also learnt BEA (Science) and MLT (Mathematics) activities for the following themes (MIE & ECCEA, 2013):

- ***My family—BEA**: Family tree games using computer; Representing different types of family using pictures from magazines and family photos; **MLT**: group three familiar items for father and mother; classifying clothes for mother and father;*
- ***Celebrating Our Independence Day—BEA:** visit to Trou aux Cerfs; 'Our island' **MLT**: Guessing—Kim's game; comparing big and small dodo;*
- ***My health—BEA**: Observation of different plants; tidying up the classroom; **MLT**: Classification game; matching of "pairs;"*
- ***My Garden—BEA**: 'Recognition of vegetables; sowing of seeds -lentils, mustard, coriander, MLT: counting of seeds, comparing height of plants;*
- ***Water—BEA**: watering of plants; experimenting with soluble and insoluble materials; **MLT**: Measuring; filling and emptying cups;*

- ***World of animals—BEA:*** *observation of a snail; collecting pictures of animal products, MLT: counting of toys "animals' figurines"; Matching of pictures to numerals;*
- ***Means of Transport (to enable child to develop an awareness of the technological world)—BEA****: different means of transport; description of pictures, MLT—sequencing according to size; matching toys to numeral cards; and*
- ***Opinions may differ!—BEA:*** *colin Maillard; Telephone "Arabe"/jeu de telephone; MLT: playing marbles (hopscotch); creating patterns* (Pictures 13.1 and 13.2).

Besides the above activities, the early years practitioners were also exposed to the Reggio-Emillia model which enables them to implement projects at their schools (Learning Education Support, 2006). The teacher training thus enables them to facilitate the child's learning by planning activities and lessons based on the child's

Picture 13.1 Play with lego helps to develop understanding of mathematics and scientific concepts (indoor)

Picture 13.2 Water play helping children to develop understanding of scientific and mathematic concepts (outdoor)

interests, asking questions to promote understanding, and actively engaging in the activities alongside the child, instead of passively observing the child learning. In Mauritius, it was found that most schools were involved in a project in line with sustainable development entitled 'Go Green project' where all activities are organised to reuse and recycle scrap materials and protect the environment.

It was found that the MIE ECE courses empower the early year practitioner with relevant content and pedagogical content knowledge of STEM concepts to ensure that their pre-school pupils learn the basic science and mathematics concepts by inquiry learning. They assess children's learning of STEM through numerous ways including observation of children's participation, responses, and manipulation during learning activities, drawing activities and role play. The preschool learners can thus demonstrate evidence of acquisition and use of scientific skills (observe, question, investigate amongst others) and develop appropriate attitudes (e.g., care) for the environment (living things and non-living things). They can also engage in activities which promote logical and rational thinking in their mathematical development in the early years.

Thorough analysis of the existing local documents including institutional websites has shown degree programmes on ECE are being offered by a few of Universities in Mauritius. The University of Technology, Mauritius offers a BSc (Hons) in Early Childhood Care Management and Administration for childcare administrators/managers/teachers, which provide them with the theoretical and practical knowledge of supervision and management of childcare centres. The Open University of Mauritius offers a B.Ed (Hons) Early Childhood Education and Care. This programme is offered through a blended mode which allows mature trainees to engage in further professional development to improve the quality of teaching and learning. Another university namely Curtin Mauritius, offers Bachelor and Master programmes in Early Childhood Education and units studied include management and leadership, school curriculum and pedagogical approaches. These programmes include aspects of play-based pedagogies and early science and numeracy. It is expected that an educator/practitioner with higher qualifications will strengthen teacher leadership which will contribute to promote the achievement of the second target of United Nations Sustainable Development Goal 4 "***By 2030, ensure that all girls and boys have access to quality early childhood development, care and pre-primary education so that they are ready for primary education***".

13.7 Conclusion

In the Republic of Mauritius, the early childhood development and education is organised in two separate systems covering two distinct systems: (i) the infant/toddler period (0–3) known as the Early Childhood Development and (ii) Pre-primary schooling, the 3–5-years old attending pre-schools which operate within the ambit of the Ministry of Education. The provision of education for the birth to three years old children operate either in the formal or informal form. The informal form consists of home care. The remaining children are either looked after at home by mothers, grandparents, other members of the family or a hired caregiver. The formal form comprises day-care centres whereby the children are under the care of trained caregivers who have followed a foundation course at the MIE. It is thus highly recommended to develop an understanding of STEM learning through facilitating opportunities for experiences. The 3–5-year children undergo pre-primary education based on an integrated and thematic approach model of NCF-PP by professional early years practitioners. STEM in the early years is present in the everyday activities of the child through observation, exploration, investigation, experimentation and most importantly—different types of play. MIE is the state higher education institution mandated for teacher education, curriculum development, and research in the field of education in the Republic and thus, is the main provider of ECE courses for early years practitioners. The MIE ECE courses offer a range of modules that help to empower the early years practitioners to organise the learning environment which supports free play, scaffolding learning through mediated play and intentionally teaching through guided play activities. The pre-primary schools are managed by the Early Childhood Care and Education Authority and get the opportunity to participate in various projects. The parents and some NGOs often support the practitioners and the schools to enable the children participate actively in STEM projects and develop appropriate knowledge, skills and attitudes for the environment. The mature students can undergo further professional development in view of improving the quality of teaching and learning at three Universities in Mauritius.

Table 13.2 Science concepts covered at certificate and diploma levels

Science concepts	Certificate level			Diploma level					
	Science in early years			Science for Early Childhood I					
	Lessons/subconcepts	Types of activities	Types of Play	Lessons/subconcepts	Types of activities	Types of Play	Lessons/subconcepts	Types of activities	Types of play
Body parts	My body parts	My name I draw myself; my photo; Parts of my body	Free play	The Body parts	Inquiry learning in early years – The body parts	Free guided			
Senses	My senses	My eyes, my ears, my nose, my hands	Free Guided	The senses	Inquiry learning in early years – The sense	Free Guided			
Environment	Living things Non-living things	Identifying living and non-living things -	Guided Mediated	Living things: Characteristics and Classification	How animals move; what animals eat) Classifying/grouping according to colour/shape/other features (arranging in order of size) Identifying parts of body (e.g. leg, tail) Animals with hair/fur on their body, Birds -feathers on their body;Fishes, insects, Reptiles (Demonstration/Experiment)	Guided Animated	Animals, plants and the places where they live	Pet animals The aquarium Domestic and wild animals Where animals live	Free Guided
Water	Floating and sinking Evaporation Boiling Water cycle	Demonstration Experiment	Free Guided mediated	Properties of water Uses of water Importance of water	Demonstration Experiment visit	Free Guided			
Air				Composition of Air Properties of air Importance of air	Demonstration Experiment	Free Guided			

(continued)

Table 13.2 (continued)

Science concepts	Certificate level			Diploma level					
	Science in early years			Science for Early Childhood I					
	Lessons/subconcepts	Types of activities	Types of Play	Lessons/subconcepts	Types of activities	Types of Play	Lessons/subconcepts	Types of activities	Types of play
Weather	Sunny, rainy Cloudy,windy; the weather chart	Open discussion	Weather	Weather effects on body, e.g. wind, heat Clothes for weather The weather bulletin	Demonstration Experiment	Free Guided			
Energy	Energy Energy conversions Electric circuit	No energy, no movement (The toy car and the cell,hand driven generator) Food for energy making bottle cap to move using body heat energy (Experiment/demonstration)	Free Guided Mediated	Forms of Energy Sources of Energy Energy conversions Safe use of electricity	Experiment	Guided Mediated			
Personal Hygiene				I take regular baths I brush my teeth I wear clean clothes I sleep well	Open discussion Storytelling - toothache	Free Guided			
Earth and the solar system							Earth and the solar system	The sun during the day Light and shades, shadows The moon at night – Shapes of the moon	Guided Mediated (role play)

(continued)

Table 13.2 (continued)

Science concepts	Certificate level			Diploma level					
	Science in early years			Science for Early Childhood I					
	Lessons/subconcepts	Types of activities	Types of Play	Lessons/subconcepts	Types of activities	Types of Play	Lessons/subconcepts	Types of activities	Types of play
Matter States of matter Properties of matter							Matter States of matter Properties of matter	Demonstration Experiment	Guided Mediated
Preparing and using resources and teaching aids for science in early childhood				Preparing and using resources and teaching aids for science in early childhood	Designing/teaching of teaching aids	Free Guided Mediated			
Importance of Science and Technology in everyday life				Importance of Science and Technology in everyday life	Demonstration Open discussion	Guided Mediated			

Early childhood education has evolved with the changing educational reform over the years in the country. MIE, working under the aegis of the Ministry of Education, has been playing a pivotal role in the educational landscape of the Republic Mauritius. It thus recognises (i) the importance of relevant and quality pre-primary education to all children aged 3–5 years with the opportunity to develop their cognitive, socio-emotional and psycho-motor skills to enable them to be confident in their learning; it helps the government in providing a strong foundation in pre-primary education for later primary, secondary, post-secondary or tertiary education and (ii) the need to further promote STEM as it is an important driver for economic growth and development of any country. The Government should therefore continue working with relevant stakeholders including private sectors and professional NGOs to develop more-evidence-based policies to support ECE initiatives such as capacity building/professional development of academia/teachers, curriculum development and research related to STEM. For instance, the MIE is presently developing the new NCF-PP and it is highly recommended that this policy document provides further opportunities for learners to learn STEM activities and educators to use new innovative pedagogies and facilities more adapted to the new generation, or digital citizens. It is also important that the ECE training programmes empower teachers effectively so that STEM taught in early years becomes the foundation to develop 21st-century skills among learners. It has been noted that the current training programmes cater for play-based learning activities and the early practitioners also apply free play, mediated and/or guided play in various activities; however, there are no specific studies focusing on the use of different plays and their impact on Mauritian students. Research must be carried out to study the extent of the use of different types of plays and their impact on children, and to evaluate whether the present pre-primary education helps to achieve the goals of the government. Finally, it is also highly recommended that the toddlers prior to the 3 years be provided with a conducive environment with quality childcare and services for early childhood development and education. This will enable the practitioners to be facilitators and work with the children, to eventually help them to develop observation, problem-solving and questioning skills among others.

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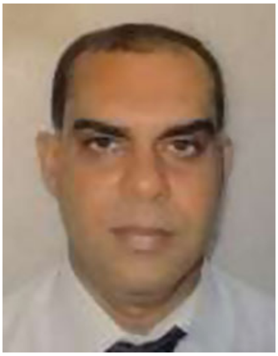

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Chapter 14
Addressing Variability in Learning in the Early Years Through STEM and Executive Function

Jacqueline Vanhear, Alexis A. Reid, Isabel Zerafa, and Melanie Casha Sammut

Abstract Early Childhood Education and Care (ECEC) policy and practice develops in the early years of life. This understanding will facilitate the implementation of inclusive and equitable quality educational programmes in ECEC. Educators play a primary role and require support and training to proactively plan and address variability in learning across learning environments. Universal Design for Learning (UDL) is a framework guided by the neuroscience and psychology of how learning occurs and guides educators to best support all learners. UDL establishes flexible learning environments that provide accessibility from the outset. By providing multiple means of engagement, recognition, action and expression, educators can promote expert learning to help each learner actualize their potential and understand what serves them best across contexts. When learning environments are established through intentional design predicated on how children learn, educators can better equip young learners with a robust platform for successful future learning impinging on their learning engagement and motivation. This chapter describes efforts in Malta that focus on national decision-making policies and strategies with a clear vision that early childhood years' experiences impact society, the environment, and the economy. With a focus on UDL and highlighting how executive function can be explicitly scaffolded during STEM learning experiences, this chapter offers examples of initiatives being implemented in Malta.

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14.1 Introduction

There is a general consensus that high-quality learning programmes in Early Childhood Education and Care (ECEC) are pivotal for future education and work as well as for social and relational competences (Johannson & Einarsdottir, 2018; Ringsmose & Kragh-Müller, 2017). Increasingly, it is becoming accepted that early years' provision is the foundation of learning throughout life and "early childhood settings around the world serve as societal platforms" (Johannson & Einarsdottir, 2018, p. 4). Research shows that children who experience meaningful high-quality childcare and early education learning programmes, perform better in their later years at school, develop better social skills and display fewer behavioural problems (Melhuish et al., 2015, OECD 2015, 2017a, 2017b, 2018, Miller et al., 2018). Furthermore, inclusive and equitable quality educational programmes in ECEC nurture a meaningful personal journey of holistic development and promote lifelong learning opportunities for all.

One example of this work in process is in Malta where there has been a shift in focus to the early years targeting national decision-making policies and strategies. This work has a clear vision that highlights how early childhood experiences have a significant impact on society, the environment and the economy as outlined in Sustainable Development Goal 4 (United Nations, 2015). The following shows measures taken by Malta to enhance actions in addressing ECEC and translate a vision into national policy and strategies which will permeate in provisions related to learners in the early years.

Enhancing the quality of education within ECEC is pivotal to respond adequately to the *Framework for the Education Strategy for Malta* 2014–2024 (MEDE, 2014b) and to keep up with Malta's commitment of reducing Early School Leavers (MEDE, 2014a). Consequently, in 2014, the Free Childcare Scheme was launched to increase female participation in the labour market, and this led to a significant increase in participation of children from three months up to three years of age in childcare centres. This impacted a steady increase in the proportion of children below three years in formal childcare and it has contributed to Malta reaching the Barcelona target of 33% of children under 3 years old attending formal childcare and which at the date of publication is above the EU average (see Fig. 14.1). The rate of children aged less than 3 years in formal childcare increased from 18.2% in 2014 to 38.3% in 2019 (European Commission, 2020).

The steady increase in the number of children under 3 years old attending Childcare Centres required attention to monitor and safeguard quality. Quality within ECEC is a complex phenomenon and following the EU Council Recommendation, adopted by EU Member States in May 2019, five (5) key areas were identified within a Quality Framework for ECEC (European Commission, 2014) (see Fig. 14.2).

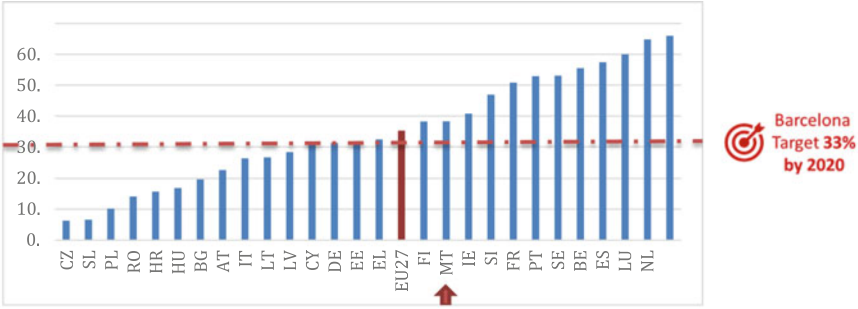

Fig. 14.1 Percentage of children (under 3 years old) cared for by formal arrangements other than by the family. This indicator shows the percentage of children (under 3 years old) cared for by formal arrangements other than by the family. The indicator is based on the EU-SILC (statistics on income, social inclusion and living conditions) (*Source* Eurostat, 2021b EU-SILC)

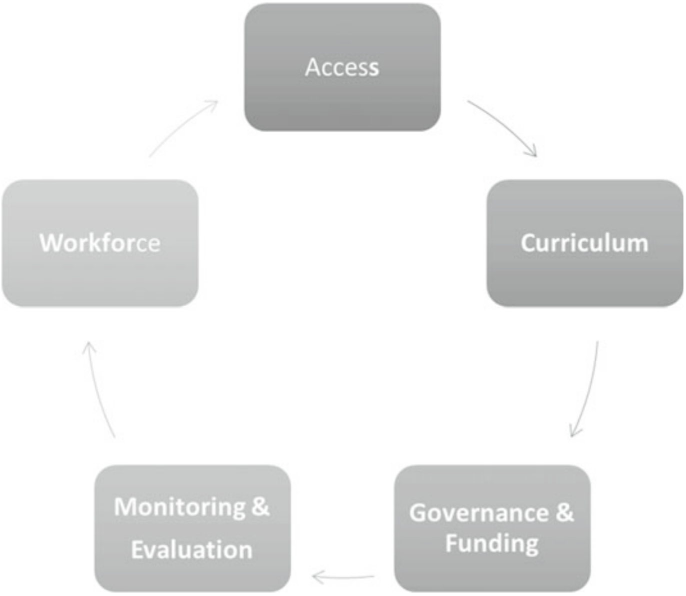

Fig. 14.2 The EU quality framework for early childhood education and care (Council Recommendation, 2019). Council Recommendation on High-Quality Early Childhood Education and Care Systems. Available online: https://ec.europa.eu/education/education-in-the-eu/council-recommendation-on-high-quality-early-childhood-education-and-care-systems_en

This ECEC Quality Framework as proposed by the EU Commission (2014) served as a basis for Malta to update the *National Standards for Early Childhood Education and Care Services* (0–3 years) (MFED, 2021a) and which target process and structure quality that together contribute to quality of outcomes (Taguma et al., 2013) in Childcare Centres. These updated standards are reinforced by a *National Policy*

Framework for Early Childhood Education and Care in Malta (0–7 years) (MFED, 2021b) and which mirrors the five areas as outlined in Fig. 14.2. Both documents were launched for a wide public consultation in 2021 to increase transparency and ownership to establish a shared vision for ECEC. The principles in these documents also aim to nourish a seamless integrated model for early childhood experiences.

Additionally, to reinforce the vision of lifelong learning, from the cradle to the grave, in 2016, the responsibility of Childcare Centres (0–3 years) shifted from the Department of Social Welfare Standards (DSWS) in the Ministry for Family and Social Solidarity (MFSS) to the Directorate for Quality and Standards in Education (DQSE) in the Ministry for Education (MFED). This has formally established an integrated model approach towards ECEC including acknowledging the educational attainment of all learners through a learning outcomes framework complemented with an authentic assessment approach revolving around a learner-centred environment.

The participation in ECEC for children between the age of four and the starting age of compulsory primary education, which in Malta is five years of age, is also above the EU average (see Fig. 14.3).

The developments previously discussed demonstrate that Malta is on track in its efforts to effectively put an edge on ECEC as a preventive measure. At the heart of these improvements one finds an early childhood experience that revolves around the notion that the child is competent and born with unlimited potential (MFED, 2021b). This chapter provides a rationale for how policy and practice can come together through a greater understanding of learning and neural development in the early years of life. An understanding of how children learn may shed more light on the concept of a learner-centred environment which takes into account that it is more than just providing information or teaching skills but rather an approach of

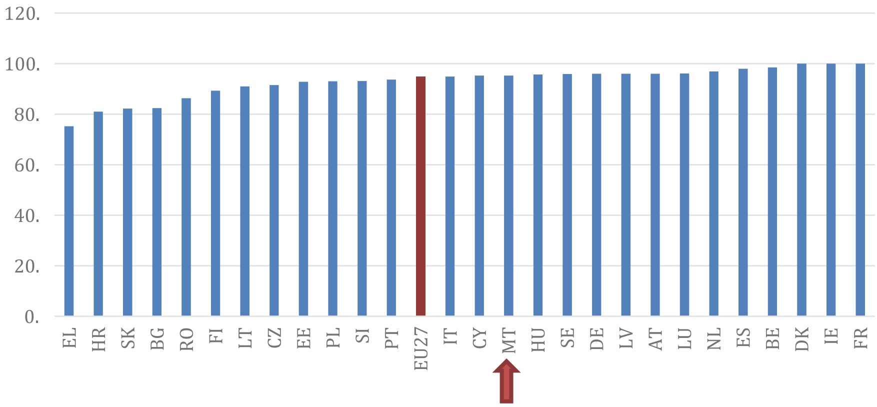

Fig. 14.3 Children between the age of four and the starting age of compulsory primary education who participated in early childhood education (*Source* Eurostat, 2021a UOE [UNESCO, OECD & Eurostat])

developing empowered and autonomous learners through a flexible learning environment and positive learner/teacher relationships (McCombs & Miller, 2007). It is important to support and nurture the role of the educator to enhance the opportunities for learning and establish supportive learning environments. Both learners and teachers are equally important, and they should be seen as partners in achieving the desired learning outcome. There is a need to complement a learner-centred approach with meaningful teacher/learner interaction through intentional design based on an understanding of how children learn. This is exemplified through STEM initiatives in Malta.

14.2 STEM in Malta

Skills and competences in science, technology, engineering and mathematics (STEM) are considered pivotal in basic scientific literacy in today's world (Kurup et al., 2019; Ministry of Education, Employment and the Family, 2011). There is both a national and international demand to promote careers in STEM. In this context, STEM education cannot only aim at targeting the elite future scientist but should also engage a more generic audience in developing twenty-first century skills and competences in scientific literacy (European Schoolnet, 2017).

The Science Centre, Pembroke (Malta) within the Directorate for Learning and Assessment Programmes is a leader in STEM Education in Malta. It is committed to provide quality STEM Education for all and to raise the general profile of STEM education within the community, namely through:

- actively contributing towards National policy documents;
- designing and supporting the implementation of curriculum programmes;
- providing professional development opportunities for educators; and
- developing innovative STEM initiatives on a national, college and school level.

Amongst challenges that the Science Centre is committed to address, is that of nurturing positive attitudes towards mathematics and science in the early years. Children are by nature curious, interested in learning new things, and ask many questions. As outlined in the *Early Childhood Education and Care, National Policy Framework for Malta and Gozo*, learning opportunities that children experience throughout the first seven years of life "mould the architecture of the developing brain and the core capabilities a child needs to achieve better outcomes and to function well in society later on in life" (MFED, 2021b). This presents an opportunity for educators to nurture children's interest in mathematics and science. Learning opportunities based on children's interests that encourage observation, critical thinking and problem solving are of key importance. This scenario is aligned to the *Learning Outcomes Framework* (DQSE, 2015) and to the the *National Curriculum Framework* (MEDE, 2012). Both policy documents call for a "move away from emphasising specific subject content teaching in favour of pedagogies which enhance curricular links and thus facilitate learning processes" in the early years (ibid., p. 46).

14.2.1 Curriculum Reform at a National Level

Challenges posed by an ever-evolving and competitive global context coupled by the Ministry's commitment to provide lifelong learning opportunities for Maltese citizens to be active citizens, prompted the need for curriculum reform on a national level (Directorate-General for Communication European Commission, 2020; Ministry for Education and Employment, 2014a). The policy document 'A National Curriculum for all' sets the foundation for the new Learning Outcomes Framework on which different programmes of learning and assessment are developed (Ministry for Education and Employment, 2012).

The new learning outcomes for primary science call for a paradigm shift and direct focus on the acquisition of competences, reflected in a constructivist way of creating meaningful knowledge and a solid foundation for lifelong learning (Borg, 2013; Letschert, 2004; Ministry of Education, Employment and the Family, 2011; Säävälä, 2008). The primary science guidelines for the early years emphasise that focus in the early years should be on stimulating children's innate curiosity and providing different learning opportunities for children to engage in meaningful learning experiences. Questions children ask are often related to science concepts and can be naturally linked to their sense of wonder about the world around them. In this context, science in the early years should be based on exploration, solving problems and trying out new ideas through hands-on activities/investigations. Scientific exploration can also help children develop language, communication and problem-solving skills as well as promote independent and collaborative learning. In this context, the early years learning space should provide opportunities conducive to the child's holistic development and scientific literacy.

Similarly, the new learning outcomes for primary mathematics put the learner at the centre of the learning experience. Problem-solving is embedded throughout, and learning opportunities in mathematics provide students with varied opportunites to apply knowledge and skills in authentic situations. Learning opportunies like journaling, show and tell, maths trails and low-floor, high-ceiling tasks, which are locally gaining ground, provide valid opportunties for authentic continuous assessment and differentiation. It is common that learners in primary classrooms in Malta, including those in early years, have their own Maths Toolbox. A personal Maths Toolbox encourages learners to develop independence and facilitates differentation.

14.2.2 Learning, Teaching and Continuous Professional Development (CPD)

Emphasis in the early years is on developing knowledge, skills and competences through an inquiry-based pedagogy. Skills include asking questions; formulating a simple prediction; investigating and observing; recording, analysing and presenting results; discussing results and drawing conclusions; and linking conclusions to initial prediction and everyday life situations. CPD organised on a national level aims at offering opportunities for educators (Senior Leadership Teams, teachers and parents/guardians) to experience hands-on and engaging STEM activities, reflect on their practices and empower them to plan the way forward.

In 2018, the Science Centre organised a seminar entitled *tikka Snin Bikrin: Matematika u Xjenza* with the aim to disseminate examples of sound pedagogical practices in teaching mathematics and science during early years education. During *tikka Snin Bikrin* two-day seminar, 12 educators from early years disseminated good practices regarding mathematics and science in the early years. In addition, the Primary Mathematics and Primary Science teams organised 12 hands-on workshops for early years educators related to engaging children in inquiry and the development of hands-on, minds-on mathematics and science learning environments.

Other CPD training/support initiatives/resources targeting early years educators and also parents/guardians of children in the early years include curriculum meetings with educators and parents, ranging from hands-on workshops; parental webinars; a repository of recorded lessons; professional development including inservice training for all teachers in Year 1 (2018) and teachers in Year 2 (2017). *Breakfast STEM PD* sessions are planned to kickstart during scholastic year 2021–2022. These professional development sessions aim to bring together educators to explore themes relevant to the respective education sector and to provide a networking opportunity. The first *Breakfast STEM PD* will target educators and parents/guardians of children in the early years.

ĊEKĊIK, *Xjentifikwiżż*, *ftit KULJUM*, *WebQuests* and *Sfida*STEM initiatives provide integrated and meaningful experiences, many of which centre around an inquiry-based approach. Initiatives like Maths Trails, Science fieldworks, Digital Scavenger Hunts/Virtual Quests and Mathletics provide students an opportunity to experience STEM outside the classroom. These initiatives make learning more engaging, enjoyable and relevant (Waite & Rea, 2007). This ensures that from the early years, schooling is meaningful and an action to prevent early school leaving (MEDE, 2014b). See Fig. 14.4 for example activities highlighting STEM in Early Childhood Education and Care (ECEC).

14.2.3 STEM Outreach

STEM outreach merits an integral part of early years and primary education. Primarily to cultivate future generations that are interested and skilled in STEM fields and also to combat gender stereotypes in STEM fields and STEM careers (Cvencek et al., 2011; Kurup et al., 2019). This requires investment in STEM education earlier on in primary. The Science Centre, is committed towards elevating STEM education. This commitment is reflected in STEM outreach initiatives organised on a national level from early years to post-secondary level. The following STEM initiatives presented, mainly target children in the early and primary years.

Fig. 14.4 Examples of STEM learning opportunities in ECEC in Malta

X'hemM? a Mathematics and Science popularisation initiative, which kick-started in 2014 provides integrated and meaningful experiences to students to apply mathematical and scientific concepts through engaging, problem-solving activities in a non-formal setting. Furthermore, *X'hemM?* provides a platform for collaboration between schools and entities providing non-formal education, including museums/centres, libraries, NGOs, local councils, sports clubs, activity clubs, scout groups, girl guides and the industry.

tiny Teen Science Café is another STEM initiative that aims to address gender stereotypes through informal encounters with various STEM professionals and educate parents/guardians in supporting and guiding their children towards STEM careers.

Other STEM initiatives that are established within the primary sector and are planned to evolve to target the early years include:

- *Junior Science Club* aims to provide learners opportunities to experience science investigations and practical science-related activities that extend their learning beyond the classroom environment. During the sessions, that are held after school hours, the learners practise science-related process skills and nurture their potential to develop problem-solving, critical thinking, communication and self-appraisal skills and competences.
- *Summer STEM Camp* aims to provide learners with a holistic experience to embrace STEM, team-building and the arts in a non-formal environment.

- *Maths Family Connect* invites children, accompanied by a parent/guardian to take part in engaging, challenging, hands-on Maths tasks, puzzles and games. Through these after-school sessions, participants have an excellent opportunity to develop a range of skills such as perseverance, decision making and problem solving.

The vision for promoting STEM in the early years is embraced through different STEM outreach opportunities organised in formal and non-formal settings while integrating multiple stakeholders from different sectors including industry and NGOs. See Figs. 14.5 and 14.6 for examples.

14.3 Gaining Clarity in How Children Learn

Learning is a complex process, and everyone's learning experience may present "as unique as our fingerprints" (Meyer et al., 2014, p. 49) which necessitates a flexible model for how learning occurs. Models of learning that exclude a focus on thinking, feeling and acting as connecting component parts of learning may produce unbalanced, disengaged and disenchanted learning (Jarvis, 2006; Johnston, 1996; Novak & Gowin, 1984). This intricate process of finding balance between thinking, feeling, and acting involves different processes that develop and change over time based on interactions with the environment, others, and emotions that may arise. Learning through the navigation of space and time to acquire new knowledge, wisdom, skills, and strategies is part of our being and prepares individuals to become contributing members in society. This process may be empowered by developing an understanding of how one learns (Pritchard, 2018; Slavkin, 2004).

Understanding the processes related to learning and development provides a way to create learning environments that nurture individual needs of learners. Research in neuroscience and developmental psychology demonstrates that cognition (thinking), affectation (feeling) and conation (acting) cannot be studied as disparate elements in terms of learning, but one must analyse systems and networks of connections which lead to an understanding of how learning occurs (Johnston, 1996; Meyer et al., 2014; Novak & Gowin, 1984). Rather than aim to define learning as simply an outcome measure, such theories of learning emerge as paradigm shifts to consider learning as a complex dynamic system of networks and mental processes that impact cognition, affect, and action. Consequently, such approaches to understanding learning require supports for educators to better determine their role in facilitating learning opportunities, not only for content acquisition, but to increase the quality of teaching and learning experiences. These foundational teachings and skills are as important as supporting learners and aim to amplify learning environments' impact on young learners.

In this premise, especially in the early years, to create a learner-centred environment where learner variability is the norm, not the exception (Pape, 2018), educators should provide different opportunities and choices for participation that are developmentally appropriate, accessible, and in consideration of learning preferences. It

Figs. 14.5 Exploring maths and science concepts during *X'hemM?* għal Dinja Aħjar STEM initiative

is beneficial for educators to listen to the voices of learners to understand why, what and how they feel, think and act. Engaging learners in the process of reflecting on their own learning allows for the development of a sense of self, agency, and building communities of learning. Engaging in curious, collaborative learning provides additional opportunities to explore questions and establish inquiry-based learning environments. The 'learner's voice' in this context refers to the shift in how to interact with young children in a more meaningful, intentional way to provide opportunities

Figs. 14.6 Exploring maths and science concepts during *X'hemM?* għal Dinja Aħjar STEM initiative

for them to voice their ideas about what matters most to them and that impact their learning. When educators intentionally observe the nuanced cues and emerging interests of children and trust that they can guide their own learning, young people further connect with their experiences and learning (Dutton, 2012). Additionally, this level of understanding and perspective further solidifies more meaningful relationships between educators and learners (Bateman, 2017).

In any learning environment there will be differences in how learning occurs. Such differences discussed here will be described as learner variability (Meyer et al., 2014). This relates to how students may have varying needs and different approaches to how they navigate through learning environments. These different pathways to learning may also be impacted by how learners respond to stimuli in the environment and stimuli's impact cognition, affect, and behaviour (Matthews et al., 2000). This can be demonstrated through how the Reticular Activating System (RAS) communicates with the frontal lobes in the brain to determine which stimuli we pay more attention to in an environment and what we are motivated by (Wittrock, 1992). For instance, Brain (2000) suggests that while some incoming information is selected for attention, other information may be neglected. Brain's work on how information is received shows that information enters the senses through a 'sensory buffer' where the information is selectively filtered. This selectivity view is also presented in Sousa's (2017) model. The way in which an individual perceives a situation can differ based on several variables that can shift or change the point of initiation for that experience. Similarly, affective responses of how we feel about experiences can physiologically change a learner's performance (Immordino-Yang & Damasio, 2007). These perceptions are considered as initial points of engagement or disengagement for learning (Meyer et al., 2014) as an emotional response which can skew a learning experience even before it occurs. These differences in how students engage or disengage with learning highlight the need to pay greater attention to the emotionality around learning and create accessible as well as supportive learning experiences that bolster how students learn best.

Many theories of learning further distil the emotional and cognitive influences on learning. For instance, Forsten et al. (2006), Dweck and Masters (2008) and Brophy (2010), reveal how learners can interpret and respond differently to learning experiences in the face of challenge. The appraisal of a perceived challenge can determine how learners feel about a situation which may, in turn, impact their performance. Marshall Shelton and Stern (2004) as well as Smith (2018) suggest that having teachers who are attuned to understanding feelings, referred to as 'emotional information', may increase the effectiveness of teaching and student learning. Other authors such as Matthews et al., (2000, p. 16) state that there are differences in "stylistic variables such as willingness to respond and preference for speed over accuracy." When observing learners in action, different behaviours may be employed based on their preferences and responses to numerous stimuli internally or externally. How learners feel about the work they are doing, if it seems relevant, purposeful, and accessible, may impact their performance. The limbic system and its corresponding neural components establish a system for emotion that is related to behaviours and patterns in learning. These emotions are noted by Jarvis (2006, p. 177) to "play a major role in behaviour and in human learning since they are at the heart of our personhood." Immordino-Yang and Damasio reminds us that "we feel, therefore we learn" (2007) and Novak (2010, p. 30) extends this notion and proposes that "feelings or what psychologists call affect, are always a concomitant of any learning experience and can enhance or impair learning." Without consideration of the affective side of learning, an integral part of the learning process may be missed.

It is evident that learning is quite a complex process involving cognition (thinking), conation (acting) and affectation (feeling). Many authors refer to an ongoing interaction of these three mental processes (Johnston, 1996; Meyer et al., 2014; Novak, 2010; Novak & Gowin, 1984). Learning can no longer be viewed as a process which solely involves content acquisition. While learners are going through a process of thinking during learning, they are also doing and feeling. Novak and Gowin (1984, p. xi) in the preface to their book claim: "Human experience involves not only thinking and acting but also feeling, and it is only when all three are considered together that individuals can be empowered to enrich the meaning of their experience". Therefore, by taking into consideration the connectivity of thinking, feeling, and doing, especially during the early years, educators can aim to plan meaningful interaction and learning experiences that will serve to generate a robust platform for future successful learning to take place.

14.4 Learning Outcomes

Malta has recently embarked on a learning outcomes approach as the keystone for learning and assessment. The Maltese Directorate for Quality and Standards in Education indicates that "The aim of the Learning Outcomes Framework is to free schools and learners from centrally-imposed knowledge-centric syllabi, and to give them the freedom to develop programmes that fulfil the framework of knowledge, attitudes and skills-based outcomes that are considered national education entitlement of all learners in Malta" (DQSE, 2015). In Malta, this is currently complemented by the emergent curriculum approach. This approach calls for early years educators to create flexible and responsive learning environments that support children's development as active and engaged learners.

A common working definition of a learning outcome is "a statement of what a student should know, understand and/or be able to demonstrate after completion of a learning process" (Bernholt et al, 2012, p. 111; Kennedy, 2009, p. 126). One interesting definition is the one put forward by Watson (2002, p. 208) where he defines a learning outcome as "being something that students can do now that they could not do previously… a change in people as a result of a learning experience." One popular way of constructing learning outcomes is by using the structure as presented in Bloom's taxonomy (Bernholt et al., 2012; Kennedy, 2009). This has provided a scaffold for teachers to follow when writing learning outcomes. However, Hussey and Smith (2002) have criticised approaches to writing learning outcomes that rely on a generic level descriptor such as those based on Bloom's Taxonomy. Allan (1996) argues that learning outcomes limit the students' learning experience or focus on minimal learning. Ecclestone (1999, p. 29) points out that "if unchecked, there is a real danger that uncritical acceptance of increasingly prescriptive, standardised outcomes will create cynical, instrumental attitudes to learning in teachers and students alike and remove critical dimensions of student centeredness."

In the literature, there seems to be a common critique proposed by various authors (Eisner, 2000; Hussey & Smith, 2002, 2003; Wisdom, 2001) that although learning outcomes may provide added value to educational processes since they bring more clarity to the learning process, however they will be counterproductive if they serve as fixed prescriptions or recipes or as Eisner (2000, p. 344) puts it "uniformed army of young adolescents [learners] all marching to the same drummer." Neuroscience provides evidence that how individuals learn is unique, therefore having fixed learning outcomes would not be responding effectively to the reality of diverse classrooms (Meyer et al., 2014). One should not regard learning outcomes as a way to accomplish a task and move on, but as Wisdom (2001) points out, to indicate an iterative process that involves both learners and teachers as active participants in their development. Therefore, the use of learning outcomes can add value to the educational process to anchor learners in their experiences and elucidate the purpose and goal for their actions. When provided in a flexible way, outcomes guide the process of learning in the early years (Woods, 2013).

If learning outcomes are used too rigidly, they will limit the unplanned outcomes or what Hussey and Smith (2002) refers to as 'emergent outcomes' that tend to arise during learning. These 'emergent outcomes' are extremely important during the educational process, particularly in the early years and promote deep learning (Pianta, 2012; DQSE, 2015, OECD, 2017b). This very much depends on the teacher and how adept they are in recognising and tolerating these unintended outcomes that emerge as the learners engage with the content and relate it to their own experience while encouraging creativity. This is in congruence with the recently implemented learning outcomes for the early years in Malta which clearly state "In the very early years, learning outcomes should be conceptualised as a compass not a map: they point in possible directions that children can learn and grow, but do not lay down templates that all children must follow" (DQSE, 2015, p. 5).

Learning outcomes that move beyond the traditional view of focusing on knowledge and skill acquisition would also integrate affective factors to promote enthusiasm for learning, feeling safe in a learning community and skills to increase self-regulation (Meyer et al., 2014). This notion is also mirrored in Hussey and Smith (2003, p. 367) "accepting that student motivation is an essential element in learning, we propose that those who teach should begin to reclaim learning outcomes and begin to frame them more broadly and flexibly, to allow for demonstrations and expressions of appreciation, enjoyment and even pleasure." With more pleasurable learning experiences, learners will foster a persistent motivation to take on greater challenges and more meaningful learning. This is further revealed in Darling-Hammond's (2000) findings on the effects of quality teaching on student outcomes where the quality of teaching and teacher education seem to be more strongly related to student achievement and outcomes sought than other variables such as class size, teachers' salaries, or students' background. Likewise, Hattie (2003) provides compelling evidence for the importance of quality teaching through a meta-analysis of the relevant evidence-based research which was drawn from an extensive review of literature and a synthesis of over half a million studies. This constantly evolving and valuable work identifies the greatest source of variance that is shown to make a difference in learning as the teacher, and excellence in teaching as the single most powerful influence on students' achievement (Hattie, 2003, pp. 3–4). This was also asserted by Rowe et al. (1993) where based on their findings it was argued that effective educational institutions were only effective to the extent that they had effective teachers. Moreover, Hattie distinguishes between expert and experienced teachers and identifies one of the five major dimensions in an excellent teacher as being that "expert teachers can attend to affective attributes" (Hattie, 2003, p. 5) by having a strong respect for their students and by sharing their passion for teaching and learning. Perhaps one of the most impactful contributions and examples are through modelling a love of learning with students.

Teaching is very personal and idiosyncratic (Vanhear, 2015) and therefore, it is important for educators to gain a greater understanding of the learning process while taking on a more active and intentional role. As a result, educators can be better supported by pedagogical tools and strategies that support them to become more engaged themselves and increase the intention with which they facilitate meaningful learning opportunities. The teaching process becomes most effective when teachers plan intentional approaches in response to how students are learning (OECD, 2019). Effective tools and strategies are important, but they very much depend on the delivery and teachers' commitment and willingness to use them intentionally. It is not a particular strategy or tool that matters most, but the teachers' belief that utilizing different approaches will improve their practice and expand their reach to meet the needs of all learners. This is where a paradigm shift is necessary to design flexible learning environments and experiences to be more intentional and amplify positive teacher-student interactions from an understanding of how children learn. This is where Universal Design for Learning can support these efforts.

14.5 Universal Design for Learning

The institution of education aims to meet the needs of all learners, to increase their participation in society, and to prepare learners to better themselves for the future. Within institutions of education, we can predict that every classroom inherently maintains a wide range of systematic variability in learning and learners. No two learners will present with the same strengths and areas of challenge on any given day. This may lead to a perception that there is an added complexity to each students' learning needs. To address individual learner variability, educators also need support and understand how to proactively plan for and address such needs across learning environments. Anecdotally, not addressing variability in learning may lead to an uptick in early school leaving and attrition for learners. Universal Design for Learning (UDL) is a framework that is founded upon and guided by neuroscience, educational sciences, and psychology relative to how learning occurs with the aim to support educators to proactively plan for anticipated learner variability (Meyer et al., 2014). Rather than waiting for learners to struggle or fail, UDL is predicated on the proactive integration of options to create flexible learning environments. These environments aim to establish accessibility for learning practice and exploration, evaluation and assessment, as well as to promote learner engagement from the outset of instruction and learning. By providing multiple means of engagement, recognition, as well as action and expression, educators can promote expert learning to help each individual actualize their potential and understand what serves them best across contexts (Meyer et al., 2014). Expert learning is a goal for learners to better understand the way in which they learn across context, space, and time (Meyer et al., 2014). One point of focus to support expert learning is to scaffold, support, and often explicitly teach skills and strategies. One such set of skills that will be highlighted here is executive function. Executive function is a term used to describe a set of cognitive skills that are involved in goal directed actions (Zelazo et al., 2016). The three core executive function skills are working memory, response inhibition, and cognitive flexibility (Diamond, 2013; Nigg, 2017). Executive functions involve the ability to regulate attention, pause to consider options, establish a plan or pathway, reflect on previous experiences, allow for creative problem solving and can often predict a variety of outcomes related to learning, development, and success throughout life (Diamond & Lee, 2011; Zelazo et al., 2016). While developing expert learning skills, learners benefit from explicit guidance and scaffolded support to establish, practice, and strengthen their executive function skills. This allows even young learners to recognize that there may be multiple paths to one goal. From a neurological perspective, executive function are primarily located in the prefrontal cortical regions of the brain and do not act on their own (Meyer et al., 2014). Perceptual reasoning, affect and emotion, and the executive function networks- the thinking, feeling, and doing components of learning all work in conjunction with one another to allow for learning experiences to be maximized (Meyer et al., 2014).

Universal Design for Learning is a pedagogical framework that provides scaffolds to design teaching and learning opportunities that best support a wide range of learners and is guided by the fundamentals of how the learning brain works (Meyer et al., 2014). Since the early 1990s, an original focus on individual learning support development shifted focus from individual learning differences to evaluating barriers that exist in learning environments for individuals with special needs and diagnosed disabilities. Learning environments can be found in and outside of traditional school buildings and classrooms. This term, as used here, encompasses any space where learning is intentionally occurring. While adjustments to learning environments prove necessary for individuals with disabilities, the additional access and flexibility that is created, will benefit many students (Meyer et al., 2014). For example, in traditional classrooms, curricula are typically built around text-based materials that are not always accessible to all learners. With the increasing ubiquity of available technologies, CAST, the founders of UDL, began to design digital curricula and materials that were flexible from the beginning, rather than needing to retrofit to meet specific students' needs after a point of struggle. Not only are students with specifically diagnosed disabilities in need of more flexible options, but all learners benefit from alternate pathways to meeting learning goals (Meyer et al., 2014). Learning goals are pre-established outcomes that educators and learners may define to work toward in any given lesson, activity, or segment of time (Meyer et al., 2014). Similar to "learning outcomes," learning goals through a UDL lens establish a guide for learners to aim for and have a clear path to that goal. Reaching a learning goal is not necessarily an end point, but a step along a student's learning journey to demonstrate their understanding of new concepts or skills. Ideally, learning goals designed through a UDL lens are clear, flexible, and maintain developmentally appropriate rigour (Meyer et al., 2014).

While technology is becoming more readily available and inexpensive, there is an opportunity to also design digital environments for learning through a UDL lens. The additional flexibility incorporated digitally provides support to those who had not previously been able to participate in traditional learning experiences. Though digital technology is one way to design accessible learning opportunities, it is not the only way. Through years of research and the amalgamation of best practices and studies from the fields of education, psychology, and neuroscience, CAST developed a set of guidelines that establish intentional and innovative pathways for educators to better meet the needs of all learners (CAST, 2018). Rather than providing options after a need arises, supports and scaffolds can be integrated directly into learning environments from the start. This is further solidified through the provision of clear, rigorous goals, with flexible means which help to increase self-awareness and the development of skills for learners to increase mastery, confidence, and what is known as "expert learning" (Meyer et al., 2014). Understanding oneself as an expert learner in UDL terms is to be resourceful, knowledgeable, strategic, goal-directed, purposeful, and motivated (CAST, 2018). The UDL guidelines and framework set out to provide intentionally planned options to allow for the optimal navigation of different learning environments across context and time (Meyer et al., 2014). Ultimately, this helps to transform teaching and learning experiences for all.

Over the years, educational institutions have recognized the increasing diversity that is inherent in all classrooms and learning environments around the world. The UDL framework was established to provide more flexible options to accommodate such learner variability at the point of design and also supports educators in their committed work to serving all learners. Learner variability is simply defined as the uniqueness in how each individual learns (Meyer et al., 2014) and accounts for the inherent systematic variability that is present. It is undeniable that each learner brings with them a unique set of experiences, strengths and needs that vary depending on the situation and context (Meyer et al., 2014). The authors believe that this is what builds a beautiful tapestry of unique styles, approaches, and contributions to learning environments.

As a framework that started in the margins of the normal distribution where learners may typically fall in one region or another, UDL shifts the focus from individual differences to predictable variability that exists among all learners (Meyer et al., 2014). Rather than conceptualizing learning through a normal distribution, it is imperative that we recognize how variability impacts learning and how learning experiences are context dependent (Meyer et al., 2014). Learning from individuals who may "fall in the margins" allows us to witness just how variable learning really is. Learning is interactional and therefore a learner's traits will have an interaction with the environment (Hattie & Clarke, 2018). Learning environments may necessitate different demands where learners' internal as well as external states can influence learning and performance (Immordino-Yang & Damasio, 2007). Understanding how the environment, expectations, and interactions can shift and change how learners navigate through different learning experiences provide opportunities to increase expert learning (Meyer et al., 2014) and ways to amplify a student's experiences getting to know themselves as learners.

Learning environments can often dictate how and why students will perform or engage in different activities, lessons, or experiences. One of the key tenets of UDL is that the environment can provide structure, support, and flexibility that is proactively planned to allow for learners to access resources, interactions, and different components of the environment that will best meet their needs (Meyer et al., 2014). Traditionally, education has taken more of a clinical approach to supporting learning differences where there is a recognized need or deficit that is identified and then some corresponding reaction or response to manage the identified need occurs. At its core, the UDL framework provides a lens to support the establishment of learning environments that have flexible pathways to reaching developmentally appropriate, rigorous goals. Such environments proactively integrate supports that are necessary for leveraging learner variability through the activation of the networks of the brain to allow for holistic learning experiences.

14.6 The UDL Guidelines

The UDL Guidelines (see Fig. 14.7) (CAST, 2018) highlight three neural networks that work together to activate learning. Each of these guidelines provides a roadmap to consider how learning occurs. For each guideline there are three levels of principles that establish opportunities to access, build or practice skills, and ultimately internalize skills and checkpoints within each principle to provide options for learning. The top level of principles, at the access level, provides options that educators can manipulate in learning environments. Further, they provide ways for learners to practice and build their skill sets and eventually be able to internalize skills that lean toward embodying expert learning. Often, educators find that they are already incorporating many of the principles into their teaching. However, the UDL framework encourages the integration of options to promote expert learning skills in more intentional ways. Ultimately, the UDL Guidelines are intended to serve as a tool to design goals, assessments, methods, and materials that provide access to rigorous and authentic learning experiences for all (Meyer et al., 2014). When providing options for young learners to build their skills they practice, reflect, and adapt to situations as they refine their own expertise on how they learn best across contexts, challenges, and time.

At the internalize phase of the UDL Guidelines (CAST, 2018), higher level skills to be developed revolve around providing options to increase self-regulation, comprehension, and executive function (CAST, 2018). These three sets of skills come together as learners increase mastery and comprehension while regulating

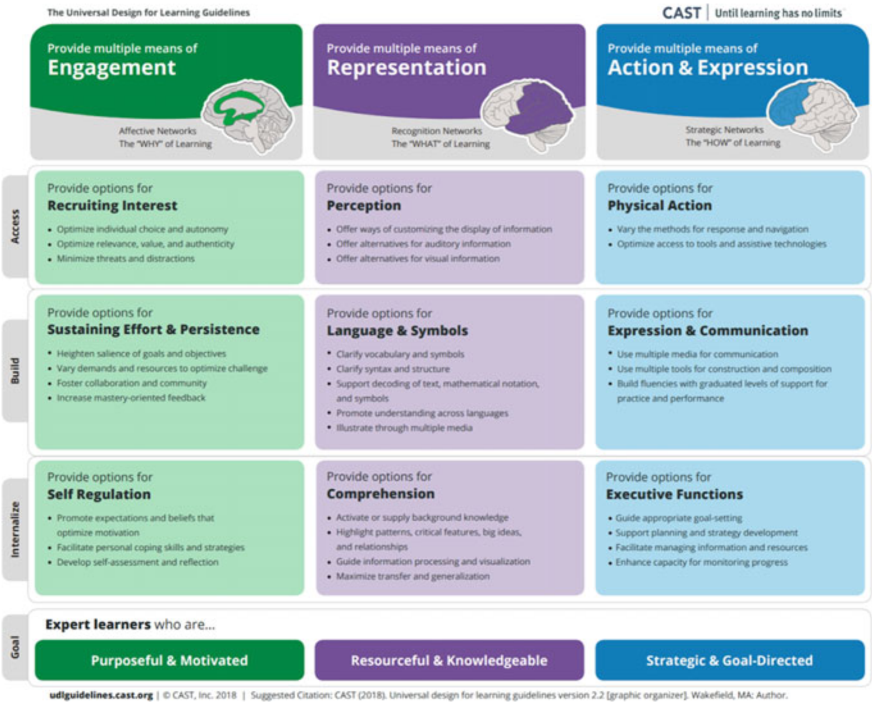

Fig. 14.7 UDL guidelines (CAST, 2018). Universal design for learning guidelines version 2.2 [graphic organizer], Wakefield, MA: Author

their emotions to access and effectively utilize executive function skills. Developmentally, this may look different across contexts and time. However, many of the ways in which executive function is established and strengthened is determined by the learning environment. During early childhood, the learning environment and social interactions become opportunities to strengthen these important skills for learning and life.

14.6.1 Provide Multiple Means of Engagement

Initially, establishing a safe, comfortable learning environment that minimizes threats and promotes self-regulation through the clarity of goals and expectations can help to provide a welcoming space. However, this proactive planning allows for so much more. These clear expectations can optimize motivation while fostering collaboration and community. When spaces are organized, predictable, and clear of clutter, distractions are minimized, and learners can best navigate through their spaces without anticipating irregularity they increase connection to learning and the community. Learning is heavily emotion driven and supporting the affective network promotes engagement and motivation for learning. Immordino-Yang and Damasio (2007) have elucidated the connection between cognition and emotion through a neurobiological perspective to show the interconnections of cognition, emotion, and social functioning.

The more that environments and educators understand the important role of emotion in learning, the better generalizable skills will be outside and across classrooms. Integrating aspects of social emotional learning increases the likelihood of children using coping mechanisms to better regulate how they are feeling, their focus, attention, cognition, and biophysical responses to stimuli within themselves or in the environment (Reid et al., 2017). In consideration of variability among learners, providing mastery-oriented feedback in conjunction with varying demands and resources to optimize challenge allows for engagement that can be generalized across contexts. As learners interact with their environment, it is critical that they are provided with feedback that is authentic, timely, and accurate to their experiences (Hattie & Clarke, 2018).

Consistent feedback can guide the process of learning as the more mastery-oriented or growth mindset focused feedback will establish a narrative that functions as a protective factor against maladaptive learning or social behaviours (Elliott & Dweck, 1988). Elliott and Dweck's (1988) early research showed that regardless of the perceived skillset, mastery-oriented response to failure can help to increase motivation and the choice to take on greater challenges in the future while minimizing the chances of learned helplessness. For young learners, perceiving their ability to attempt a novel task or lesson can become an access point or barrier to learning. For feedback to be effective, it must be in the context of learning and can have different intents from reframing an understanding of a topic or experience, to sharing information or providing an alternate approach or strategy (Hattie & Timperley, 2007). Feedback is information that guides the learning process and when it provides genuine as well as specific information, it can increase motivation and support future attempts at novel tasks (Elliott & Dweck, 1988).

Ultimately, the goal is for learners to utilize feedback in a way that translates into self-assessment and reflection. In addition to providing explicit, mastery-oriented feedback modelling and explicitly teaching ways to recognize, identify, and regulate emotion is pivotal to establishing a safe and productive learning environment. As educators we have the power to shape environments to promote resilience by the way in which we present, face, and support interactions with challenges in our learning environments. Teaching mindfulness as a prompt to reflect, by way of developing breathing skills to pause, take a breath, and assess what is happening allows for inhibition to pause before responding to a challenge or stimuli can be helpful across situations. Noticing when a strong emotion or point of distraction occurs can allow a reset, recalibration, or shift in approach to optimize next steps. Susan Kaiser Greenland (2021), Thich Nhat Hanh (2019), and others have developed stories, tools, mindfulness cards, and games that can be practiced with young children as soon as they enter the classroom. Developing and practicing these skills along with young learners promotes a positive space and community that allows emotion to come up and not take over an experience or space. The development of emotional regulation skills in young learners establishes a basis for building executive function (Zelazo et al., 2016) and expert learning skills (Meyer et al., 2014) as they recognize what tools and approaches are most helpful for them to access across different situations.

14.6.2 Provide Multiple Means of Recognition

Providing multiple means of recognition establishes access points that create opportunities where learners can utilize different materials to access the curriculum. This is most closely related with the way in which learners take in information from their environment. In a text-based world, especially in early childhood, learners need multiple means of representation for symbols, text, and other forms of information to increase clarity of communication. Integrating multiple means of representation not only shows learners that they are seen and noticed because they are provided with supports for them to access the curriculum, but also that they are respected and understood. At this crucial developmental time point, learners are still finding their voices and figuring out how to best access and learn information. In early childhood classrooms this may look like words and symbols paired with visuals, tactile manipulatives, role playing, modelling, playing, storytelling, problem solving, or information provided in other formats for young, often not independent readers. Options for perception allow for learners with and without disabilities to interact with new content and information independently.

These options to optimize perception activate the senses to offer ways to customize the display of information, alternatives for auditory information, and alternatives for visual information (Meyer et al., 2014). Additionally, options for language and symbols promote the opportunity for a shared understanding. These different access points become ways for learners to approach and interact with content and learning experiences in different ways. These options bolster and activate the recognition network of the brain to allow for the generation of new understandings through the consolidation and comprehension of new knowledge. To allow for practice and internalization of these skills it is imperative to supply background knowledge, highlight patterns, critical features, big ideas, and relationships among new information (Meyer et al., 2014). A visual display using images and words to make connections using a tool like a concept map can connect one concept to its component parts (Vanhear & Reid, 2014). If a lesson centres around understanding the importance and use of numbers, a concept map can highlight how and where we see and use numbers in our world. From counting buttons in a collection, to using currency to pay for different items of interest, establishing a background knowledge through exposure and scaffolded experiences becomes a starting point for new learning. By connecting the concept to real world experiences, for example, seeing, using, or hearing about numbers, helps to maximize the transfer and generalization of learning across contexts. How information is presented and represented transforms a learner's experience.

14.6.3 Provide Multiple Means of Action and Expression

When learners express what they have learned there are a complex set of skills that activate for the generation and organization of ideas, establishment of a plan, and execution of that plan while monitoring progress and navigating toward a goal (Meyer et al., 2014). The UDL guidelines encourage the provision of options that promote physical action or how learners act on what they are learning. Using accessible and flexible tools and materials helps learners to vary the methods for response and navigation through access to tools and assistive technologies when needed or beneficial (Meyer et al., 2014). These access points provide options for how learners choose to show what they know or have been learning. Further, as learners practice how they express or show what they have been learning, options for expression and communication can be provided with multiple media for communication, tools for construction and composition, or ways to build fluencies with graduated levels of support for practice and performance (Meyer et al., 2014).

This level of support relates to how learners can choose from developmentally appropriate options to demonstrate their learning. In the early years, learners can choose to tell a story, construct an image, record their voices, a video, or sequence a series of images to show what they know. For example, if learners explored how a worm becomes a butterfly to demonstrate the skill of establishing sequence and order, they can show what they learned about the steps of that process in many different ways. Images, digital apps, games or image manipulation, using cards with images on them, acting out how the organism changes form, or using another media (finger puppets, stick puppets, etc.) can share the experience they learned and enjoyed together. When developmentally appropriate and clear goals are established, it allows learners to develop skills in planning and strategy development. Ultimately, the development and strengthening of executive function skills is the goal. Although the three core executive function skills; working memory, response inhibition, and cognitive flexibility (Diamond, 2013; Nigg, 2017) are not explicitly highlighted in the UDL guidelines at the time of this publication, checkpoints in the guidelines do support setting a goal and establishing a plan to work towards it (CAST, 2018). In conjunction with this set of cognitive skills, emotional regulation directly influences the support and development of executive function skills.

Though each of the UDL guidelines highlight options to support different networks in the brain, they are not working in isolation of one another. They are working together to establish cross-cranial connections that activate optimal pathways to learning (Meyer et al., 2014). Though each individual may have their own unique path to achieving and finding expert learning, the provision of options and flexibility within a learning environment provides developmentally appropriate challenge and support to promote expert learning. The UDL guidelines and framework ultimately bolsters educators to support all learners.

14.6.4 Diving Deeper into the Importance of Scaffolding for Executive Function

To best support developing learners, it is imperative that we understand how their brains are growing and learning. The development of the prefrontal cortex, or front part of the brain coincides with the refinement of executive function skills. These are a collection of cognitive processes that are not automatic and typically require additional forethought through the activation of the core executive functions: inhibition, working memory, and cognitive flexibility (Diamond, 2013; Nigg, 2017). Examples of automatic actions that our brain and body activate are in the pulmunary system when our hearts beat or our respiratory system providing the movement of oxygen throughout our bodies. Both are actions we typically do not need to think about for them to occur. Whereas learning to tie a shoelace or categorize types of toys into their respective containers requires the activation of executive function skills to allow for learners to plan for, learn, practice, and complete such tasks. Executive function skills are not necessarily developed naturally as a learner progresses through their schooling or by means of exposure to academic content (e.g., literacy or numeracy). Many times, executive function skills are developed during the early years through social, creative, active, and play-based experiences in and outside of the classroom (Diamond, 2013; Shaheen, 2014). There are a number of evidence-based interventions and promising practices that have been shown to improve executive function (Diamond & Lee, 2011). However, Diamond and Lee (2011;1) highlighted that "children with worse executive functions initially, benefit most; thus, early executive-function training may avert widening achievement gaps later."

For educators, it is important to both challenge and support these developing skills without overly taxing them. Finding a learner's "zone of proximal development" (Vygotsky, 1930–1934/1978) allows for a balance between both. From an early years perspective, it may seem as though articulating a learning goal is not important due to child's level of understanding, however, by establishing goals that are clearly stated, it models how to establish and work toward such goals in the future. Maintaining clear goals with flexible means honours each learner's individual journey and supports their quest to learn more about themselves as learners. Goal setting and planning can be explicitly taught by establishing a schedule or plan for a lesson or the day, thinking about steps it takes to complete a goal, or even component parts of a bigger task. Verbalizing the steps and rationale to demonstrate how an adult thinks about multiple options to reach a goal increases willingness to try new approaches. This may be especially helpful after the student struggles to complete a previous task. Articulating what is needed (materials, resources, assistance, partnership, time, etc.) along with verbalizing which stage of the process you may be in while working through a project, task, or lesson, establishes connections for learners to incorporate with and without support moving forward. Ultimately, becoming their own coaches as they develop expertise in how they learn. The key is to focus on the "why and how" while making reference to the options you may consider to show that there are multiple pathways to reach a goal along with the reasoning and reasonability of possible choices available.

For young children, inhibitory skills help them to wait their turn, monitor physical and bodily control, emotional control, and impulsivity (Diamond, 2006). The act of waiting, increasing focus and attention, as well as to have greater skills to monitor how they are doing while learning helps to increase self-discipline and inhibition. With inhibitory control comes persistence in the face of challenge, resiliency, problem solving, and often greater learning outcomes (Diamond, 2006) that often continue throughout life. To support these skills, educators can establish learning environments with minimal and intentional decorations on the walls to limit potential points of distraction (Zelazo et al., 2016) while providing tools and activities like mindful awareness to increase points of focus. Establishing clear expectations for how to be safe and respectful in class, as well as having predictable schedules, places to find materials, and expectations also help to minimize potential threats and distractions. Playing go-no go games like Simon says, red light, green light, and others all help to promote inhibitory control (Diamond & Lee, 2011). Additional feedback to praise appropriate behaviours when a child inhibits an urge, like calling out in the middle of directions being delivered, also reinforces inhibitory control. Working memory allows for learners to hold ideas in mind and manipulate or use such information in some new way. This skill is important for the development of language skills, monitoring progress, and remembering what needs to be completed in sequence. Working memory allows for learners to hold details in mind about the information they are interacting with or hearing in their environment, during direct instruction or storytime. Following clear, simple, multi-stepped (though not too many) directions and taking turns, story reading and storytelling also strengthens working memory. As new information is being delivered visually or verbally, learners take in and hold onto details to make sense of the bigger picture or goal (Diamond & Lee, 2011). Cognitive flexibility is a higher order skill that has to do with recognizing and understanding that there may be alternate options, strategies, or approaches to accomplishing a task. Often young learners may get “stuck,” seem inflexible and shut down if they are not sure how to solve a problem or determine another option to get around a barrier, challenge, or distraction. Recognizing that there needs to be a change in an approach requires the activation of executive function skills. Asking the learner to “press pause and zoom out” to consider what the goal is and consider any problem-solving steps they could take to adjust their plan to reach the goal helps to encourage creative and often collaborative problem solving.

With the appropriate level of practice and support, these cognitive skills can improve over time through learning experiences (Diamond, 2013; Zelazo et al., 2016). However, high levels of stress or fewer opportunities to practice these skills can limit executive function (Diamond, 2013; Zelazo et al., 2016). The goal for early learning is to scaffold, support, and provide explicit and implicit opportunities to strengthen executive function skills. Educators and adults can support these efforts by considering ways to integrate such opportunities into learning environments or at home while being mindful not to “swoop in” too often to offer support or do an action for young children, rather than provide a scaffold or guidance. Without opportunities to practice making a mistake, reflecting on the process, and making adjustments when needed, or having access to the proper scaffolds, learners may not be building or improving their executive function skills to activate and utilize them independently in the present or future. It is imperative to show patience with learners who are navigating through their work and practice, even if they may seem a bit clumsy when attempting a novel task or something that has not yet been mastered. It has been posited that learning is emotional (Immordino-Yang & Damasio, 2007; Posey, 2019) and when learners feel connected, encouraged, and capable they will feel more comfortable taking on greater challenges more consistently to improve their skills (Dweck & Masters, 2008). If the learning environment is set up to support executive function skill development, it may also minimize stress, frustration, and emotional dysregulation (Diamond, 2013; Zelazo et al., 2016).

Often interventions that have been present in early childhood classrooms like storytelling, movement, play, using manipulatives, playing or creating music or art, as well as other forms of creativity, problem-solving, and social interactions can be more intentionally focused and supported to strengthen executive function skills (Diamond & Lee, 2011). Incorporating joy, mindfulness, collaboration, and helping one another can establish emotional and cognitive connections that transform and strengthen executive function and expert learning skills. Additional recommendations are listed at the end of this chapter. Ultimately, the goal of supporting learners is to increase confidence, self-regulation, resiliency, and autonomy. Anecdotally, a common concern for young or struggling learners is that they may be limited by their own expectations for themselves or self-fulfilling prophecies. This may lead to the expectation that extensive efforts are needed to achieve learning success and, as young learners without fully developed executive functions, they may not see alternative options to reach a goal and may lose trust in themselves and their capabilities. Nurturing and supporting executive function and expert learning skills allow for learners of all ages and stages to have agency around how they navigate through learning environments and utilize flexible means to meet rigorous goals. Ultimately, increasing opportunities for learner retention and minimizing early school leaving.

14.7 Conclusion and Recommendations

The provision of equitable educational opportunities promote long-lasting, inclusive economic growth and social cohesion (OECD, 2017b). Global research and evidence acknowledge the power of ECEC as an entry point to address issues of inequities and social justice. The first years of childhood are a short span of time in one's life which is critical for neurodevelopmental (Zelazo et al., 2016) and individual growth. Early childhood experiences are important due to the unparalleled speed at which the brain develops in a short amount of time which affects learning, health, behaviour and consequently, social capital and income (World Bank, 2016). In a climate of Sustainable Development Goals (SDGs) investing in early years is investing in the future of our world. It is one of the most cost-effective interventions any country can make to yield the highest economic return in human capital when compared with investments made at later stages in life (Heckman, 2013; Miller et al., 2018). Focusing on the support of developing executive function skills through STEM initiatives and encouraging expert learning through a UDL lens can empower learners and impact the retention of students to prepare them for their future.

Malta is putting an edge on ECEC as a prevention measure to address early school leaving and the STEM initiatives are value added in this regard. A way forward to enhance these efforts is by bringing together policy and practice and the early years educators are key to this process. This chapter may serve as a steppingstone for educators and administrations to emphasize the importance of a learner centred environment in the early years enhanced through intentional teaching and complemented by a better understanding of how children learn. UDL is a practical framework to provide supports for educators to create flexible learning environments that respect learners' individual journeys while equipping educators to support expert learning. By providing multiple means of engagement, recognition, and action and expression, educators facilitate expert learning to help each individual actualize their learning potential and understand what serves them best across contexts. This awareness and understanding will assist educators to equip young learners with a robust platform for successful future learning while increasing their engagement and motivation in lifelong learning.

When planning for early childhood supports it is important to consider appropriate conditions to promote learning and development. It is advantageous to integrate supports that will enhance executive function, critical thinking and problem solving. When learners navigate through their experiences with supports embedded into learning environments and from adults facilitating learning helps to establish a focus on learner exploration, not just adult guided activity. This stimulates affective and cognitive connections to strengthen expert learning and autonomy (Meyer et al., 2014). Recommendations here are intended to be integrated into learning environments through the prepared environment, intentional interactions, and establishing a community of learning that is safe, inclusive, and accessible. Considerations for executive function skill development are especially helpful to mediate the higher demands during STEM learning. When students employ reasoning skills, they are utilizing executive functions as they make hypotheses, collect evidence, and refine their claims through an iterative process (Zelazo et al., 2016). When supporting young learners to develop such skills it is helpful to follow the UDL guidelines to design and develop STEM projects that activate the three neural systems through the provision of multiple means of engagement, representation, and action and expression (Meyer et al., 2014).

As discussed, in Malta, the aim of the Science Centre within DLAP is to strengthen and support STEM in early and primary years, nurture positive STEM attitudes through meaningful experiences for students and the wider community. As outlined earlier, this is achieved through a multidimensional approach, involving multiple stakeholders, towards achieving and reinforcing the vision highlighted in national policy documents. This facilitates more effective STEM teaching and learning and nurtures children's engagement and achievement. This multifaceted approach will provide the necessary impetus for STEM to evolve further and impact positively STEM uptake and future STEM careers.

14.7.1 Using UDL Guidelines to Design STEM Learning Experiences

Listed here are some examples of options for where to begin:

- *Setup a safe and inclusive environment*
  - Create a community of inquiry, exploration, creativity, collaboration, and respect. Recognizing variability in learning by designing scaffolds and supports that allow for autonomous learning, provide options for choice, learning from mistakes, and truly seeing learners as individuals as a part of a community helps to elicit a sense of safety. Feeling safe allows for young learners to feel comfortable being curious, making mistakes, or providing feedback to themselves and others. Design and STEM challenges can serve as an opportunity for these communities of learners to practice their skills.
- *Establish background knowledge*
  - Use shared experiences (brief activity, a video, story, or discussion) and/or allow for the sharing of previous related experiences to the concepts being discussed. This will facilitate critical thinking by posing questions for inquiry.
  - Discuss 5 W's and H: Who, what, where, when, why, and how to make additional connections.

    For example, if a class was exploring where rain comes from they can respond to questions similar to:
    - "Where have we seen rain before?"
    - "What does rain (feel, smell, sound, taste, look) like?"
    - "Who has experiences with rain?"
    - "When does it usually/ has it rained?"
    - "How do we respond when it rains?"
    - "Why does it rain?"
    - "What else is rain related to? What else do we know about rain?"

      Students can share responses to be categorized under each question or in a concept map to show initial information that is known before starting their exploration. Organizing their thoughts visually helps to support executive function and clarity in their approach.
      What gets uncovered through their investigations can be added to each category using different coloured markers to show changes and additions from the original responses to new extensions in order to show how their

knowledge grows as they work together to complete experiments and inquiry.

- *Using language wisely*
  - Utilizing scientific language to label and explain concepts while modeling the process will help make additional connections to the work.

    For example: "This (show an example of graduated cylinder) is a graduated cylinder that we will use to hold liquid. It has lines and numbers on the side to help us measure how much liquid is collected. This liquid (show the liquid) represents the rain because it is clear and we can see through it, it is wet, and has similar qualities to rain."

  - Providing clear, timely, and inquiry-based feedback can help to stimulate additional exploration, critical thinking, and increase persistence motivation. The way in which this is delivered in a supportive way will determine the effectiveness of the feedback in terms of inspiring motivation. Additionally, when we praise the behaviours we want to see more of, we often reinforce the importance of the behaviour.

    For example, "You posed a really great question, can you think of a way we can collect observations or clues to help us answer that question?" or "You did a nice job thinking about different questions to ask and including your group members to help come up with helpful ideas to answer them. What is the next step in your process?"

    - Focusing on what is "helpful" and "not helpful" allows for the shift to a point of reflection rather than "good" or "bad" labelling that does not always improve learning. Examples of potential questions are below:
      "I noticed you started collecting more water and then stopped. I wonder what may have gotten in the way of you collecting more?"
      "Was it helpful for you to ask your friends the question first before you started to brainstorm ideas for how to start?"
      "What were some things that may have been unhelpful when you went through each step of the process?"

- *Focus on the process of learning, not only the outcome*
  - Emphasize the importance of each step of the process, not just the end result.

    Show enthusiasm for each step of discovery, curiosity, data collection, analysis, or re-working a plan. Highlighting that each part helps get closer to a result and that we can reflect to see how each part of the process contributed to the larger outcome.
    If there is a point where a learner feels stuck or is unsure of how to proceed, it is important to investigate options or alternative paths that may allow for flexibility and a new approach to the process. STEM projects are opportunities to explore different perspectives or approaches that can refer

back to initial points of connection from the establishment of background knowledge.

- *Demonstrate understanding: show what you know*
  - Allow for students to take photos, draw images, create and demonstrate different parts of their process to provide options for how learners report back to show what they learned.

    Students can report back to share their findings in a presentation, in video, audio, or visual format to discuss what they uncovered and how they got there. Many creative options and expressions can emerge from this process. Celebrating each phase of the process highlights the value of each step, rather than only the end product or goal.
  - Provide clear goals for the investigation that are posted, labelled, and shown visually while shared verbally to serve as a reference point to why students are exploring and doing what they are doing. This is a point to explicitly discuss from the beginning of a lesson or project and refer back to regularly throughout the process. It can become the perch for students to come back to when checking how the work they are doing is connected to their goal.

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Jacqueline Vanhear, Ph.D. Dr. Jacqueline Vanhear joined the University of Malta in December 2021 as Senior Executive, Quality Support Unit. Prior to this role she was Director—Quality Assurance Department (QAD) within the Directorate for Quality and Standards in Education (DQSE) in the Ministry for Education in Malta for 7 years, leading a dynamic team with the aim of evaluating and promoting the quality of learners' holistic education provision in Maltese pre-compulsory and compulsory educational institutions. Within its regulatory role, the DQSE is also responsible to issue and renew operational licences for educational institututions (0–16 years) and monitors compliance to national legislation and standards. Furthermore, the DQSE accredits learning and assessment programmes up to MQF Level 3 of academic, applied, vocational and non-formal nature, thereby creating diverse opportunities for all learners and contributing to inclusive and equitable quality education. During her tenure, Jacqueline played an instrumental role in the launching of the *National Policy for Early Childhood Education and Care (0–7 yrs) for Malta and Gozo* and the *National Standards for Early Childhood Education and Care Services (0–3 yrs).* Jacqueline has taught in the early years, secondary and tertiary sectors and coached educators, with a special focus on learning how to learn. She focused all her researches on how children learn and explored teaching and learning models which facilitate meaningful learning while addressing learner variability. Over the years Jacqueline has written papers and given presentations as well as published locally and internationally on the learning process focusing on Let Me Learn, Concept Mapping and Vee Heuristics collaborating with other passionate colleagues in the field. She has in recent years expanded and integrated her previous knowledge and research with in depth understanding of Universal Design for Learning.

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Part III
Early Years Experiences in Kindergarten and Formal Schools for 5–8-Year-Olds

Chapter 15
Learning Environments that Improve STEM Capabilities in Israel: Constructional Play and Preschoolers' Engineering Habits of Mind

Ornit Spektor-Levy and Taly Shechter

Abstract Early childhood is ideal period for introducing STEM concepts and engaging children in developmentally appropriate activities to begin understanding the world around them. The Preschool Education Division of the Israeli Ministry of Education has initiated the Future Kindergarten model—encouraging educators and children to initiate, explore, and create their own diverse learning environments and resources. The model is conducive to developing knowledge, skills, and values tailored to the children's needs, based on four anchors: Personal Expression; Community; Entrepreneurship and Productivity; Learning in Living Spaces. In accordance with this initiative we describe research-based evidence that shows that when educators allow children to play and collaborate independently in an educational environment richly equipped with construction materials, the children improve their Engineering Habits of Mind (EHoM) and their design products. Preschoolers (N =228, 5–6 years of age), from six mainstream classrooms, took part in this study. The intervention group (N =126) experienced 6 month of free-choice construction experiences in the enriched learning environment with diverse materials. This group performed significantly better in EHoM practices and the quality of the design product in an open-ended, problem-solving construction task. These results demonstrate the ways in which well thought learning environments, enriched with open-ended materials can enhance preschoolers' cognitive capabilities in a play-based manner.

Keywords Engineering Habits of Mind · Preschool · Play · Learning environment · STEM education

15.1 Introduction

During the first years of life, young children explore their environments and use this information to develop language and construct abstract concepts and theories about the world around them (Bowman et al., 2001; French, 2004; Worth, 2010). These early

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cognitive structures are the foundation for academic learning and are characterized as being deeply rooted in the child's environment and early interactions (Bowman et al., 2001; Eshach, 2006; French, 2004). The richness of the environment, types of interactions, and early experiences are linked to elaborate cognitive structures and better preparedness for further learning. Children constantly explore and question the mathematical and scientific world around them (Bowman et al., 2001; Brenneman et al., 2009; French, 2004; Worth, 2010), making this period of early childhood ideal for introducing STEM concepts and engaging children in developmentally appropriate activities to begin understanding the world around them (Sibuma et al., 2018).

15.2 Tailoring Relevant Learning Environment

The Ministry of Education in Israel deems the purpose of modern education to be the development of student capabilities such as high-order thinking—asking, hypothesizing, referring; self-regulated learning; independent life-long learning; collaborative learning; adapting to new situations; and solving new problems using both previous and new knowledge. Cognitive, metacognitive, interpersonal, and social skills are some of the capabilities described as vital for developing independent and adaptive learning (Preschool Education Division, 2018).

In preschool, the focus is placed on thinking and learning skills, life skills, and social-emotional skills. The Ministry's Preschool Education Division is responsible for children 3–6 years of age, who are enrolled in preschools[1] under the Compulsory Education Law. The Preschool Education Division ensures the provision of equal opportunities and resources based on children's diverse needs. The current division's policy is that early childhood learning is based on the creation of a tailored learning environment in which educational practices are adapted to the preschoolers as diverse individuals and as a group to establish a culture of growth and learning in a safe, supportive and rich learning environment. Furthermore, a number of compulsory programs are implemented in Israeli preschool curriculum, including: Language and Literacy; Math; Science & Technology; Life skills; Health & Physical Education; along with other subjects such as: Music; Arts; Theater; Environment and Sustainability; Technology Integration (Preschool Education Division, 2018). The predominant undertaking of the Preschool Education Division is the Future Kindergarten initiative.

[1] In this chapter, the terms preschool and kindergarten are used as synonyms.

15.2.1 The Future Kindergarten Initiative

The current generational cohort of children, Gen Alpha, are being born into a complex and dynamic world where knowledge is accessible to everyone, everywhere, and at any time. This cohort has never known a world without screens and social network technologies. Gen Alpha children are more independent, more educated, and more innovative as a result of their access to knowledge, information, people, and resources from a young age (Fell, 2018). Thus, it is necessary to apply appropriate pedagogies that accommodate the knowledge, skills, and values required to prepare this young generation for future realities (OECD, 2018). Accordingly, the Preschool Education Division of the Israeli Ministry of Education has initiated the Future Kindergarten model (Future Kindergarten Model, 2019). This model rests upon having faith in the ability of the children and the education team to initiate, lead, study, explore, and create their own learning environments, while interacting constructively with all partners in ways that utilize diverse environments and resources (e.g., parents, experts, local community, physical environment, technological environments). This educational approach allows different models of kindergarten frameworks to flourish: kindergartens operating in natural spaces (in the forest, at the seashore, at archeological sites); kindergartens that emphasize dialogic discourse; project-based learning; play-based learning; digital kindergartens; and so on. The learning culture is based on planned and spontaneous, authentic, explorative experiences recognized by the education team as having potential for learning in general and in the STEM areas (Tourgeman et al., 2019). The Future Kindergarten places the preschoolers at the center of their own learning processes. Learning is often triggered by the children's own interests and questions.

15.2.2 The Future Kindergarten Model

The design of the Future Kindergarten model was undertaken after investigating the anticipated changing trends as far as ten years in the future. Understanding future trends in education helps to formulate effective responses and directions to promote education and society in Israel in accordance with the needs of the twenty-first century.

The four cornerstones of the model address pedagogical issues, while also allowing the education teams to generate a unique atmosphere for their own kindergarten classrooms. The model is conducive to developing knowledge, skills, and values tailored to the children's needs, based on four anchors (Tourgeman et al., 2019):

1. Personal Expression—Treating kindergarten children as active and involved in learning, while cultivating a secure space that allows nurturing and implementing the children's ideas, enables them to express their desires, and promotes personal efficacy.

2. Entrepreneurship and Productivity—Fostering creativity and innovation by means of regarding kindergarten children as entrepreneurs and manufacturers of their own content and products. These are attributes of the do-it-yourself (DIY) culture that is transforming elements of society from consumers to manufacturers.
3. Community—Addressing the essence of community relationships enables the creation of consciousness, identity, and cultural affiliation (local and global), while promoting values of social responsibility and involvement.
4. Learning in the Living Spaces—This applies to all the spaces (e.g. natural spaces, the role play center, the yard) in the kindergarten environment as educational spaces, enabling authentic learning that occurs at anytime and anywhere.

15.2.3 The Future Kindergarten Educational Spaces

Studies indicate that physical spaces matter and may even increase student academic engagement levels (Scott-Webber et al., 2018). In this regard, the Future Kindergarten initiative can be realized in the various classroom spaces where the Future Kindergarten anchors can be expressed. These environments can exist inside the kindergarten or outside in the yard while the kindergarten children and the educational staff are involved in dialogic discourse. Thus, the children can use their inner compass to identify areas of interest, attachments, and values that motivate them. This affords opportunities for the children to be involved and active in creating and designing the spaces. During these processes, and while being engaged in these spaces, the children gain knowledge, skills, and values to reinforce the self-realization of each and every one of them (Tourgeman et al., 2019). Example of such spaces include: The construction center; a workshop area for creating games; a workshop area for fixing broken toys; a real cooking and baking center; a tea house; a scientific lab center; a vegetable garden; a center for exploration of materials; etc.

There is a wide consensus in scholarly literature regarding the significance of developing and organizing learning spaces to support education in general and early childhood cognitive and emotional development in particular (Barrett et al., 2015; Berris & Miller, 2011). In the next sections, we will describe the investigation of a specially designed, engineering-enhanced preschool construction spaces. The study sought to identify the contribution of such spaces to the cognitive development of preschool children and to cultivate their Engineering Habits of Mind.

15.3 Early STEM Education and Engineering Habits of Mind

Early STEM education has become a major focus of educational systems largely because research has shown that already in elementary grades students who have limited exposure to early STEM education are lacking key mathematical and scientific knowledge and skills (Pantoya et al., 2015). Even though engineering is a key component of STEM education (represented by the letter E in STEM), it remains largely neglected in the early and elementary years (Aguirre-Munoz & Pantoya, 2016; English, 2016; Cunningham et al., 2005; Watkins et al., 2014).

The interdisciplinary nature of engineering establishes it as a perfect vehicle for promoting natural and problem-solving curiosities, which characterize early childhood classrooms (English, 2018; Tank et al., 2018). These behaviors can be considered precursors to engineering thinking (Bagiati & Evangelou, 2011, 2015; Bairaktarova et al., 2011; Brophy & Evangelou, 2007; Brophy et al., 2008; Gold et al., 2015; Lippard et al., 2017, 2018; Van Meeteren & Zan, 2010).

Every day and wherever they go, children are surrounded by artifacts. These artifacts are produced by creativity and are the handiwork of engineering (Petroski, 1992). As such, they introduce young children to a tangible, affordable and useful approach to engineering. Some studies discuss the use of exploratory play in early education (Bonawitz et al., 2011; Cook et al., 2011; Evangelou et al., 2010). They investigate engineering thinking as disclosed in young children's manipulation of artifacts and interactions with objects from their surroundings, showing that children exhibit curiosity, interest, motivation, and the capacity to draw conclusions in free play or interaction with familiar or unfamiliar artifacts. Moreover, just as engineers work collaboratively, children enjoy planning and building with peers (Gold et al., 2020). Children communicate and collaborate about what elements to apply to their construction or how to procede in their design proceses. Such communication help children to practice vocabulary, and challenge their thinking (Lippard at el., 2018). Thus, manipulating devices identified as objects made by humans and constructive play, provide authentic opportunities to develop engineering thinking and design processes in the preschool's learning environment. Gold and Elicker (2020), further elaborate that from adults' perspective (e.g. educators, researchers, parents), direct observations on children's constructive play may provide rich context for understanding how children employ engineering thinking during peer play; how to support development of problem solving capabilities, and how to increase young children's early STEM awareness and interest.

Problem-solving processes in Engineering require high order thinking and habits of mind.

Katehi et al. (2009) define Engineering Habits of Mind (EHoM) as a set of "values, attitudes, and thinking skills associated with engineering" (Katehi et al., 2009, p. 7). They defined six EHoM to be fostered in K-12 education: systems thinking, creativity, optimism, collaboration, communication, and ethical considerations.

Another definition of EHoM has been suggested by Lucas, Hanson, and Claxton (2014), published in a report by the Royal Academy of Engineering, and according to which, there are six EHoM:

1. Systems thinking: Seeing whole systems and parts and how they connect, pattern-sniffing, recognizing interdependencies, synthesizing.
2. Problem-finding: Clarifying needs, checking existing solutions, investigating contexts, verifying.
3. Visualizing: Being able to move from abstract to concrete, manipulating materials, mental rehearsal of physical space, and of practical design solutions.
4. Improving: Relentlessly trying to make things better by experimenting, designing, sketching, guessing, conjecturing, thought experimenting, prototyping.
5. Creative problem-solving: Applying techniques from different traditions, generating ideas and solutions with others, generous but rigorous critiquing, seeing engineering as a team sport.
6. Adapting: Testing, analyzing, reflecting, rethinking, changing both in a physical sense and mentally.

The engineering habits of mind refer to values, attitudes and learning abilities which intimately match the abilities of the twenty-first century—components that increase learning in all fields (Bellanca, 2010; English & Gainsburg, 2015; Lucas et al., 2014; Van Meeteren, 2013, p. 39).

15.3.1 Investigating Engineering Through Preschool Constructive Play Objects

The sparse research on engineering play during young children's engagement with various objects used for construction (e.g., Snap Circuits™, water tables, sandboxes, large foam blocks, and small blocks) has found that various elements of the engineering design process occur during engagement with these kinds of manipulatives and block materials. This includes observable engineering play-behaviors (Bagiati & Evangelou, 2016; Bairaktarova et al., 2011; Brophy & Evangelou, 2007; Gold, 2017; Gold et al., 2015). Less-structured play activities with construction-oriented materials could be valuable in encouraging children's interest (Pattison et al, 2020) and engagement in engineering play if framed appropriately in educational contexts (Gold et al., 2015).

Shechter and Spektor-Levy (2018) argue that an engineering learning environment for children must provide a wide degree of freedom of operation. In this setting, a variety of materials are given to children—who are naturally curious—to plan, build, and create during their experiments, including making errors; thus, promoting the development of EHoM. The innovation in this study is, therefore, the identification and measurement of EHoM among preschoolers, before and after an intervention program that designed an engineering-enhanced environment in the preschool classroom. Accordingly, the following **research question** was asked: How does enriching the preschool learning environment with diverse construction materials have an impact on the development of Engineering Habits of Mind (EHoM) of young children.

15.4 Methodology

15.4.1 Study Sample

The sample consisted of 228 children, 120 males (52.6%) and 108 females (47.4%). The mean age of the participants was 64.28 months (SD 4.86). The children who participated in the current study were divided into two groups—intervention and comparison. Of the participants, 126 children were assigned to the intervention group (68 boys and 58 girls), and 102 children were assigned to the comparison group (52 boys and 50 girls). No significant difference in gender distribution was found between the two study groups $\chi^2(1) = 0.20$, $p = 0.653$.

The children's basic cognitive level was measured by the Raven test (Raven, 1956), measuring their non-verbal general and visual intelligence and by the PPVT test (Peabody Picture Vocabulary Test; Dunn & Dunn, 2007) measuring their passive vocabulary level. The scores on the Raven test revealed normal, typical range between 85 and 129 (M = 109.88, SD = 10.41). The scores on the PPVT-4 ranged between 36 and 143 (M = 99.96, SD = 17.45). Of the 228 children, 30 were not born in Israel. Therefore, their scores on the PPVT test were below the typical development range. However, it should be noted that none of the children was diagnosed with developmental or language delays.

15.4.2 Research Tools

The study applied a mixed method approach, in order to expand, deepen, and reinforce the intellectual and practical insights based on quantitative and qualitative evidence (Johnson et al., 2007).

15.4.2.1 Open-Ended Problem-Solving Construction Play-Like Task

In accordance with Fleer (2020) the open-ended task included a narrative and a motive. Fleer (2020) suggested that the development of children's engineering competence, can productively be conceptualized as an engineering motive. When children's play involves 'as if' imaginary narratives, their play actions and their engineering solutions become more complex. Therefore, the setting of the open-ended task included a giant pictorial map of a river lay on a table, along with 40 assorted LEGO® bricks and three miniature figures. The story was that children went to preschool on the opposite riverbank and needed to cross the river safely every day. The participants were asked, “Can you help them, using these LEGO® bricks?” The participants were told they had to fulfill three requirements regarding the bridge: it had to be constructed between the two riverbanks (marks were indicated on the picture) with no pillar placed in the area that depicted water; it had to be high enough so a small boat (provided) could pass beneath; it had to be stable so the figures could cross the bridge safely.

The task was performed during school hours, in a quiet room within the preschool facility. The task procedure lasted approximately twenty minutes. Children’s responses (verbal and non-verbal) were recorded in writing and on video (after obtaining parental consent) and a detailed coding scheme was developed.

15.4.2.2 The Early EHoM Coding Scheme

The Early EHoM coding scheme (Shechter, Eden & Spektor-Levy, 2021). aimed to identify engineering capabilities based on the Engineering Habits of Mind model by Lucas et al. (2014). In this coding scheme, the coding was based on several indications, including seeking different solutions for the engineering problem; visualizing the various solutions; testing the solutions; choosing the most appropriate solution; manifesting creativity; reflecting; and improving.

The coding scheme sought to represent verbal and non-verbal manifestations of Early EHoM by numerical counts. Responses could be manifested by thinking aloud; private gestures and private speech; procedure of construction; actual construction; behaviors; and final bridge construction. The validity of the Early EHoM coding scheme was determined by three preschool educators and three early STEM education researchers who were asked to examine the task and the coding scheme in accordance with the objective of the study and age-appropriate requirements. Disagreements were resolved by discussion until a consensus was reached, and only statements achieving full agreement were included in the analyses.

These six specialists also served as raters and coded 13% of the video data gathered in this study. The three raters watched the videos carefully (each video at least twice) and analyzed each video in accordance with the Early EHoM coding scheme. Inter-rater reliability was calculated, producing a Cronbach’s Alpha score between 0.7 and 0.9.

15.4.3 *Research Procedure*

15.4.3.1 Pre-intervention Interview with Open-Ended Play-Like Task

Each child was asked a few questions to become familiar with the researcher and to gather background information. Questions included: What's your name? How old are you? Are you familiar with LEGO®? Did you ever play with LEGO® before? Then, the *open-ended problem-solving construction play-like task*—constructing a bridge—was presented to the child.

This kind of task requires identifying the problem, planning, abstract thinking, self-expression, critical thinking, constant awareness of task requirements, and so on.

A fine-grained, video micro-analysis was carried out for each video (a total of ~150 h of videos). Each video clip was carefully viewed and every second of the recording was coded according the Early EHoM coding scheme.

Quantitative data was analyzed using SPSS Statistics® (Version 25). Utilizing this software, we calculated frequencies, mean values, *t*–Tests for independent surveys, and so on.

15.4.3.2 Intervention Period of Six months

In the 6 classrooms (6 preschools with 126 preschoolers) comprising the intervention group, the teaching environment was reorganized so as to encourage more building and engineering practices, in view of the Future Kindergarten initiative. The Construction Center as well as other spaces in the classrooms of each preschool was supplemented with many construction games and diverse accessories such as: wooden frames, wooden pillars, planks, miniature figures of people and animals, rollers, engravings, fabrics and the like (see Figs. 15.1 and 15.2). The preschoolers could choose to play with these objects and materials individually or in a group according to their own desire, with no mediation or guidance from the teacher.

At the same time, for the control group classrooms, objects were introduced to the learning environment such as: dolls, balls, markers for coloring, and other accessories not related to construction and the engineering field.

Fig. 15.1 Construction processes in the preschool's intervention classrooms

Fig. 15.2 Examples of the open-ended construction task products—bridges

15.4.3.3 Post-intervention Interview with Open-Ended Play-Like Task

Individual interviews (exactly like during the pre-intervention stage) and the same open-ended construction task were also conducted with each of the children participating in the study to assess their Engineering Habits of Mind, and to test for changes.

15.5 Findings

The dependent variables were the measures of children's engineering habits and the quality of their construction product. The result of the first analysis indicated that due to the large variability in the children's ability at this age, some of the dependent variables were not normally distributed. Therefore, we examined the study question by conducting parametric and non-parametric tests. Most of the results of the non-parametric and parametric tests were identical; therefore, for most of the findings section, the results of the parametric analyses are reported.

We conducted a two-way repeated measures ANCOVA for all of the dependent variables.

The independent variables were *groups* (as the between-subjects variable) and *time* (as the within-subjects variable). The dependent variables were the children's EHoM (measured by six measures: systems thinking, problem-finding, creative problem-solving, visualizing, adapting, and improving), and the quality of their construction product (measured by the length, height, stability, and the complexity and creativity level of the bridge). The scores on the PPVT test served as the covariate variable. A finding was considered significant when the level of significance was $p < 0.05$.

15.5.1 Differences in the Children's EHoM by Group and Time

The *main effect of group* was significant on the total measure of the children's EHoM (EHoM-total) and on the four EHoM measures: systems thinking, problem-finding, creative problem-solving, and improving. The intervention group scored higher on all of the four dependent variables. *The main effect of time* was significant on the children's EHoM-total variavle and on the two EHoM measures of visualizing and adapting. The results indicated that children's scores on these measures increased after the intervention compared to before the intervention. Finally, the *two-way interaction of group and time* was significant on the children's EHoM-toal and on two EHoM measures, problem-finding, and visualizing (see Table 15.1).

Bonferroni analyses comparing the two time points in each study group indicated that both the intervention and the comparison group significantly increased their scores on EHoM-total and on two EHoM measures, problem-finding and visualizing, after the intervention compared to before the intervention. However, the effect sizes of the differences between the two time points in these measures were greater among the children from the intervention group ($d = 0.70$ for the total measure, $d = 0.80$ for problem-finding and $d = 0.90$ for the visualizing measure) compared to the comparison group ($d = 0.38$ for the total measure, $d = 0.34$ for problem-finding and $d = 0.18$ for the visualizing measure).

15.5.2 Differences in Children's Quality of Construction Product by Group and time

The *main effect of group* was significant on the two quality of construction product measures—height, and stability. The intervention group scored higher on these two dependent variables. *The main effect of time* was significant on the quality of construction product measure—height—indicating higher scores on this measure after the intervention compared to before the intervention. Finally, *the two-way interaction of group and time* was significant on all of the quality of construction product measures (see Table 15.2).

Bonferroni analyses comparing the two time points in each study group indicated that while the scores on the length measure and on the stability measure increased after the intervention as compared to before the intervention in the intervention group ($p = 0.000$ and $p = 0.000$), no significant differences between the two time points were found on the scores in these measures in the comparison group ($p = 0.558$ and $p = 0.278$).

Regarding the scores on the height measure and the level of complexity and creativity of the bridge, Bonferroni analyses indicated that both groups increased their scores on these measures Post the intervention compared to the Pre intervention. However, the effect sizes of the differences between the two time points in these measures were greater among the children from the intervention group ($d = 0.88$ for the height measure and $d = 0.45$ for the complexity and creativity measure) compared to the comparison group ($d = 0.41$ for the height measure and $d = 0.23$ for the complexity and creativity measure).

Table 15.1 Mean, SD, M.E and F-values of the children's EHoM by group and time while controlling the PPVT scores ($N = 228$, $df = 1{,}225$)

		Before			After					
EHoM	Group	M	SD	M.E	M	SD	M.E	Time	Group	Interaction
Systems thinking[b] (0–9)	Intervention	2.85	2.57	2.95	2.83	1.66	2.89	0.62	34.51***	1.15
	Comparison	1.70	1.27	1.57	1.93	1.30	1.85			
Problem-finding[c] (0–14)	Intervention	9.93	3.80	10.08	13.00	2.22	13.10	2.89	7.97**	14.12***
	Comparison	10.25	3.78	10.06	11.04	3.85	10.91			
Creative problem-solving[a] (0–2)	Intervention	0.63	0.87	0.66	0.17	0.38	0.19	0.10	7.98**	1.37
	Comparison	0.43	0.81	0.39	0.09	0.29	0.07			
Visualizing[a] (0–2)	Intervention	1.01	0.98	1.05	1.89	0.46	1.90	9.83**	3.12	11.57***
	Comparison	1.18	0.99	1.12	1.51	0.86	1.49			
Adapting[a] (0–1)	Intervention	1.96	0.20	1.97	2.42	0.96	2.39	4.13*	0.96	0.09
	Comparison	1.86	0.35	1.84	2.31	0.85	2.33			
Improving[b] (number) (0–4)	Intervention	0.76	0.86	0.78	0.44	0.70	0.47	0.58	29.62***	2.90
	Comparison	0.31	0.53	0.29	0.23	0.44	0.20			
EHoM-total[c] (0–34)	Experiment	15.92	7.37	16.28	20.82	3.56	21.04	5.06*	20.68***	5.26*
	Comparison	14.77	6.26	14.33	17.18	5.54	16.91			

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; M.E = Mean Estimate; [a]Variables are in ordinal scales—results of non-parametric and parametric tests were identical; [b]Variables are in Ratio scale; [c]Variables are in interval scale

Table 15.2 Mean, SD, M.E and F-values of the quality of constriction product by group and time while controlling the PPVT scores ($N = 228$, $df = 1{,}225$)

Quality of constriction product		Before			After					
	Group	M	SD	M.E	M	SD	M.E	Time	Group	Interaction
Length[a] (0–4)	Intervention	2.98	1.37	3.01	3.60	0.96	3.62	0.47	2.47	8.81**
	Comparison	3.21	1.26	3.17	3.09	1.28	3.07			
Height[a] (0–4)	Intervention	3.30	1.44	3.37	4.60	0.89	4.63	7.10**	4.33*	5.46*
	Comparison	3.41	1.50	3.32	4.10	1.37	4.06			
Stability[a] (0–6)	Intervention	3.65	1.87	3.70	4.80	1.05	4.85	0.62	10.59***	10.75***
	Comparison	3.63	1.92	3.56	3.85	1.67	3.79			
Complexity and creativity[b] (0–4)	Intervention	1.33	1.68	1.37	2.44	2.10	2.60	2.42	1.12	7.27**
	Comparison	1.66	1.64	1.61	2.16	1.71	1.96			

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; [a]Variables are in ordinal scales; [b]Variables are in interval scale

15.6 Discussion

In this intervention study, we examined indications of Engineering Habits of Mind (EHoM) among preschoolers during authentic play-like, open-ended, problem-solving construction task. This construction task was applied before and after enriching the preschool learning environment, for six months, with varied construction materials and construction games, in the intervention group.

Data analysis revealed significant improvement in the children's EHoM-total measure and two EHoM measures, problem-finding and visualizing among participants of the intervention group. A significant positive change was found in both groups showing improved performances, but the intervention group showed higher and significant improvement than the comparison group. The main effect of time was significant on the EHoM-total and on the two EHoM measures, visualizing and adapting. This indicates that all the children improved their performance regarding these variables.

The results can be explained by the fact that in the intervention group, children were exposed to construction materials in their daily enriched learning environment. During their daily free-play they could choose to experience solving construction problems initiated by themselves. As a result, they gained much more experience in construction. These experiences stimulated engineering and design processes, enhancing their EHoM practices: systems-thinking, adapting, problem finding, creative problem solving, visualizing and improving, and other aspects of the engineering field. Above all, developing EHoM and the ability to think as an engineer, as Lucas et al. (2014) maintained, helps to attain overall life-long success. Implementing an EHoM culture of learning can help achieve success in solving problems and is particularly effective in many areas of life.

With regard to the two EHoM measures, problem-finding and visualizing, the results indicated that the children's scores (in the intervention group) had significantly increased. This can be explained by the fact that problem finding is at the heart of the design process and involves clarifying needs, checking existing solutions, investigating contexts, and verifying with reference to task requirements. Thus, a child with good problem-finding skills already thinks like an engineer. Lucas et al. (2014) argue that the EHoM model trains the individual to solve problems. Children also spend time addressing problems that appear to be accessible and unstructured, with overlapping issues and engineering-typical problem-solving skills (Brophy et al., 2008; Watkins et al., 2014).

As regard to the visualizing habit of mind, the scores of the children in the intervention group were especially high. We surmise that in order to build a bridge in a way that meets the task requirements, a child had to figure how the bridge should look like. The child had to create a mental picture in terms of all the elements of the bridge; in other words, the child had to be able to visualize the bridge. Therefore, the intervention group which was already trained with various construction and engineering processes, showed higher levels of visualizing then the comparison group.

15.6.1 Children's Construction Product by Group (Intervention or Comparison Group) and by Time

The results of the current study show that the intervention group significantly improved in all construction measures. There was a significant interaction between all variables of the product quality: length, height, stability, complexity, and creativity. There were significant differences in the scores on all four quality of construction measures. Regarding the height and stability measures, both groups' performance improved, but the intervention group improved more.

As the results have shown, the intervention program significantly improved the total EHoM in the intervention group. The same applies to visualizing, which affects the quality of the construction: length, height, stability, complexity, and creativity. If the EHoM are greatly improved, the product is likely to be so, as well.

However, regarding the scores of the height, complexity and creativity measures of the bridge, it was found that the extent of the effect was greater among the children from the intervention group than those in the comparison group. The main effect of time was significant on the quality of construction product measure—height—indicating higher scores on this measure after the intervention compared to before the intervention.

In the pre-tests, the height measure showed the poorest performance compared with the other measures. Following the intervention, it was found to be the most improved measure. This suggests that the intervention—enhanced free play with construction materials and games—had a profound effect and that children were able to achieve better construction product in accordance with its' prior requirements and high levels of EHoM performances.

15.6.2 Limitations of the Study

Due to the age limitations of the children participated in this study, the findings were primarily based on deriving meaning and interpreting the observed children's responses, rather than based upon the children's verbal explanations and verbal elaborations. Moreover, the observation method enabled detailed observation and analysis of verbal and nonverbal responses of young children in the context of the engineering task. Despite the advantages of the observation method, it also has its limitations, given that only observable behaviors can be coded. Therefore, it is possible that some of our interpretations may be inaccurate. In a future follow-up study, it is recommended that more time be given to children at the end of the task to verbally express their impressions of the task: both of coping with the engineering challenges they faced and coping with the emotional challenges.

15.7 Conclusion and Recommendations

In order to establish a learning environment that enhances cognitive capabilities of young children such as the EHoM, we recommend organizing a large, spacious area for construction. Large area can afford more children to play and collaborate and can afford allowing the children to leave their construction projects for long enough time to fulfill their construction plan. It is recommended the construction spaces will consist of a variety of inspiring, generic construction materials and assembly games for open-ended, problem-solving play.

The preschool teacher should provide scope for a wide range of free-play, independent constructional activities throughout the classroom and allocate enough time during the day for continuous construction. It is recommended there should also be planned activities that yield rich opportunities for the children to define problems and solve them independently.

To conclude, the Israeli Future Kindergarten initiative encourages the formation of new models or inspiration, in order to suit the unique space and culture of each kindergarten classroom. The learning culture is based on planned and spontaneous, authentic, explorative experiences recognized by the education team as having potential for learning in general and in the STEM areas. The teachers are encouraged to reorganize and redesign the preschool classroom in order to encourage young children, by free choice, to play, experience diverse materials and artifacts, to explore them and to enhance their own exploration and engineering practices. In this chapter we described research-based evidence that show that if educators allow children to play and function independently in a well-established educational environment richly equipped with construction materials, the children improve their EHoM and their design products. These results demonstrate the ways in which well thought learning environments, enriched with open-ended materials can enhance preschoolers' cognitive capabilities in a play-based manner.

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Chapter 16
Fostering 5- to 6-Year-Old Children's Conceptual Knowledge of Gear Functioning Through Guided Play in German Kindergartens

Timo Reuter and Miriam Leuchter

Abstract In this chapter we describe a guided play learning environment for 5- to 6-year-old kindergarten children that aims at fostering children's conceptual knowledge about meshed gears' turning direction and turning speed (the *gear play environment*). In an experimental study we have investigated 5- to 6-year-old's learning about gear functioning by comparing children who engaged in the *gear play environment* (guided play condition) with children who freely played with gears (free play condition). The *gear play environment* consists of gear construction sets and a choice of task cards focusing children's attention on turning direction and turning speed. Moreover, an adult verbally scaffolded children's play towards the learning objectives. In the free play condition, children were provided with the construction sets without the task cards. Findings were mixed: With respect to turning direction, the results suggest that only the children in the guided play condition learned. With respect to turning speed, the results indicate that the children in both conditions were able to improve their conceptual knowledge. We conclude from our findings that guided play can facilitate scientific learning in kindergarten children, but it might depend on the learning content how much guidance is needed to achieve the best learning outcomes.

Keywords Gears · Conceptual knowledge · Guided play · Free play · Constructivist learning

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16.1 Introduction

From birth, children in highly developed countries like Germany are exposed to all kinds of technology like mobile phones, wheeled vehicles, or household equipment like the vacuum cleaner and the lawn mower. However, the functions and mechanisms of technical objects remain obscure to them. Early technical education should therefore give children the opportunity to dismantle technical objects and to explore how they work. Moreover, early technical education in Germany is supposed to foster engineering thinking, i.e. children should learn to identify needs, plan solutions, and to construct, test and optimise devices to solve engineering problems. Toy gear construction kits allow children to practice engineering thinking and explore basic mechanical functions. In this chapter, we describe a guided play learning environment with gears (the *gear play environment*) that we developed and tested in German kindergartens. German kindergarten serves children between ages three and six. Kindergarten attendance is voluntary, but 93% of children of the relevant age attended kindergarten in 2019 (Statistisches Bundesamt, 2019). Children from the first year of age to their third birthday can go to an infant–toddler centre, which in 2019 was done by about one in three children of this age group (Statistisches Bundesamt, 2019). Instead of infant–toddler centres (0 to 3 years) and kindergarten (3 to 6 years), there is the possibility for children from the first year of age to six years to go to a day-care-centre or home-based day-care. Infant–toddler centres, day-care-centres and home-based day-care usually cost a fee. Since each of the 16 federal states in Germany has sovereignty over its Early Childhood Education and Care (ECEC) policy, the amount of fees varies from federal state to federal state and is partly determined by the parents' income. For kindergarten, some—but not all—federal states offer free entitlement. At the age of six, formal schooling starts with primary school (grades 1–4) with a curriculum inclusive of science and technology. After that, secondary school is compulsory for six years (*Realschule,* vocational-oriented, preparing students for an apprenticeship), or eight years (Gymnasium, preparing students for university study).

For the last two decades, German kindergarten is supposed to promote academic learning (Anders, 2015; OECD, 2006). Each of the 16 federal states has its own education framework that outlines various learning areas, e.g., pre-literacy, math, and science. However, these frameworks neither prescribe specific learning objectives nor do they give binding directives for implementation (Anders, 2015). The vast majority of kindergarten teachers have completed a three-year vocational training program. Since about 15 years there are numerous higher education degree-level courses in early childhood pedagogy, however, the proportion of kindergarten teachers with a university degree is still low (Anders, 2015). Coming from a social pedagogy tradition, German kindergarten teachers value child autonomy and emphasize the promotion of children's socio-emotional development through free play, whereas direct teaching of academic skills is not a part of this tradition (Anders, 2015). Thus, German kindergarten teachers usually see themselves responsible for creating a setting conducive to free play by e.g., preparing materials, and providing the children enough time to freely play with the materials (O'Connor, 2014).

During free play the children initiate the play and direct their activities without any guidance of an adult and without pursuing any extrinsic learning objectives (Weisberg et al., 2016). For academic learning, however, research indicates that a stronger involvement of the kindergarten teacher might be favourable (Pyle et al., 2017). When children have the freedom to both initiate the play and direct the activities by themselves, they may not explore available materials at all (Nayfeld et al., 2011) or only superficially (Butts et al., 1994). Thus, the learner might fail to encounter the to-be-learned objectives (Mayer, 2004). Therefore, curricular frameworks in Germany started arguing for kindergarten teachers to initiate and support children's explorations, and to allow child autonomy at the same time (Anders, 2015). In guided play, the kindergarten teacher purposefully prepares a play environment with carefully structured materials that aim at a specific learning goal (material scaffolding), and initiates children's autonomous explorations (Weisberg et al., 2016). Additionally, the kindergarten teacher might verbally scaffold children's activities towards the learning goal (Weisberg et al., 2016). Verbal scaffolding aims at dynamically extending and complementing the guidance embedded in the materials (Martin et al., 2019) and has been found to be effective for science learning in kindergarten (e.g. Fisher et al., 2013; Reuter & Leuchter, 2020; Weber et al., 2020) and for primary school students (e.g., Leuchter & Naber, 2018). The kindergarten teacher's verbal scaffolding might involve asking questions (Chin, 2007) and modeling of certain behaviors and thinking styles, thereby offering the child a possibility for imitation (Hmelo-Silver et al., 2007).

In this chapter, we first describe the *gear play environment*. Second, we report an experimental study in which we have examined 5- to 6-year-old kindergarten children's learning about gear functioning by comparing a guided play condition, namely the *gear play environment*, with a free play condition.

16.2 The Gear Play Environment

The design of the *gear play environment* is based on a constructivist view of learning with the aim of conceptual change (Appleton, 2010; Bransford, 2000). Thus, learning is perceived as an active and constructive process in which the learner has to make sense of the learning materials by actively building coherent and organized knowledge representations (Mayer, 2004). Learning as conceptual change means that children have intuitive but often naïve concepts about their surrounding environment (Bransford, 2000), e.g., physical phenomena as the functioning of gears (Reuter & Leuchter, 2020). Early science education in Germany is supposed to take up children's naïve concepts and promote restructuring these into concepts that are closer to a scientific point of view (Vosniadou, 1994). The *gear play environment* aims at fostering children's conceptual understanding of gears' turning direction and turning speed (rotational speed). Both turning direction and turning speed are visible. Moreover, building up an understanding of gears' turning direction and turning speed is relevant for science learning later in school, since these two properties form a foundation for the acquisition of advanced physical concepts, e.g., torque. In the *gear play environment*, children should experience and learn (1) that meshed gears turn in opposite directions and (2) that turning speed is negatively related to gear size (i.e., large gears turn slower than small gears).

The *gear play environment* consists of commercially available plastic toy gears of various sizes that can be plugged into corresponding peg boards. Additionally, children are provided with a choice of task cards related to the learning objectives, allowing them to explore gears' turning direction and turning speed in a structured way (for examples, see Fig. 16.1). The task cards depict gear configurations on three difficulty levels which aim at supporting the children to construct the corresponding gears. The reconstruction of the gears shown on the task cards and the exact observation of the gears' turning direction and turning speed aim at stimulating and supporting the children's conceptual change of their naïve ideas into adequate concepts. Various studies have shown that children's ideas about how gears work develop in phases in which most children have specific naïve concepts of gears' turning direction and turning speed (Lehrer & Schauble, 1998; Metz, 1991; Reuter & Leuchter, 2020). According to Metz (1991), children before the age of four often explain gear rotation with the function of the object (e.g., gears rotate because they are made to rotate). From the age of 4 years onwards, children more often mention the connection between two gears as the reason for the rotation of the driven gear (e.g., because the gears are plugged together). These concepts are prerequisites for the development of more advanced mechanical explanations which form the basis for an understanding of gears' turning direction and turning speed.

With regard to gears' turning direction, studies show that the naïve concept of meshed gears rotating in the same direction is widespread in children aged 5 to

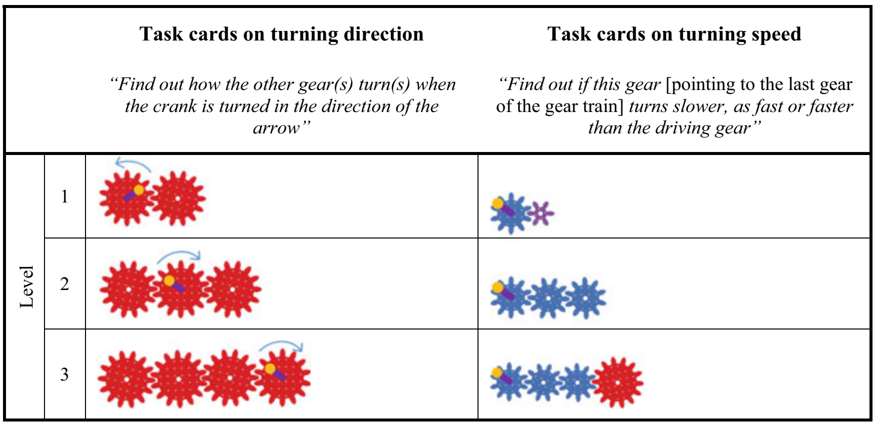

Fig. 16.1 Examples of the task cards on turning direction and turning speed

6 years (Lehrer & Schauble, 1998; Reuter & Leuchter, 2020). To enable the children to restructure this naïve concept into an adequate concept, each card on turning direction depicts a driving gear with an arrow indicating the turning direction. The driving gear is meshed with one or more other gears of the same size and the children have to determine the resulting turning direction. Level 1 cards depict a pair of meshed gears, level 2 cards a train of three gears, and level 3 cards a train of four gears. The position of the driving gear alters from card to card (see Fig. 16.1 for examples). Additionally, the children are provided with cardboard arrows that can be placed on the gears to visualize their turning direction.

With regard to gears' turning speed, different naïve concepts can be found in 5- to 6-year-old children (Lehrer & Schauble, 1998; Reuter & Leuchter, 2020). Some children think that gears always turn at the same speed, regardless of their size, whereas other children associate "large" with "fast" and "small" with "slow", thus both groups of children having an incorrect size concept. Moreover, children might have the naïve concept that turning speed depends on the number of gears that are meshed in a train. These children either think that the last gear in the row is faster ("amplifying forces") or slower ("disappearing forces") than the driving gear (Lehrer & Schauble, 1998). The cards on turning speed always depict a medium-sized driving gear. With level 1 cards, the driving gear is connected to one other gear. This gear is either smaller, of the same size, or larger than the driving gear. Level 1 cards allow the children to test their size concepts. Level 2 cards show a train of three gears. The driving gear is meshed with a gear of the same size. The third gear in the train is either smaller, of the same size, or larger than the driving gear. Level 3 cards follow the same principle, but depict a train of four gears (see Fig. 16.1 for an example). The level 2 and level 3 cards allow the children to test the naïve concept that the turning speed depends on the number of gears in a train.

The kindergarten teacher sorts a sufficiently large number of cards into six boxes (three boxes for the cards on turning direction, three boxes for the cards on turning speed). Each box is provided with symbols indicating whether the cards in the box are on turning direction or on turning speed as well as the difficulty level. The children sit around a large table or on the floor. The plastic gears and the corresponding construction materials such as plugs, connectors and peg boards are sorted in boxes. Each child has enough space to build, all boxes with components are easily accessible for the children and the task cards are clearly visible and accessible to the children.

During the children's construction play, the kindergarten teacher might guide the children's activities using verbal scaffolding techniques to channel and focus their attention towards the turning direction, or turning speed, respectively. The teacher may support children's reconstruction of the depicted gears (e.g., "*Look carefully, which parts do you need?*", "*Where exactly do you have to build the large red gear?*") or assist the child with observing the turning direction or turning speed (e.g., "*Look, I turn the crank very slowly and carefully observe this gear! Now, you try!*"). When the child has discovered the turning speed or the turning direction correctly, the teacher may summarize the results (e.g., "*Okay, you have now found out that if you turn the driving gear in this direction, the other gear goes in the opposite direction!*") (Figs. 16.2 and 16.3).

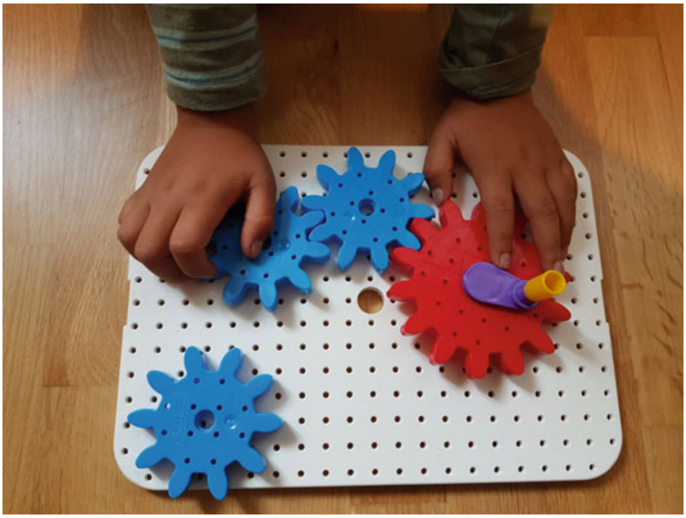

Fig. 16.2 Child assembling gears on the peg board

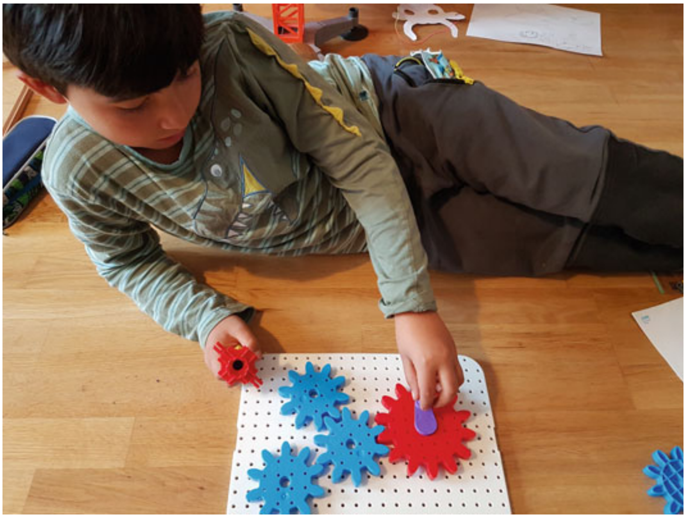

Fig. 16.3 Child observing the gears' turning direction by turning the crank

16.3 Experimental Study

To investigate kindergarten children's potential learning with respect to gears' turning direction and turning speed, we conducted an experimental study. Participants were 104 children aged 5 to 6 years (M_{age} = 69.5 months, SD_{age} = 4.43 months; 63

females). The children were in their last year of kindergarten before starting primary school. We compared a guided play with a free play condition. The children were randomly assigned to one of the two conditions in each of the nine participating kindergartens. In the guided play condition, the children (n = 57) participated in the *gear play environment* for 45 min. In the free play condition, the children (n = 47) were provided with the same selection of plastic toy gears and corresponding plugs and peg boards. However, there were no task cards in the free play condition, thus the children were not specifically encouraged to explore turning direction and turning speed. The experimenter invited the children in the free play condition to play with the gears at the beginning of the 45 min long session. Besides initiating the play and assisting the children in case of problems with the handling of the material, the experimenter did not scaffold the children's play in the free play condition. In contrast, in the guided play condition, the experimenter channelled and focused children's play towards the learning objectives by verbal scaffolding using a script with detailed standards for asking questions, modelling, and summarizing (see Table 16.1 for examples). However, the kindergarten teacher did not summarize until the child had discovered a solution on its own. The interventions of both conditions were videotaped for a manipulation check.

To measure children's concepts of turning direction and turning speed, we conducted a pretest approximately one week before the play session, an immediate posttest directly after the play session, and a delayed posttest approximately two weeks after. The test consisted of six items on turning direction ($\alpha_{\text{immediate posttest}} = 0.834$) and nine items on turning speed ($\alpha_{\text{immediate posttest}} = 0.874$). The items on turning direction always depicted a driving gear with an arrow indicating the turning direction. The driving gear was meshed with one or more gears of the same size for which the children had to determine the resulting turning direction and draw an arrow above the respective gear(s) as an answer. The items on turning speed always depicted a medium size driving gear that was either meshed with one or two other gears. Moreover, each item depicted a small, a medium (same size as the driving gear) or large gear. The children had to decide which of these three gears had to be added at the end of the train so that it would turn either as fast, slower or faster than the driving gear. The test was administered paper-pencil in groups of 4 to 5 children sitting back-to-back to prevent them from copying. The experimenter explained the test format and led step by step through the test.

16.4 Results

We first looked at the children's learning based on the development of mean solution rates. Correct predictions were scored with "1", incorrect prediction with "0", resulting in a mean value between 0 and 1 for each child for turning direction and for turning speed. These mean values can be read as solution rates (e.g., "0.5" = 50% correct predictions).

Table 16.1 Realization of the guided play and the free play condition

<table>
<tr><th></th><th>Guided play</th><th>Free play</th></tr>
<tr><td>Duration</td><td colspan="2">– 45 min</td></tr>
<tr><td>Groups</td><td colspan="2">– Children played in groups of 4 to 5 children</td></tr>
<tr><td rowspan="2">Material</td><td colspan="2">– Different sized gears, plugs, peg boards; sorted in boxes that were placed on the floor</td></tr>
<tr><td>– Task cards on turning direction and turning speed, 3 difficulty-levels; sorted in boxes that were placed in a position where they were easily accessible for the children</td><td></td></tr>
<tr><td rowspan="2">Role of the adult</td><td colspan="2">The adult …
– Initiated the play: “Today you can play with gears and explore how they work”</td></tr>
<tr><td>– Introduced the task cards: “There are cards where you have to find out how gears turn around and there are cards where you have to find out how fast gears turn”
– Encouraged the child to choose a card: “Would you like to try a task card?”
– If the child chose a card on the turning direction: “Find out how the other gear(s) turn(s) when the crank is turned in the direction of the arrow”
– If the child chose a card on the turning speed: “Find out if this gear [pointing to the last gear in the gear train] turns slower, as fast or faster than the driving gear”
– Channelled and focused the child’s play towards the learning objectives by asking questions (“Now look carefully, which direction does this gear turn?”), modelling (“I slowly turn the crank and now I can observe whether this gear turns as fast as the driving gear”), summarizing (“Well done, so now you found out that meshed gears turn in opposite directions”)</td><td></td></tr>
<tr><td rowspan="2">Role of the child</td><td colspan="2">The child …
– Directed the play by deciding what to do, for how long, at what pace, etc.</td></tr>
<tr><td>– Decided whether to take a level 1, a level 2, a level 3 card, or no card
– Could choose new task cards as long as she or he wanted, but was also allowed to continue constructing without a new task card</td><td></td></tr>
</table>

As can be seen in Fig. 16.4, the solution rate for turning direction did not differ between the guided play and the free play condition in the pretest, indicating that the children started from the same level. In the guided play condition, the solution rate increased from 36% in the pretest to 53% in the immediate posttest. Moreover, the solution rate remained stable at 51% as indicated by the delayed posttest. In the free play condition, however, the solution rate did not increase but remained constant at 36% in the immediate posttest. In the delayed posttest, the solution rate even slightly decreased to 33%. A linear mixed model with guided play as reference group revealed a significant change over time, $\gamma = 0.07$, $p < 0.01$, $SE = 0.02$, $t = 3.03$, indicating that this increase in the guided play condition was statistically significant. Moreover,

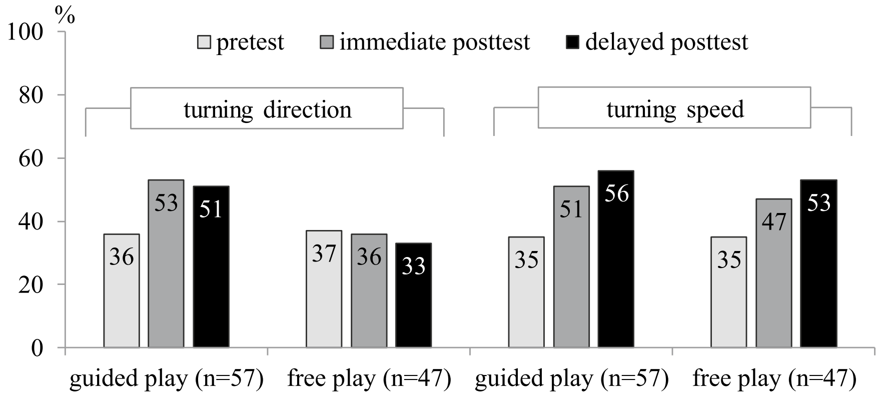

Fig. 16.4 Solution rates for turning direction and turning speed at pre-, immediate post-, and delayed-posttest in the guided play and free play condition

the change over time in the free play condition significantly differed from the guided play condition, $\gamma = -0.09$, $p < 0.05$, $SE = 0.03$, $t = -2.58$, indicating no learning effect in the free play condition.

With respect to turning speed, again the solution rates did not differ between the guided play and the free play condition in the pretest. In the guided play condition, the solution rate for turning speed increased from 35% in the pretest to 51% in the immediate posttest. Moreover, the solution rate slightly increased to 56% in the delayed posttest. In the free play condition, the solution rate also increased to 47% in the immediate posttest and 53% in the delayed posttest. Accordingly, a linear mixed model revealed a significant change over time, $\gamma = 0.10$, $p < 0.001$, $SE = 0.03$, $t = 4.23$, but the free play condition did statistically not differ from the guided play condition, $\gamma = -0.01$, $p > 0.05$, $SE = 0.04$, $t = -0.20$. This indicates an improvement in both conditions.

We also looked at children's learning on an individual level and classified children as "experts" (having an adequate concept) or "non-experts" (having a naïve or no apparent concept). We consider children to be experts on turning direction if they have made at least 8 out of 10 predictions correctly. With respect to turning speed, we consider children to be experts if they have made at least 6 out of 9 predictions correctly. The probability that this amount of correct answers is obtained by guessing is about 5% according to the binomial distribution. Consequently, it can be assumed that children with this amount of correct answers have an adequate concept of gears' turning direction or turning speed, respectively. For the analyses on the individual level, we could only use the children for which complete data sets were available ($n = 56$), i.e. children with missing values on one or more of the items were excluded.

With respect to turning direction, we identified 51 non-experts (91%) in the pretest. Eight out of these 51 children (16%) became experts in the immediate posttest. Of these eight children, seven children were in the guided play condition, and one child was in the free play condition. However, the association between improvement and experimental condition was not significant ($p = 0.119$, Fisher's exact test). Of the seven children who became experts in the guided play condition, six remained experts in the delayed posttest, whereas the one child in the free play condition did not remain an expert. However, a Fisher's exact test on the difference between immediate and delayed posttest revealed that there was no significant association between experimental condition and remaining an expert ($p = 0.250$).

With respect to turning speed, we identified 48 non-experts (87%) in the pretest. Of these 48 children, 11 (23%) became experts in the immediate posttest. Of these 11 children, seven (24%) were in the guided play condition and four (21%) in the free play condition. Again, the association between improvement and experimental condition was not significant ($p = 1.000$, Fisher's exact test). Of the seven children who became experts in the guided play condition, six (86%) remained experts in the delayed posttest. Of the four children who had become experts in the free play condition, two (50%) remained experts in the delayed posttest. Fisher's exact test was non-significant ($p = 0.491$).

16.5 Conclusion

Following a guided play approach (Weisberg et al., 2016), we developed the *gear play environment* and tested it with 5- to 6-year-old kindergarten children in Germany. The *gear play environment* aims at fostering children's conceptual understanding of gears' turning direction and turning speed. The children are provided with different sized plastic gears, corresponding plugs and peg boards. Moreover, they are able to choose from a variety of task cards focusing their attention towards the learning objectives. Additionally, the kindergarten teacher is supposed to guide the children's play with verbal scaffolding. In an experimental study, we compared the learning outcomes of children that engaged in the *gear play environment* (guided play condition) with the outcomes of children that were provided with the gears, corresponding plugs and peg boards only (free play condition), both led by an experimenter. Results were mixed. With respect to children's learning about gears' turning direction, results were in favour of the guided play approach: The mean solution rate significantly increased in the guided play condition from pre- to immediate posttest, and remained stable in the delayed posttest, whereas the mean solution rate did not change in the free play condition. Moreover, seven children in the guided play condition became experts after the play session, but only one child in the free play condition. With respect to turning speed, we found a learning effect in both conditions: The mean solution rate increased, and 11 children became experts in the immediate posttest. Hence, providing the children with different sized gears and inviting them to play with these gears was sufficient for the children to discover the to-be-learned relation of gear size and turning speed. However, for the turning direction it was necessary to draw the children's attention to this learning objective through the tasks cards and to guide the children's explorations by verbal scaffolding in form of questioning (Chin, 2007) and modelling (Hmelo-Silver et al., 2007).

These findings suggest that it seems to depend on the learning content what kind of guidance and how much guidance is needed to foster conceptual learning. In some cases, the guidance embedded in the materials might be sufficient for learning (Martin et al., 2019), whereas in other cases the kindergarten teacher's additional verbal scaffolding might be necessary to help children in making sense of the learning materials and to restructure their naïve concepts into more scientifically appropriate concepts (Vosniadou, 1994). Thus, future studies should on the one hand investigate guided play in other physics contexts and other science domains, and on the other hand systematically manipulate the level of guidance provided to the children (Weisberg et al., 2016). Moreover, upcoming research should not only look at the learning outcomes, but also at the learning process, e.g. by looking in detail at the interactions between the child and the kindergarten teacher (Yu et al., 2018).

However, the study reported in this chapter shows that guided play can facilitate science and technical learning in 5- to 6-year-old kindergarten children, combining child autonomy with learning goal orientation. Our results indicate that a remarkable number of the 5- to 6-year-old kindergarten children were able to restructure their naïve ideas about gear functioning into adequate concepts in a single play session of 45 min. In kindergarten practice, however, the *gear learning environment* should be made available to children over a longer period of time and on a regular basis, thus increasing the potential for learning. All in all, the results of our study suggest that guided play can provide a favourable learning opportunity for children, allowing them to acquire science and engineering knowledge. Our study is a first step to further investigate how playful activities in kindergarten can promote young children's engineering thinking, e.g. planning solutions, constructing, testing and optimizing devices to solve engineering problems.

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Chapter 17
Transformation of Young Children's Minds, Lives, and Society Through Science, Technology, Engineering, Arts and Mathematics (STEAM) Play About Water

Manabu Sumida

Abstract This chapter describes a Science, Technology, Engineering, Art, and Mathematics (STEAM) activity about water for four- and five-year-olds that relates to the UN's Sustainable Development Goals (SDGs). In the activity, Japanese kindergarteners read a water-themed picture book and challenged STEAM activities that developed their curious minds and enriched their understanding of science in the context of the SDGs. The children thought about a model of water in a creative way, learned about water pollution and purification by using natural things, and they discussed natural disaster prevention through STEAM-oriented play. Through the activities that involved playing with water, kindergartners could also learn about breakwaters, dams, and the history of flood control in a community. These learning activities may provide a fundamental basis for comprehending how to achieve peace and well-being as well. In twenty-first century society, which is highly information-oriented, it is important for children to acquire science literacy to prevent information poverty, as well as to acquire the competencies necessary to become practical innovators and collectively create new values and a better society. Integrated STEAM play involving familiar communities and cultures has great potential.

Keywords STEAM · SDGs · Interdisciplinary studies · Water · Innovators

17.1 Introduction

Japan has a unique history of science education (Murakami & Sumida, 2014), as indicated by the Japanese word 科学技術 (*kagakugizyutsu*) which refers to techno-science (one word), rather than science and technology (two different words). The word's language-culture origin of this Japanese word indicates the embedment of science and technology in each other (Sumida, 2012). Right from its inception in 1886, the Tokyo Imperial University, the first university to be established in Japan,

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included the College of Engineering. Further, Kyoto University, which was established in 1897, boasts of having employed the largest number of Nobel Prize–winning Japanese scientists to date (8 out of 22). It has three times the number of students in the faculty of engineering than in the faculty of science, and notably, the university's mathematics department is included in its faculty of science as separate departments of physics and astronomy, Earth and planetary sciences, chemistry, and biological sciences.

Japan has a rich cultural and historical background in science, technology, engineering and mathematics (STEM) education. Nevertheless, Japanese female high school students have been reported to have the lowest science self-concept in advanced industrial countries (Sikora & Pokropek, 2012). Further, a high degree of gender segregation in participation in science, technology, and engineering subjects is prevalent in Japan, South Korea, and Taiwan (Peng et al., 2017). Leibham et al. (2013) conducted a longitudinal study on young children's science interest, self-concept, and achievement among two cohorts of ages four and six years and six and eight years. They found that girls' early intense science interests were related to higher science self-concepts and science achievement at the age of 8 years. Further, both boys and girls showed significant coefficients between science achievement and leading achievement.

In this chapter, I discuss the introduction of a water-themed picture book as the first activity for young children in science, technology, engineering, arts, and mathematics (STEAM). STEAM education integrates the importance of early learning in both literacy and mathematics and science in a connection with technology and engineering (Moomaw, 2013). High-quality children's literature supports the introduction and examination of STEM concepts in early years (Ruzzi & Eckhoff, 2017). Science learning significantly benefits from literary activities, and literacy learning is enriched by the skills and concepts emphasized by scientific inquiry (Pearson et al., 2010). Many scientists, mathematicians, and engineers consider several skills deemed important in arts, such as drawing on curiosity, observing accurately, perceiving an object in a different form, and thinking spatially, vital to scientific success of (Sousa & Pilecki, 2018). Sumida (2012) contrasts Japanese and Western worldviews of 'Nature' from their different language-culture cognitions and proposes that the consideration of science education as second language (language of science) education can facilitate discussions on early science learning to satisfy diverse needs in a broad and practical context in today's society.

In the twenty-first century, interdisciplinary studies spanning sciences, technology, engineering, and mathematics are necessary not only to acquire new knowledge but also to solve global issues, maintain peace and spearhead social development. The United Nations (2015) proposed 17 Sustainable Development Goals (SDGs) to transform our world by promoting prosperity while protecting the planet under its 'leave no one behind' policy. These goals recognise that efforts to end poverty should go hand in hand with those to ensure economic growth and address a range of imperative needs, including education, health, social protection, and employment opportunities, along with addressing problems of climate change and environmental protection. Woodhead (2016) insists that strengthening early childhood development is key to achieving the SDGs. Further, it is important to close the gap between global policy and the development of the youngest citizens in a way that is most relevant and useful to them (Gove & Black, 2016). Regional differences and intra-region inequalities should be addressed, as well, to facilitate the complete development of children's potential (Barros & Ewerling, 2016). To address the ever-increasing challenges posed by environmental crises, poverty and inequity, and domestic and armed conflict, one should adopt a transformative approach to early childhood development (The thematic group on early childhood development, education, and transition to work, 2014, p. 3).

17.2 Early Science Education in the Japanese Context

The Japanese word 幼稚園 (*Yoochien)*, which is usually translated as kindergarten in English, refers to a school that provides pre-primary education to children aged 3–5 years. In 1956, the Japanese Ministry of Education enacted the 'Course of Study for Kindergarten', which provides legal guidelines for the education of all children aged 3–5 years in public and private *Yoochiens*. These guidelines are known for their remarkably child-centric approach and for emphasising the important role of children's spontaneous play activities in their early education (Sumida, 2013). The standards cover five areas, health, human relationships, environment, language, and expression, and incorporates science education in the area environment (MEXT, 2017). In this area, the main goal is to foster children's abilities to relate to their environment with a spirit of curiosity and inquiry and enable them to incorporate such skills in their daily lives. This goal can be divided into three specific aims:

1. Develop children's interest in and curiosity about various kinds of natural events and phenomena by enhancing their familiarity with the surrounding environment and contact with nature.
2. Initiate interactions between children and their surrounding environment and enable them to enjoy making and discovering new things and incorporating them into their lives.
3. Enrich children's understanding of the properties of things, concepts of various quantities, meanings of written words, and so on, by enabling them to observe; think about; and address events in their surroundings, natural phenomena, and personal experiences (MEXT, 2017, p. 14).

These aim to develop children's interest in and curiosity about various events, develop their familiarity with natural things, enhance their emotional sensitivity to such things, and promote the children's spirit of inquiry by facilitating their interaction with the environment. They include science, technology, engineering, arts, and mathematics (STEAM) contents in the Japanese context, as well. For example, the national curriculum standards encourage 'Leading a life in close contact with nature, being aware of its grandeur, beauty and wonder', 'Being in contact with various things in their lives and developing an interest in and curiosity about their property and structure', 'Being aware of seasonal changes in nature and in people's lives', 'Developing and incorporating an interest in things surrounding them, such as nature', 'Acknowledging the importance of life, and appreciating and respecting it through experiences of becoming familiar with local animals and plants', 'Being familiar with different cultures and traditions of Japan and the community in their daily life', 'Developing an interest in surrounding things and play equipment, thinking about (comparing and relating) them and challenging them to create ways to make the best use of these', and 'Developing curiosity about the concepts of quantities and diagrams in everyday life' (MEXT, 2017, pp. 14–15).

Accordingly, Japanese kindergartens currently offer many activities aimed at 'getting close to nature'. For example, children often grow plants and raise small animals in kindergartens. They are taken on hikes to explore their environment and find birds, bugs, fish, flowers, grasses, trees, and so on. Moreover, their daily spontaneous play activities enable children to learn from working with various materials, including water, sand, mud, clay, and blocks. These activities adhere to the aims of integrated STEAM education and SDG education in the Japanese context (Sumida, 2017).

17.3 Learning About Water

In this study, water was chosen as the content of STEAM education programmes targeting children in their early years. Even in educational programmes targeting young children, scientific activities focusing on water often include contents such as the physical properties of water and other physical science concepts. For example, Chalufour and Worth (2005) proposed a science curriculum that promotes practical teaching planes on 'flow', 'drops', and 'sinking and floating'. Further, Harlan and Rivkin (2004) suggested that the curriculum includes the change of states and dissolution and scientific activities focusing on the following eight scientific concepts: 'water has weight', 'water's weight and upward thrust help things float', 'water goes into air', 'water can change forms reversibly', 'water is a solvent for many materials', 'water clings to itself', 'water clings to other materials', and 'water moves into other materials'. Devonshire (1991) gives an example of introducing some basic scientific principles even when factoring of art positively into scientific activities about water.

Even when scientific concepts form the core of the curriculum, the learning process itself is emphasized over these concepts in some cases. Hoisington et al. (2014) introduce four types of questions: questions that (1) support descriptions of observations, (2) support explanations of procedures, (3) support the making of predictions, and (4) spark children's reflection and stimulate their spirit of inquiry and investigations on sink-and-float phenomenon. Another curriculum encourages children to perform concept mapping by using key words, such as 'flow', 'found in nature as', 'has three states', 'changes states by', 'which is called', 'dissolves', and 'does not dissolve', to develop vocabularies and experience the wheel of scientific investigation and reasoning that includes 'make observations', 'ask questions', 'learn more', 'design and conduct the experiment', 'create meaning', and 'tell others what was found' to enhance children's ability to perform higher-order thinking (College of William & Mary, 2008).

Some studies have contrasted the scientific activities targeting young children, which emphasize scientific concepts and logical thinking, followed in Western countries with those implemented in Japanese kindergartens. Fukada et al. (2005) introduce a traditional Japanese kindergarten education system that emphasizes 'educating through the environment' and implements both 'sink and float' activities that were adapted from the Western curriculum and the 'rain gutter activity' that was adopted from Japanese play. Further, they discuss the importance of combining these different approaches to achieve high-quality science education during children's early years. Harlan and Rivkin (2004) propose the inclusion of mathematical experiences such as 'weather charting', art-based activities such as 'weather mobile' and 'rain painting', and creative movements in their science activities focusing on water as an integrated affective approach.

Moreover, integrated science, technology, engineering, arts, and mathematics (STEAM) education is appropriate to implement scientific activities for young children in a glocal (global + local) context (Sumida, 2017). Such efforts adhere to the Sustainable Development Goal (SDG) concept of 'leave no one behind', as well. Water is a significant aspect of the SDGs, as evidenced by Goal 6: Clean water and sanitation, Goal 3: Good health and well-being, Goal 2: Zero hunger, Goal 11: Sustainable cities and communities, Goal 13: Climate action, and Goal 14: Life below water. The integrated STEAM play introduced in this chapter has significant potential to advance STEAM education not only in Japan but also in a global setting.

In this chapter, I introduce a sample programme that combines the use of a water-themed picture book and STEAM activities to be implemented for 4–5-year-old children in a Japanese kindergarten to develop the curious minds of children and enrich their understanding of science in connection with SDGs.

17.4 STEAM Programme Focusing on Water to Transform Young Children's Minds, Lives and Society

Nakajima et al. (2016) claim that one of the powers of picture books in early years' education is 'fostering interest in and knowledge of unfamiliar worlds and developing concentration in the process'. First, I selected a picture book that includes scientific elements, draws children's interest, and can be easily expanded to a variety of activities based on the content. The title of the book was 'The Raindrop's Adventure (Terlikowska, 1965)'. This is a story that expresses a range of emotions, following the adventure of a drop of water evaporating and precipitating again as rain. Since the raindrop speaks in the same language and has the same emotions as humans, it gives children a sense of being on the adventure together with the raindrop, drawing them into the world of the story. In addition, water is a familiar matter, and it has several different properties, which can be used to create play activities from a variety of perspectives.

After reading the picture book, children did a physical warmup before the various activities. Specifically, this involved reviewing scenes from the story while performing physical movements pretending to be the drop of water. The children expressed four scenes from the story: when the sun shines on the drop of water and it evaporates, when it solidifies into ice, when the temperature increases and the frozen water drop sends the rocks around it flying, and when the drop of water spins around and around in a washing machine. For the evaporation scene, the children raised both arms and stood on their toes to demonstrate water rising up into the sky when the sun shines down on it. For the ice scene, the children crouched on the floor, curled up in tight balls, and shivered to express freezing. Next, starting from the ice condition, everyone jumped up powerfully at once to express the explosion scene. For the washing machine scene, the children raised their arms and spun around on the spot to show water spinning in the washing machine. From this activity, they learn that water does not stay in one position; instead, it moves through a variety of processes and is in constant circulation (Fig. 17.1).

Children have the ability to test and apply scientific thinking in their imagination through play, and carrying out real-world activities helps make a lasting impression on their minds (Brown & Craik, 2000). Here, four main activities are introduced based on the theme of water: ‘Story Relay’, ‘Let’s Make Coloured Water’, ‘Let’s Clean Dirty Water’, and ‘Let’s Make a River’. The activities were put into practice with 4–5-year-old children in a Japanese kindergarten.

Fig. 17.1 Picture 1: Embodiment of Water 1: Evaporation; Picture 2: Embodiment of Water 2: Condensation

17.4.1 'Story Relay' Activity

In this activity, children used pictures to link two images, making up their own stories about the drop of water. Thinking up an original story is also an activity that enables creative expression.

The items used in this activity are drawing paper and crayons or markers. Children are shown two pictures: one of a clean water droplet and another of a dirty droplet of water. They are asked to imagine what could happen between the two droplets and express their story with a drawing. The story begins with a dirty droplet of water in a river and the end depicts a clean droplet of water coming out of a tap. Each child had to think what the droplet underwent to become clean and draw a picture on a sheet of drawing paper to express their story. The following are some of the stories the children drew on the paper (Figs. 17.2, 17.3, 17.4, and 17.5).

Fig. 17.2 Story Relay: What could happen between the two droplets?

Fig. 17.3 Dirty water containing trash flows from above, but the current splits it midway, with the rubbish going in one direction and clean water in the other. Only the clean water comes out of the tap. The face of the water drop is drawn in the middle, showing that the droplet is passing through the centre

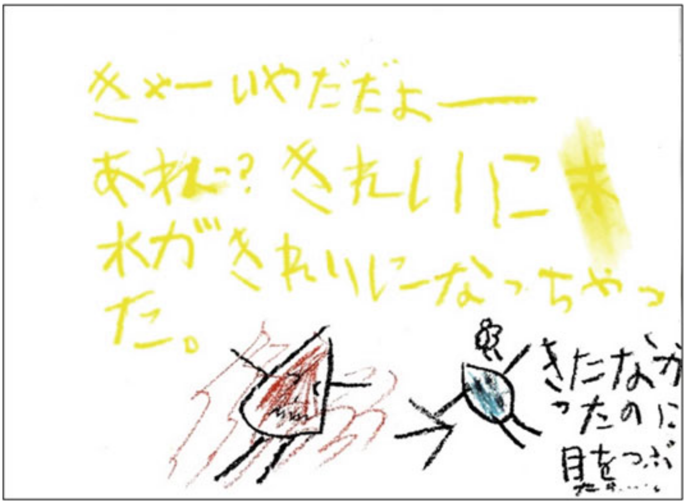

Fig. 17.4 As the drop of water flows along the dirty river, it closes its eyes to become clean, then comes out of the tap

Most of the pictures were drawn using two colours to represent water, light blue or dark blue for clean water and brown for dirty water, skillfully linking the dirty river in the first picture with the clean water in the second. Many children used green to express grass and pink for flowers. Some of the children knew about waterworks facilities such as dams and pipes, and they used this knowledge to draw water flowing through pipes. A few of the children even considered the filtration process inside a pipe. There were some pictures with unique ideas, such as a carpet that removes rubbish and a pipe that splits into two, with clean water coming out of one side. During the activity, children used a variety of approaches, such as working silently by themselves or drawing together with their friends. The children who drew in groups were observed showing their finished pictures to friends and trying to explain their ideas. The children frequently took initiative to share their opinions, especially when talking to their preschool teacher.

This kind of activity allows children to confirm whether things actually happen as they imagine and connect multiple ideas to create a story. Placing cups of sea water, muddy water, or juice in direct sunlight for observation can enable children to recognize the phenomenon of evaporation. If the local area had been a salt field in the past, it would be meaningful to learn about the production of sun-dried salt in those days.

Fig. 17.5 The right side shows dirty water flowing from above. Then, the water makes a U-turn to the left, transforms into clean water, and comes out of the tap. In the river, rubbish is drawn flowing along with the water

17.4.2 'Let's Make Coloured Water' Activity

The Story Relay activity covered how dirty water becomes clean. Adding colour to water is another extremely interesting activity for children. A variety of familiar flowers and plants can be used with common tools to make coloured water. This activity enables children to notice how the colour released varies depending on the type of flower and part used and to explore ways of producing colours. By mixing coloured waters together and changing the concentration of colours, children can recognize the dissolving, solvent, and mixing properties of water. This also elicits children's interest and imagination to think, 'I wonder what colour this flower will produce'.

For this activity, a mortar and pestle, cloth, plastic bottles, plastic bags, and a plastic egg box or a similar container are used. Children were asked to pick flowers from the preschool garden, a nearby public park, or from their home, place them inside a plastic bag, add water, and rub. When the colour is released, they were asked to put the water into the container.

The coloured waters shown below were made with mirabilis jalapa, sage, pink wood sorrel, and wood sorrel. The leaves and flowers were separated, and the colours were extracted from the leaves and flowers of each plant by rubbing or grinding. The leaf or flower was placed in a plastic bag with water and rubbed by hand until colour appeared. Alternatively, the flower was placed in a mortar and pestle with a small amount of water and ground into a paste. If sufficient colour was extracted by rubbing, grinding was not performed. It was harder to extract colour from leaves than from flower petals for all the plants, but colours were successfully extracted using the grinding method. In addition, it was easier to extract colour from soft flowers with high water content (mirabilis jalapa, wood sorrel) than from hard flowers with low water content (sage, pink wood sorrel). Mirabilis jalapa flowers produced especially vivid colour with rubbing alone. Some of the waters changed colour or turned clear when left to sit for about three days (Fig. 17.6).

The children enjoyed using the coloured water they prepared by pretending they were juice drinks and used them to play shop. They also tried using the coloured waters to paint pictures or dye plain handkerchiefs or white paper bookmarks. Other fun activities included mixing different colours together, as well as observing how colours change over time.

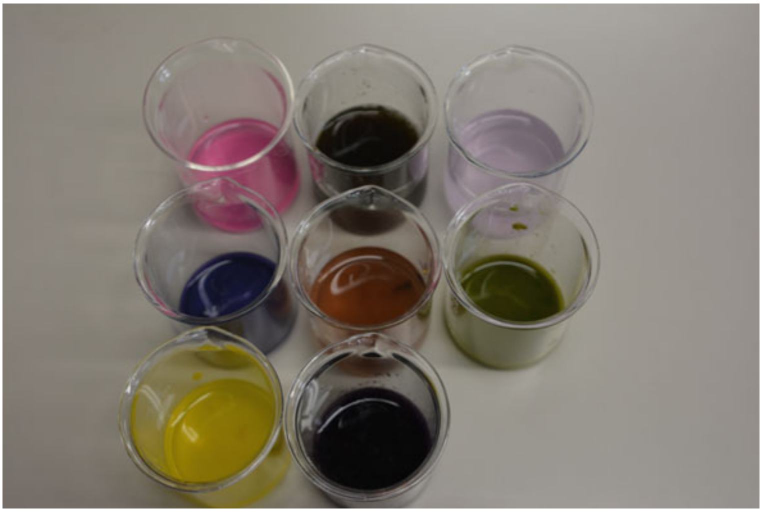

Fig. 17.6 Coloured Waters from Plants

17.4.3 'Let's Clean Dirty Water' Activity

In this activity, we created a simple water purifier using sand and pebbles to see if it can clean muddy water. By using a transparent plastic bottle to make the purifier, children can observe the muddy water passing through it and coming out clean.

The items needed for preparation were a plastic bottle, cotton wool, activated charcoal, pebbles, and sand. First, the base of the bottle was cut off. Then, we opened the cap of the plastic bottle and stuffed the cotton wool in to plug it. The bottle was then upended and filled with pebbles, cotton wool, activated charcoal, and sand, ensuring that there were no gaps. Using the cut-off base of the bottle as a holder, the water purifier was inserted to prevent it from falling over.

In a preliminary experiment, we made two types of plastic bottle water purifiers with different degrees of purification and covered them with drawing paper, so that the contents of the bottles could not be seen. The teacher then poured muddy water into the two bottles and the children observed the difference in the purification levels. One was a simple water purifier with layers of pebbles and sand, and the other was a more efficient water purifier containing cotton wads and activated charcoal in addition to the pebbles and sand. When muddy water was poured through the simple water purifier, the children commented "it's only a little bit cleaner." However, when the muddy water passed through the more efficient purifier, the children—noticing the difference from the first purifier—exclaimed in surprise, "What? It's cleaner than before!" and "It's transparent!" The children were curious about the hidden contents of the bottles. When the covers were removed, they observed the bottles closely and made various discoveries about the different contents and quantities and told their teachers what they discovered. Some children showed interest in the sand and activated charcoal and examined them by touching them (Fig. 17.7).

The children then created their own water purifiers based on their ideas related to the efficient purifier. They created one purifier each and upon completion, muddy water was poured through them. Some children adjusted their eye level to the bottle and intently watched the clean water, while others in their observations noticed that the slower the water came through, the cleaner the water came out. The children were given a sheet of drawing paper with an illustration of an empty plastic bottle and were asked to draw a picture of how they imagined that the muddy water became clean as it went through the bottle. Some of these results are presented in Figs. 17.8 and 17.9.

Many of the children drew pictures of the materials inside the bottles. The pictures showed a change in their perception of purification, compared with when they participated in the "Story Telling" activity. One child suggested that the dirty water droplets turned clean by closing its eyes in the "Story Telling" activity; however, after making their own plastic bottle water purifier in the "Let's Clean Dirty Water" activity, they realised that it was the materials inside the bottles that purified the water. When they did the "Story Telling" activity, they did not consider how the dirty water became clean. After creating the water purifiers, some children started thinking about the

Fig. 17.7 Self-made Water Purifiers

purification process, such as imagining clean water running down the sides of the plastic bottle.

Through these activities, children can design various water purifiers by changing the materials, their order, and their quantities. They can thereby investigate the effectiveness of water purification by pouring something other than muddy water through their bottles. They will become interested in how tap water, an essential part of our daily life, is purified and learn how water is cleaned every day. This will also help them realise that water is a limited resource.

17.4.4 'Let's Make a River' Activity

Compared with other countries, many kindergartens in Japan have large sandpits on their playgrounds. These sandpits are a great for learning the mechanism and behaviour of waterflow in a river. By building a dynamic river in the sandpit, children learned that water flows from high to low elevations; they also observed the scouring and transporting properties of water.

The items needed for preparation were a gutter, a board or chair (to hold the gutter in place), and a bucket or similar container to carry the water. During this activity, the children thought and worked together to build a river using the tools they had prepared and the objects they found around them. They discovered that to make the water flow well, the river needed to have a gradient, and that the water flowed faster if the gradient was increased. When the flow of water became rapid, the sand banks that were initially built collapsed. This helped the children to gain a better understanding

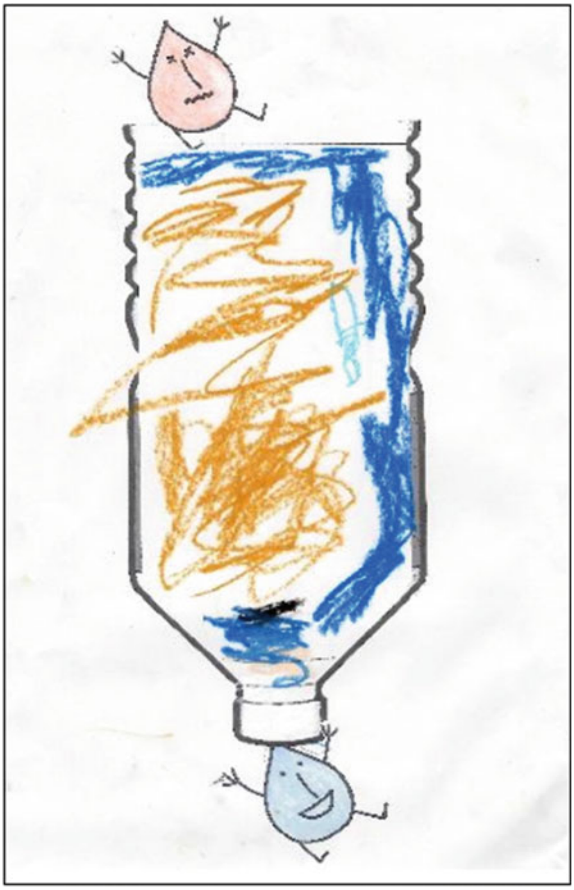

Fig. 17.8 The drawing shows clean water flowing down the sides and muddy water passing through the centre of the bottle. The child said that the water that came out of the plastic bottle was just clean water that had passed down the sides

from the changes in the shape of the sand of whether the inside or the outside part of the river collapsed, and how the sand collapsed. By thinking about where the water runs, they were able to visualise the water cycle (Fig. 17.10).

In the area where this kindergarten is located, a river has flooded many times with heavy rain damage in it's history. Due to the short distance between sea and mountains in the area, and the great height difference between sea level and the summit of a mountain, the amount of water is usually small, but heavy rain can cause a lot of flooding. The Shigenobu River gets its name from the achievement of 'Adachi Shigenobu', the individual who repaired the river, a very rare instance of naming a river after a person in Japan.

Through enabling a connection between their own river and real rivers familiar to them, this activity also taught them about scale and the local area. Children naturally become interested in the local history of the river and advances made through engineering. In addition, varying the amount of water helped the children to imagine

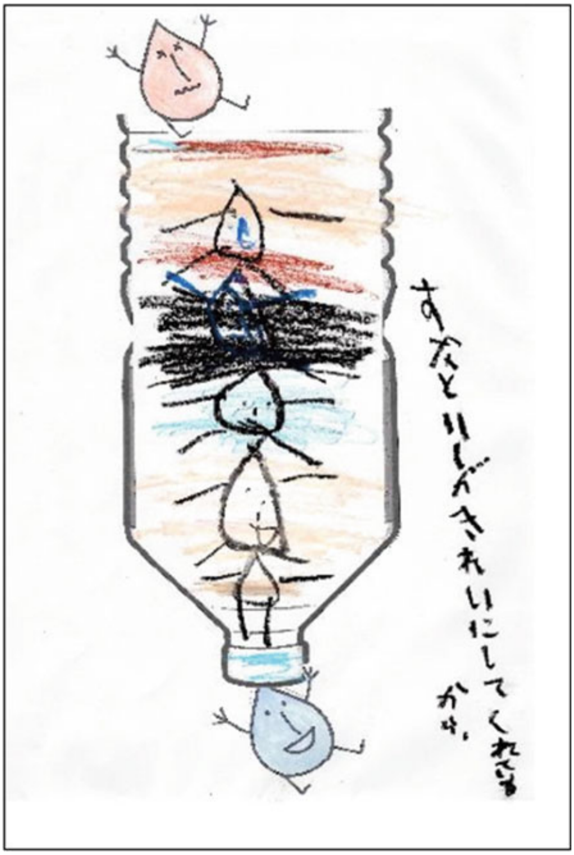

Fig. 17.9 The sand and pebbles made it clean

natural disasters and their effects and to think of ways to prevent water shortages and flooding, such as dams and breakwaters.

17.5 Conclusion and Recommendations

The Earth is sometimes referred to as ‘the water planet’, with animals and plants dependent on water for their survival. About 60% of the human body is made up of water, and water is indispensable to daily life. Water even dictates how our food tastes. Water serves as both a familiar and new learning topic for young children and is suitable for STEAM education.

While most water-themed activities involve learning about the scientific properties of this matter, here I proposed beginning with ‘being read to from a picture book’ followed by ‘embodiment’ activities. As mentioned earlier, there are few women in the STEM field in Japan. However, both boys and girls love being read to from

Fig. 17.10 Children's River in the Sandpits

picture books, and young children actively participated in this activity regardless of gender, with many girls showcasing their creativity in the subsequent 'Story Relay' activity. These activities are related to both science and the arts. Children actively participated in activities where they made coloured water using familiar plants. The fact that the colours which can be extracted differ depending on the type and part of the flower can be thought of as a play activity related to science and extraction technology. Moreover, learning that the colour of the water changes over time is tied to mathematics. Play activities that resulted in the creation of a simple water purifier made from sand and pebbles are centred on technology- and engineering-related learning. Through considering the size of the grains used for the filter of the purification device and quantifying the water quality, mathematics learning may also be included. In fact, many children's homes have water purifiers installed. Children's questions extended to water purification plants, water purifiers, and differences in the taste of various mineral waters. The last activity, entitled 'Let's Make a River' is a science activity that involves learning about the 'erosion' and 'transportation' effects of rivers, with technology, in the form of dams and breakwaters, and the arts, in the form of local history, also playing a part. With all of these activities, 'sense of beauty', 'communication', 'discovery', 'natural hazards', 'design', 'performance', 'innovation', 'creative thinking' and similar terms are also included as keywords for learning.

The water-themed activities introduced in this chapter have many important implications from an SDGs perspective. First, Goal 6 of the SDGs is 'Clean Water and Sanitation', with new ideas and actions sought to address water shortages, poor water quality and inadequate sanitation. Goal 12, 'Responsible Consumption and Production', points out the importance of conserving water resources. Water is also the key to thinking about agriculture, forestry, and fisheries while protecting the global environment with relation to Goal 2, 'Zero Hunger'. Furthermore, water is important from the viewpoint of improving sanitation according to Goal 3, 'Good Health and Well-being', and Goal 11, 'Sustainable Cities and Communities', through which we see that it is necessary to consider issues related to urbanization, such as fresh water supply and proper sewage treatment. Goal 13, 'Climate Action', points out the rise in seawater temperatures, while Goal 14, 'Life below Water', emphasises that managing the seas as a global resource requires problem solving through global cooperation. Above all, however, providing an interdisciplinary, developmental, and innovative STEAM education program that connects these communities with the world from early childhood is tied to Goals 4, 'Quality Education', 5 'Gender Equality' and 17 'Partnerships for the Goals'.

It might be difficult to discuss 'age appropriateness' in STEAM education only from this case activity because it was a pilot study only for 4–5-year-old children in a kindergarten, the activity was conducted in a free-play context, and there might be individual differences as well. Learning about 'water', however, has the potential to greatly expand and deepen early childhood learning based on the STEAM educational model and is also critically significant in fostering innovators who will create new value and citizens who will collectively create a better society. To build a healthy, happy, and hopeful future as the bearer of a better society in an era of great change, children's education should connect the past, present and future through modern, high-quality learning beginning in early childhood, with familiar communities and cultures connected to the world.

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Chapter 18
Early STEM Implementation in PreK and Kindergarten in Mexico

César E. Mora Ley

Abstract The multidisciplinary approach to student exploration in Mexico places high priority on developing science, technology, engineering, and mathematics (STEM) skills aimed at facilitating students to think and act as scientists and engineers during their earliest experiences of play. These hands-on, minds-on activities make STEM disciplines both fun and interesting for young children, developing skills such as creativity, problem-solving, innovation and invention at an early age. Development of these skills during the early years is essential in order for students to be comfortable with and engaged in STEM in their later academic years, igniting a life-long love of exploration and learning. This chapter describes our use of the Lipman Philosophy for Children to incorporate STEM challenges into the PreK and Kindergarten curriculum in Mexico, including student opportunities for play and discussion. Descriptions of face-to-face activities as well as virtual workshops conducted online are provided.

Keywords STEM challenges · Philosophy for children · Problem-solving · Innovation · Invention

18.1 Introduction

In Mexico, the first school level is preschool/kindergarten which focuses on children from 3 to 6 years old. The Secretary of Public Education (2017) coordinates the Preschool Education Study Program (PEP) which organizes Preschool Education in six training fields: Language and communication; mathematical thinking; exploration and knowledge of the world; physical and health development; personal and social development; and expression and artistic appreciation. Preschool teachers must design didactic situations respecting the focus of each educational field so that each child meets the graduation profile. Likewise, each training field must be treated in a balanced way. However, the reality is that teachers tend to dedicate more time

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to two of the six fields: language and communication and mathematical thinking (Franco, 2018). Unfortunately, the field of exploration and knowledge of the world, which has a lot to do with STEM education, does not receive adequate attention. The problem is that many preschool teachers lack a solid science education training and often think that children are too young to understand natural phenomena (Nieto, 2015). Therefore, this field is one of the least taught areas. We consider that this situation can be improved by providing additional training to preschool teachers in scientific subjects, using teaching resources specially designed for children of preK (3 years) and Kindergarten (3–6 years). This chapter describes some of the STEM activities that have been developed for preschool children in Mexico, many of which use scientific toys in science "centers of interest." It should be noted that this type of educational proposal with young children was inspired by programs such as "Einstein's Box" that includes educational activities for children from 1 to 6 years old, and in the working experience of preschool education from those trained in graduate programs in physics education research at the National Polytechnic Institute of Mexico.

Additionally, there is a very successful methodology for the development of philosophical competences in children developed in 1968 by Lipman (2008), known as Philosophy for Children (FpN), in which through an initiation to philosophical dialogue, children learn how to ask questions and how to answer them, and seeks to develop critical thinking in children to encourage them to be more independent in their decisions. This was the starting point of Lipman in 1968, when he found that his high school students, and even his fellow philosophers, did not know how to think correctly, which he believed blocked them from making adequate decisions. Lipman identified the complicated problem regarding modifying the way of thinking in an adult, and therefore, he decided to focus on children, and thus with the collaboration of several philosophers, he developed a philosophical program for children and adolescents from 3 to 18 years old which it has been very successful worldwide. Lipman had a very active collaboration in Mexico resulting that the philosophy for children's programs has had a great acceptance in the Mexican school since the 1980s.

The last section of this chapter presents how we have used the Lipman methodology to teach science to children from 4 to 5 years of age, and how we have carried out STEM projects for them with the collaboration of their parents. Furthermore, our results about the development of the Mexican Philosophy for Children for science teaching and learning in times of social confinement due to sanitary restrictions imposed by the Mexican government during the epidemic of the SARS-CoV-2 (COVID-19) virus. We have investigated the usefulness and application of Lipman's Philosophy for Children to introduce scientific topics, and we have found it to be extremely useful for teachers and students, even while doing activities at a distance.

18.2 STEM in PreK and Kindergarten in Mexico

The kindergarten age of 3–6 years is basically a stage of questions with a continuous and eternal, why? where the child will build the foundations for his development of cognitive, social, and affective skills throughout his life. During his transit at school, the child must learn to live with his peers, to be in solidarity, to share experiences and emotions, to express himself through language, to observe reality, to be amazed at new things, to seek answers, to listen, work together, hypothesize and experiment. Therefore, some science goals for kindergarten children are as follows (Secretaria de Educación Pública, 2011):

i. Contribute and promote interesting ideas in children.
ii. Increase children's understanding of their physical and biological environment and identify their place in it.
iii. Promote awareness of the role that science has in everyday life: Help children in their interactions with the world; for example, in relation to health and safety, making things work or caring for living things.
iv. Encourage critical thinking: respect for evidence and interest in the environment.
v. Develop positive attitudes and approaches to learning, and support students to "Learn to Learn."
vi. Promote a foundation for future science learning.

STEM education in kindergarten is not intended to train small scientists, but to help children develop scientific skills through practice, which is achieved through the use of toys or teaching tools. Thus, through dynamics, usually in teams, students create connections between the different STEM disciplines to solve a problem according to their level. An indispensable aspect to carry out the learning activities is that they be fun and creative (Rodriguez & Ketchum, 2000). Robotics for preschool is a very fruitful tool to help students develop scientific skills by exploring basic technology concepts, codes, sequences, conditions, and repetitions. In general, it can be said that the characteristics of STEM tools for preschool should (Sullivan & Umaschi, 2016):

i. Be playful and creative; the child has to have fun to work with the material during the appropriate periods.
ii. Promote the development of transversal knowledge that covers more than one competition. For example, covering engineering and technological areas at the same time.
iii. Involve computational programming for basic education, which is not yet part of the study plans.
iv. Be designed for a specific age and school level.

Preschool teachers are free to approach the instruction of young children according to their own opinion and experience. Therefore they must be trained in STEM disciplines to help the child generate new knowledge through simple activities that contribute to the construction of thought and promote their comprehensive training through activities that encourage reflection, creativity, curiosity, patience, communication skills, attitudes, and values, in the context in which they operate.

It is also important to include school visits to interactive museums, science fairs, industries, laboratories, universities and research centers, which can help young learners recognize the importance and usefulness of STEM disciplines in real life, as well as motivate them to study scientific topics and ask questions to scientists, technicians and engineers. The development of STEM projects and their exposition in class provides children with the opportunity to express their ideas and learn to answer questions related to their project or those of their peers, in this sense it would be interesting to introduce project competencies of STEM as motivation to students, teachers and parents (Varela, 2005).

18.3 Centers of Interest in Science for Kindergarten

The centers of interest emerge from the new school with Decroly (Decroly & Monchamp, 2002), encompassing both respect for the child's own aspirations and the pressures of intellectual training. In order to develop the centers of interest, Decroly proposed three types of exercises through feeling, thinking and expressing:

i. Observation: The student establishes direct contact with objects and situations; the child obtains knowledge by observing the environment with the help of the teacher.
ii. Association: The student relates in space, time, in their reactions, in the cause-effect relationship.
iii. Expression: The student exercises reading, calculation, writing, oral expression, drawing, manual work, etc., everything that allows them to express their thinking in a more accessible way.

> The Decroly method is based on the discovery of the interests and needs of children, this will make children protagonists of their own learning, having a motivation from the first moment as they can promote their learning with concepts that will appeal to them. By feeling motivated, they will have more attention and they will be the children who are capable of seeking knowledge by enhancing learning. (Gasso, 2007, p. 51)

Decroly's pedagogical principles are as follows (Castillo et al., 1998):

i. Place the child in a suitable environment.
ii. Provide stimulating activities.
iii. Ensure that the end you want to reach is in proportion to the abilities of the children.

These experiences, while maintaining the pedagogical principles, seek to contribute to the development of autonomy, creativity, expression, promoting a warm climate that favors affectivity and personal acceptance. The implementation of the centers of interest implies an organization of space, time and materials. The duration of each center of interest is usually short, and implies a distribution of space where all children are encouraged to participate in each one of them.

"In the center of interest all activities are focused on the operational core or work topic and in programming the teacher globalizes the content to the maximum and therefore establishes activities of all kinds related to the topic: conversation, graphics, plastic techniques, perception, sensory exercises, experimentation, written language, qualitative relationships, measurement, topology and geometry, memorization and music. The methodology proposed by Decroly is based on the implementation of a prototypical sequence for all activities: observation, association and expression" (Gasso, 2007).

Although Decroly's proposal for centers of interest was made in the last century, it is currently still useful today. It has been used to develop activities focused on four training fields including: Personal and Social Development; Language and Communication; Mathematical Thinking and Exploration; and Knowledge of the World.

It is in this last field, where through the use of STEM type toys, some situations can be designed in order to get children into science topics. Franco (2018) comments that the other training fields of kindergarten are also taken up because it starts from the idea that by developing thinking skills, these will collaterally favor the other training fields.

18.4 Some Successful STEM Activities in Kindergarten

In Mexico, STEM education in Kindergarten takes place in order to attend to the training field focused on the development of reflective thinking, and seeks to inspire children to put in practice the skills of observation, formulating questions, solving problems and preparing explanations, the formulation of hypotheses, inferences and arguments based on direct experiences, observation and analysis of the phenomena of nature that help them to advance in their training by developing critical and creative reasoning skills, in order to give explanations of objective reality. Also, it is sought that the child develops awareness about environmental problems and worries about preserving it. Table 18.1 shows the different fields of education for children in kindergarten in Mexico.

Based on the structure shown in Table 18.1 and focusing on the field of "Exploration and Knowledge of the World," which is where we can integrate science and STEM topics, the information below provides some simple examples developed by kindergarten teachers who have graduated from the master's in physics education of the Research Center in Applied Science and Advanced Technology of the National Polytechnic Institute.

The first example experience is related to movement and was implemented with 3rd year preschool children (5–6 years). Four activities related to the concept of movement will be presented, along with three STEM-type projects that involve

Table 18.1 Training fields of the Preschool Education Program 2011 in Mexico

Training fields	Aspects in which it is organized
Language and communication	• Oral language • Written language
Mathematical Thinking	• Number • Shape, space and measure
Exploration and knowledge of the world	• Natural world • Culture and social life
Physical development and health	• Coordination, strength and balance • Health promotion
Personal and social development	• Personal identity • Interpersonal relationships
Artistic expression and appreciation	• Musical expression and appreciation • Body expression and appreciation of dance • Visual expression and appreciation • Dramatic expression and theatrical appreciation

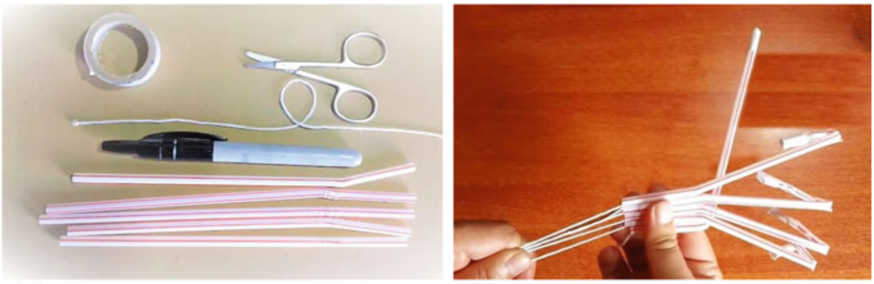
the construction of a mechanical hand (Franco, 2018, pp. 55–56) as well as the construction of a propulsion car and another traction car.

18.4.1 Activity 1 "What Is the Movement?"

To begin the activity, participation criteria are disclosed, that is, when a partner speaks, the others listen; speaking will occur in turns respecting each other's thoughts; and that in situations where the partner does not want to speak, they will be respected. These ideals instill the idea that al participation is important, and that we work together with pleasure.

To start the conversation the following questions are asked: How does our body move? What makes our body move? How is it moving? What happens inside my body to make my hands, legs, head, eyes or lips move when speaking? The children's responses will be written on the board.

Later children view a video to see what happens in our body to cause movement, followed by discussing the information seen in the video. At the end of the lesson, the children are asked to record what they learned about the movement in their booklets. In addition, each child is asked to explain to their parents at home what they learned about movement.



(a) (b)

Fig. 18.1 (**a**) Materials from the "Robotic hand" activity, straws, black marker pen, yarn, scissors and tape. (**b**) Robotic hand already done

18.4.2 Activity 2 "My Body Moves"

The activity begins by explaining to the children that they will work in teams to visit four different centers and that they will spend 20 min in each center.

Descriptions of the four centers are provided below.

18.4.2.1 Center of Interest for Science (STEM Project)

In this center of interest, children will be assisted to develop a robotic hand, questioning at the end: What makes you move your fingers?, and Why do they move? And what was seen in the previous session will be recovered. Later, the children will be asked to record in their booklet how they made the robotic hand. This STEM project is carried out with flexible plastic straws, scissors, thread, adhesive tape and a black marker pen. Figure 18.1 shows the final shape of the robotic hand. These types of STEM projects can help students to understand body motion and the movement of other objects, such as a simple robotic hand and a small car with air propulsion or with rubber bands traction. Therefore, small projects of low-cost materials are useful to relate and develop different skills. The list of materials and final form of each project can be seen in the Figs. 18.1, 18.2 and 18.3.

18.4.2.2 Center of Interest for Mathematics

Children will be given a puzzle of the human body and asked to complete it.

18.4.2.3 Center of Interest for Language and Communication

Each child will be provided with images of girls or boys (according to their feminine or masculine gender) and they will write the names of the parts of the body that are marked.

18.4.3 Activity 3 "Trip Through the City"

The group is organized into small teams, remembering the participation agreements explained previously. Each team will be integrated into a center of interest and will remain there for 20 min, at the end of this time they will change to another center of interest. Each of the centers of interest in the "city" are described below.

18.4.3.1 Center of Interest for Science (STEM Project)

We will sit on the city mat and give each child a pull toy car and one that is not. Children will be asked to drive to different places in their car. For example: go from church to school, trying with both cars. Each child will take turns and as we pass, we will all question the following:

i. Do cars move the same?
ii. How did you get them to move?
iii. Is there something different about them?
iv. Why do you think they don't move the same?
v. How is the path they follow?

According to the children's responses, the teacher should try to shape concepts such as movement, trajectory and speed. Requesting the children to record what was observed in their booklets. In this part, the construction of a propulsion car can be done using a plastic bottle, 4 plastic caps, 3 plastic straws, 2 wooden sticks, scissors, silicone glue, 1 balloon, and 1 black marker pen. In Fig. 18.2, the materials and the finished car are shown.

18.4.3.2 Center of Interest for Mathematical Thinking

Each child will be given wooden blocks and asked to build different models.

18.4.3.3 Center of Interest for Language and Communication

The name of objects and places that are visible on the mat of the city will be formed using the mobile alphabet.

(a) (b)

Fig. 18.2 (**a**) Materials for the activity "Propulsion car", plastic bottle, straws, wooden sticks, black marker pen, silicone glue, scissors and a balloon. (**b**) The propulsion car already made

18.4.4 Activity 4 "Let's Play Big"

The group is organized into small teams remembering the agreements for participation. Each team will be integrated into a center of interest and will remain for 20 min. At the end there will be a change of center of interest until goal centers have been visited. Each center is described below.

18.4.4.1 Center of Interest for Science (STEM Project)

The mechanic workshop is played. Each child will be given a friction car and one without traction and will be asked to open them. At the conclusion of this task, the following questions will be asked:

i. What are they like inside?
ii. Are the pieces inside them the same?
iii. Do those pieces make them move differently? why?
iv. How are they alike? What makes them different?

Children are asked to record what they have observed and discussed, recording their comments in their booklets. The responses of the children will allow keeping track of the achievements.

In this center of interest, the children can also engage inanother STEM project, a "Traction Car." using some of the previous knowledge obtained or some innovation from it, along with tongue depressors, covers, plastic straws, wooden sticks, silicone, scissors, and rubber bands. In Fig. 18.3, the materials and the cart made are shown as well as a completed cart.

Fig. 18.3 (**a**) Materials to make a traction car: 2 tongue depressors, 4 screw caps, 2 plastic straws, 2 wooden sticks, silicone glue, scissors, and rubber bands, 2 discharged AA batteries. (**b**) The traction car already built

18.4.4.2 Center of Interest for Mathematical Thinking

Children will play in the infirmary where some children will take on the role of nurses or patients, recording the weight and height of each one and registering on their card.

18.4.4.3 Center of Interest for Language and Communication

Children will take the role of doctor and sick person in turn, checking the doctor's patients and making medical prescriptions.

18.5 Philosophy for Children

The Philosophy for Children is a successful methodology to promote the development of critical and creative thinking, therefore, we have adapted it to teach the STEM model to preschool students in Mexico, as there is a strong trend in Mexico to include the study of philosophy in preschool education (Sumiacher, 2020). Philosophy develops in children critical, creative and careful thinking (Nomen, 2018). The main reason it is good to learn philosophy from a young age is to teach them to think for themselves and to draw their own conclusions. Through philosophy one learns to think, to question, to draw conclusions, to apply critical responses to everyday problems and to live reflectively. The reflective method of philosophy helps children learn to be more reasonable people. It helps them understand and interpret the experiences of the world that surrounds them in an existential conscience that allows them to learn how to think, through their personal, family and social life relations, the interaction space where they are taught to learn. The objective is to educate children through philosophical practices of logical and hermeneutic reasoning that will allow them to develop creativity and imagination within conditions of freedom, where their personal growth will increase with each learning experience (Márquez-Fernández & García, 2007).

Philosophy for children is an educational proposal that provides children with adequate instruments just at the moment when they begin to wonder about the world and their interaction with it. It was designed by Lipman (2008) in the late 60s with the aim of taking the philosophy out of the academy and applying it to real situations of children and adolescents with the aim of helping them to develop critical thinking. It is a systematic and progressive program that starts from traditional themes of the history of philosophy and from everyday situations in the child's environment, which seeks to stimulate curiosity and wonder, by teaching them to listen and ask questions in order to develop complex thinking (high order thinking). They are taught to make value judgments, to give meaning to life, to be respectful, tolerant and supportive, as well as to integrate reasonably into society. It is not intended to turn children into professional philosophers, but rather to make them citizens with a critical, creative and careful attitude towards the other (caring thinking).

This is done through philosophical accounts that serve as triggers for philosophical discussion. There is a great diversity of books for teachers that provide different exercises for philosophical analysis. Also, there are national and international associations for the certification of the methodology, which provide a wide variety of training programs for teachers so that they can carry out Philosophy for Children in an efficient and fruitful way, managing to create investigative student communities.

In Mexico in 1993, the Mexican Federation of Philosophy for Children was created to ensure the quality and integrity with which the Philosophy for Children program is applied throughout the country. In addition, it seeks to make philosophy a compulsory subject in basic education in Mexico, since the cut of humanities subjects in the plans and programs of all educational levels has been overwhelming. This speaks of a great "silent crisis" of the world that Nussbaum (2010) pointed out well, which prevents the formation of "sound citizens, with the capacity to think for themselves, to have a critical view of traditions, and to understand the importance of the achievements and sufferings of others." This is precisely what education in Mexico sought to compensate with the Philosophy for Children.

In the specific case of science learning, it is interesting to consider the vision of Lipman (2013), who mentions that one of the areas where education fails is precisely the assumption that students learn only by knowing the answers to certain Scientific questions, because even knowing the correct answers, they do not know how to solve scientific problems. The biology student must know the classification of the different kingdoms of living beings, the chemistry student must know the chemical elements, the physics student must know the physical laws, the mathematics student must know mathematical theorems, etc., but this type of education is incorrect because it leads to the categorical error of confusing the results and final products with the initial research topic. In this way, the study of the final result is more important than the solution process itself, and the students simply seek to memorize formulae, concepts and laws instead of committing themselves intellectually to the complexity of the problems under investigation (Elicor, 2016). At this point, it is where we can see the richness of the STEM model of education, to involve children from a young age in scientific research, finding the connection and usefulness of the different sciences to explain nature. Pérez and Araya (2014) have reported encouraging results when using the Philosophy for Children methodology for teaching science concepts with primary school children.

18.6 Workshop On-Line of *Philosophy for Children* for Learning Science

This section provides additional details leading to the implementation of *Philosophy for Children* in science education using simple STEM projects in preschool. Initially, the plan was to hold a workshop with 2nd grade preschool children, but due to the COVID-19 epidemic the Mexican government-imposed restrictions on social contact and the 2019–2020 school year ended through online environments. Therefore, the *Philosophy for Children* workshop had to be structured through a virtual format using the ZOOM platform. We do not know of any report in the world about the realization of philosophical practices with children in virtual environments. In fact, the COVID-19 pandemic triggered the realization of different philosophical practices in cyberspace (Mora, 2020). Initially, we contemplated a group of 10 children from 4 to 5 years old, following the recommendations of experts in philosophical counseling who recommended 5 to 10 participants (Brenifier, n.d.; Lahav, 2017). However, various problems occurred, one of which being that preschool children can hardly use Information and Communication Technologies without the help of an adult, and unfortunately not all parents were willing to help their children, despite the social confinement that families were experiencing during the pandemic. Another unfavorable point was that it takes a lot of work for the children to be still and attentive during an hour-long workshop. This led us to seek the collaboration of a student of the Master of Science in Physics Education at CICATA-IPN, who has experience of performing physics experiments disguised as a clown.

The initial group of 10 students, in one week was reduced to six, of which only 3 to 4 students who did have the support of their parents continued with the 8 sessions of the philosophical workshop. In the first sessions of the workshop, the STEM model of education was explained to parents and children, and that in each online philosophical session, experiments and discussions would be carried out, and each week the children should do a STEM project with the help of their parents.

On the other hand, the philosophical competences that are sought to be developed in *Philosophy for Kindergarten* workshop for children are the following:

i. Dialogue in a polite and orderly manner.
ii. Inquiry, go beyond what you think.
iii. Form hypothesis to explain natural phenomena.
iv. Find examples and counterexamples.
v. Questioning properly.

vi. Contrast, ask for evidence.
vii. Be sensitive with the context.
viii. Make correction and create alternatives.

During the philosophical workshop, in addition to knowledge, children were also taught attitudes. The workshop was moderated and accompanied more than just giving them a science outreach presentation or trying to get them to understand a physical concept (Fig. 18.4).

The activities that were carried out during the virtual sessions were based on the demonstration of attractive home experiments, on Socratic dialogue with the students, as well as the analysis of videos and the development of origami activities. Also, some STEM projects were focused to concepts about solids and fluids, density and mass, and light diffraction (Fig. 18.5).

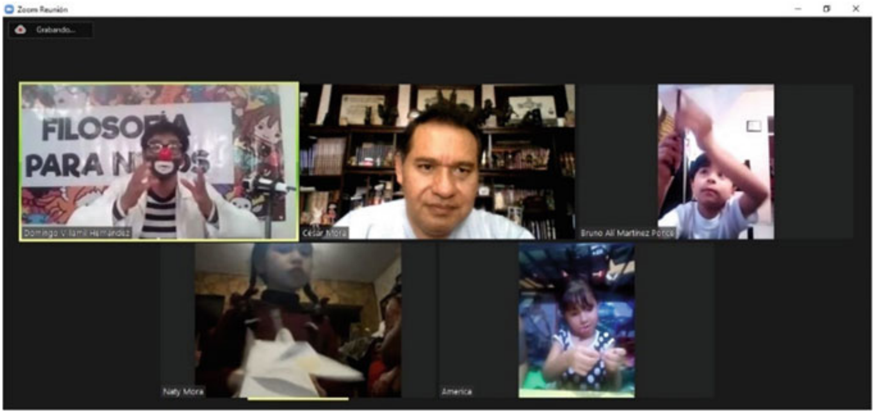


Fig. 18.4 Philosophy Workshop for Children for learning science on the ZOOM platform

Fig. 18.5 STEM projects on the construction of a small boat that can float and navigate, carried out by the students in their homes and presented in the workshop on the ZOOM platform

18.7 The Use of Empirical Material in STEM Programs for Young Learners in Mexico

Empirical material is very important for STEM education. Eckhoff (2017) states that early STEM experiences should include exploratory learning, allowing children to learn content through the processes of inquiry. The STEM experiences teachers provide for young children can involve a variety of learning materials, including children's literature, consumables and manipulatives, and web-based resources. In this sense, we have proposed some activities to develop with young children, mainly with low-cost materials. Also, in early STEM activities, the open-ended materials can result in interesting learning experiences in the classroom. This often involves many different materials for exploration, however it does not require purchasing manufactured curricular materials. Providing children with access to open-ended materials can broaden and extend their explorations while also limiting expenditures.

On the other hand, the situation of STEM education in Mexico is incipient. The initiative has been taken by private, non-governmental and "non-profit" institutions, since they are educational companies that offer certification and training programs for teachers of all levels of education. Some of these companies offer "free" publications as a hook and a national award for the best STEM teachers (Movimiento STEM, 2019). However, the Ministry of Education in Mexico (SEP) recognizes the importance of STEM education but has not yet officially made its formal inclusion in the study plans.

The main public universities in Mexico such as the National Polytechnic Institute, the National Autonomous University of Mexico, the Mexican Physical Society, the Latin American Science Education Research Association (LASERA), and the Inter-American Network of Teacher Education of the OAS, promote projects of STEM education research and international STEM congresses for the dissemination of results, as well as teacher training in STEM methodologies. There are some programs in different states of Mexico where girls are motivated to study science since only 30% of young people who choose to study STEM or science careers are women, therefore, there is a great gender difference in the studies of science in Mexico.

We know that STEM goes beyond grouping science, technology, engineering and mathematics, it is a model that deeply develops scientific and mathematical thinking with a focus on innovation, with profound repercussions for the economies of countries. Among the challenges of STEM education in Mexico we have the following:

1. The STEM model should be officially included in the new educational model of "La Nueva Escuela Mexicana" (Secretaría de Educación Pública, 2019), which seeks to contribute to the formation of critical thinking, transformation and solidarity growth of society; strengthen the social fabric to avoid corruption, through the promotion of honesty and integrity, in addition to protecting nature, promoting social, environmental, and economic development, as well as favoring the generation of productive capacities and promoting a fair distribution

of income; and combat the causes of discrimination and violence in the different regions of the country, especially that which is exercised against children and women, among others. All of which is possible, as some of the core competencies in STEM are critical thinking, problem solving, creativity, communication, collaborative work, scientific literacy, digital literacy, and computer science.
2. Create STEM training centers for teachers in public universities that include educational research results.
3. Motivate young students to study science careers through science fairs and contests.
4. Carry out a national scientific and STEM literacy campaign, in accordance with the UN 2030 Agenda for Sustainable Development (United Nations, 2018).
5. Link the school with the industry for the sustainable development of communities (Suárez & Reyes, 2021).

18.8 Conclusion and Recommendations

Mexican kindergarten teachers tend to have a general prejudice about scientific disciplines because of their complexity. These subjects are hard for young children to understand due to lack of mathematical language, or due to their incipient interaction with natural phenomena. However, in the studies carried out by Nieto (2015) and Franco (2018), it has been made clear that one of the biggest obstacles in preschool education for the inclusion of science and STEM models is precisely that preschool teachers do not know science, and a plausible solution is the training and updating of preschool teachers in the scientific disciplines, as well as in the STEM model, and how to start using new technologies in their teaching practice, such as robotics, smart phones and tablets.

The implementation of Decroly's proposal about centers of interest in science for preschool and STEM projects have shown the strengths of offering a space of almost personalized attention to the little ones, generating trust, listening within these small groups, the participation and adjustment of the activity to each child, respecting learning styles and rhythms, as well as their own characteristics. Also, within these centers of interest, we are strengthening forms of relationship, respect for established agreements and self-regulation. During playtime activities with STEM toys, students were able to make use of thinking skills. With the teacher's guidance, they were able to establish similarities and differences, maintain participatory observation, argue a classification, and based on this, develop simple explanations, and build notions of scientific concepts. All these skills are not only applied in the field of Exploration and Knowledge of the World, but the child makes use of them during every learning opportunity. In this way, progress can also be seen in other training fields.

The experience of Philosophy for Children workshop online has been a very enriching experience, in the aspect that there are no records of another similar experience, because the Philosophy for Children program is traditionally face-to-face. Our recommendation for the good performance of the online workshop is to consider groups of 3–4 participants in order to have a personalized teaching. Do not turn off the participants' microphones and make it clear that there is an order of participation by raising your hand. All temptations to teach formal science with children and seek to give closed definitions of laws and principles should be avoided. The experiments to be carried out during the session must be attractive and easy to carry out. Origami exercises are also simple when under adult supervision. In addition, the STEM project to be carried out at home each week must be prepared in a family team (student and one of the parents), always giving to the student facilities to experiment and test the design and assembly of a prototype or its innovation, and avoid putting together projects as a kitchen recipe. It is also necessary to create an environment of pleasant remote participation and have alternative plans ready in the event of power failure or in case Internet connectivity fails.

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Part IV
Informal Settings and Family Involvement in Play

Chapter 19
GLOBE, STEM and Argentine Citizen Science: Collaborations in the Early Years Through Outdoor Observations

Ana B. Prieto and Teresa J. Kennedy

Abstract Young children have a natural and innate curiosity about the world in which they live, motivating them to actively engage in concepts of science, technology, engineering, and mathematics (STEM) to solve real-world problems. Balancing unstructured and structured play in outdoor environments promotes curiosity while at the same time provides a sense of purposeful learning as children take turns listening, sharing, exploring, and making decisions. Inquiry generates motivation in fun and practical ways and helps children of all ages to develop essential twenty-first century skills including critical thinking, creativity, collaboration, and communication through the development of foundational literacies. These assets prepare them to be informed global citizens in their future adult lives, contributing their thoughts, questions, ideas, and solutions to improve their world in a confident and informed manner. This chapter describes Argentina's educational system, examines pre-primary and primary education practices to promote child-driven balanced play in support of STEM learning in outdoor environments, and describes a citizen science and early years collaboration involving preschool children (ages 4–5) as they engaged in STEM activities with their older siblings (ages 8–9) in two third-grade classrooms and their family members. The results of this citizen science application of the GLOBE Program are included.

Keywords Citizen science · GLOBE Program · Problem-based learning (PrBL) · STEM education · Balanced play

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19.1 Introduction

The environment has traditionally been an important part of Argentine culture due to the vast natural resources and biological diversity found throughout the country. As a result, the importance of environmental education is well documented in Argentine legislation as well as in the National Education Act which states that "The Ministry of Education, Science, and Technology, in agreement with the Federal Council of Education, will arrange the necessary measures to provide environmental education at all the levels and modalities of the National Educational System" (Ley Nacional Nº 26.206, 2006a, p. 18).

Argentina's long history of government implemented environmental protections and policies have resulted in numerous educational initiatives. While environmental education is typically not delegated to one specific area of study in the Argentine national curriculum, it is included as a cross-disciplinary theme in subjects such as biology, Earth science, economics, history, languages, natural sciences, social sciences, and ethics, among other standalone subject areas.

This chapter describes Argentina's educational system, examines pre-primary and primary education practices to promote child-driven balanced play in support of STEM learning in outdoor environments, and describes citizen science and early years collaborations involving preschool (ages 4–5) as they engaged in STEM activities with their older siblings (ages 8–9) in two third-grade classrooms and their family members. The results of this citizen science application of the Global Learning and Observations to Benefit the Environment (GLOBE) Program are also analyzed and discussed. The chapter focuses on the importance of balancing unstructured and structured play in outdoor environments to promote curiosity while at the same time provide a sense of purposeful and safe learning. Well-known biologist and writer, Rachel Carson, points out that the company of adults sharing experiences with children helps keep alive their innate sense of wonder, joy, and rediscovery and excitement (Carson, 1956, 1965; Carson et al., 1998).

19.2 The Argentine Educational System

The Argentine Educational System is managed by the Ministry of Education, implemented at the national, federal, and provincial level, and regulated by the National Education Law 26206 implemented in 2006, and which was modified in 2014 by Law 27045 designating that each Provincial State throughout the country is responsible to guarantee equality and free education. This law grants national validity to all titles awarded by educational institutions in Argentina. Among the changes introduced with the 2014 reforms were the reorganization of the overall structure of the education system as well as the extension of compulsory education from four years of age through the end of the secondary level (Ley Nacional Nº 26.206, 2006b).

The Argentine educational system is divided into the four "levels" of Pre-primary; Primary; Secondary; and Tertiary and structured within eight educational modalities including Career and Technical Education, Art Education, Special Education, Continuing Education for Youth and Adults, Rural Education, Bilingual Intercultural Education, Education in Contexts of Deprivation of Liberty, and Homecare and Hospital Education (Education GPS, OECD, 2020; IIEP—UNESCO & SITEAL, 2020). Education in Argentina is an integrated system, and therefore structured the same for all schools throughout the country regardless of the geographical location, gender, ethnicity, or origin of the students. The levels and modalities are articulated to ensure that the students can easily transfer from one school to another.

Children generally attend preschool (*nivel inicial*) from three to five years of age, although 2-year-olds are accepted in many facilities. The term "preschool" (*preescolar*) also includes facilities that cater to young children from 45 days old to two years of age (*jardín maternal*) and those between the ages of three and five (*jardín de infantes*). However, only the last two years of preschool (students between the ages of four and five) are compulsory. Elementary education is designed for children six to 11 years of age, while secondary education serves those between the ages of 12–17. Students in Argentina are expected to attend approximately 14 years of compulsory education prior to beginning tertiary education. See Fig. 19.1 for a summary of the Argentine educational system levels with corresponding age ranges.

Enrollment in preschool environments has increased more rapidly than at any other level since the early 1980s (Education Encyclopedia, 2020). By 1986, there were more than 8,000 pre-primary schools situated across the country, with about 10% privately run and serving 18% of the age group. A strong emphasis in pre-primary education has occurred since that time. According to Monroy (2018), "Since 2015, all Argentinian children are required to attend two years of early childhood education (*educación inicial*) at the age of four, an increase from previous years when children only had to complete one year of compulsory preschool education. Current plans go even further and intend to make early childhood education compulsory from the age of three at the national level. Efforts [by the Argentina Ministry of Education] are afoot to build 9,000 new classrooms across the country to accommodate this reform,

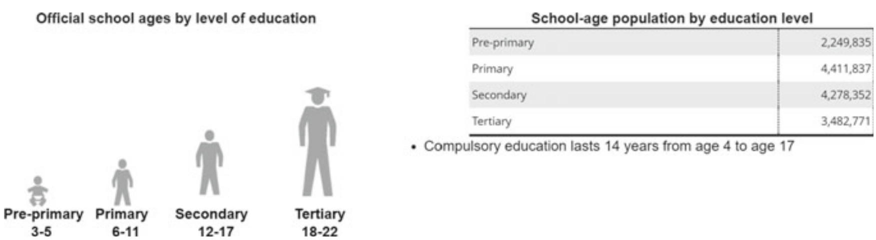


Fig. 19.1 Argentine educational system levels and associated age ranges. *Source* UNESCO Institute for Statistics (UIS), Argentina, Education System, http://uis.unesco.org/en/country/ar?theme=education-and-literacy, 2021

which is estimated to extend early childhood education to an additional 180,000 children" (para. 29).

Primary and secondary education programming, consisting of 12 years of schooling, is compulsory for all Argentine students beginning at age six. Two different structural variations are in place depending on provincial designations. Approximately half of the provinces have a 7 + 5 school system (7 years of primary education and 5 years of secondary education) and another 6 + 6 (6 years of primary education and 6 years of secondary education) (Monroy, 2018).

Although primary schools (including public and private) numbered more than 21,000 by the 1990s, fewer than 50% of the enrolled students (ages six to 11) complete all seven years of the primary curriculum resulting that only about half of those initiating primary level programs reach secondary school (Education Encyclopedia, 2020). Additionally, the number of repeaters (students enrolled in the same grade as in the previous year), is common in Argentina, especially in grades 1–4 (World Bank, 2009, p. 25). According to Valente (2013), the primary reason for the low number of adolescents reaching secondary school in Argentina is no longer due to poverty, but instead is a result of curriculum content that does little to motivate students. Current educational reforms focus on students' career paths at a younger age to help them see greater value in completing their studies and to promote programs such as *Families in the School* (*Familias en la Escuela*) which bring families and the community into the learning process to increase parental involvement in education (Zinny, 2015).

Successful completion of the primary programs results in students earning a Primary Education Certificate (*Certificado de Educación Primaria*) and eligibility to enter the secondary level, divided into two cycles: The Basic Cycle (*Ciclo Básico*) generally covering grades six through nine, and the Orientation Cycle (*Ciclo Orientado*) concluding with grade 12. Secondary level educational opportunities include both vocational and professional programs in federally funded public schools as well as in private schools. Upon completion of secondary programs, students receive the Title of Bachelor (*Título de Bachiller*), also referred to as *Bachillerato.* Graduates of any secondary program requiring completion of five or more years are eligible for further study at the tertiary level in public or private university institutions. Completion of a higher educational level is not mandatory, and the duration depends on the degree.

The financing of education is regulated by the Education Financing Law 26075 of 2005, mandating that the National State, the provincial jurisdictions, and the Autonomous City of Buenos Aires, must guarantee six percent of its gross domestic product (GDP) to finance the state educational systems. Government spending per student has steadily increased over the past decade. The educational system consists of state-run and privately-run institutions. Both public and private schools follow the same priority curriculum indicated by the government, and all students receive the same completion certificates. The state-run institutions are free, although some materials must be paid for by the students' families. Secular educational systems respect freedom of worship. Segregated and mixed gender students attend classrooms depending on the institution. Those of private management are linked to various entities including cooperatives, unions, social organizations, religious congregations,

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Government expenditure on education										
as % of GDP	5.29	5.35	5.44	5.36	5.78	5.55	5.46	4.92	...	...
as % of total government expenditure	15.2	14.5	14.5	13.8	14	13.4	13.3	12.5	...	...
Government expenditure per student (in PPP$)										
Primary education	2724.8	2847.3	2883.5	2826.7	3137.3	3091.3	3529.1	3131.3	...	...
Initial government funding per secondary student PPP$	3958.1	4061.9	4346	4190.7	4596.3	4384.8	4859.3	4066.5	...	...
Initial government funding per tertiary student PPP$	3077.8	3200.7	3374.3	3200.1	3467.6	3266.3	3985.1	3652.9	...	...

Fig. 19.2 Summary of government expenditures on education since 2011. *Source* UNESCO Institute for Statistics (UIS), Argentina, Education Expenditures. http://uis.unesco.org/en/country/ar?theme=education-and-literacy, 2021

among others. See Fig. 19.2 for a summary of government expenditures on education since 2011, documenting that secondary education has consistently received a higher level of funding than primary education for the seven-year period documented.

The curriculum in all Argentine schools follows a set of curricular guidelines for the development of competencies and Priority Learning Nuclei (Núcleos de Aprendizaje Prioritario—NAP). Each Provincial State designs its specific study plan. The National Natural Science Standards support scientific literacy and research-based pedagogies to engage students in natural phenomena research, analyze data, and engage in discussions of scientific topics (Ministry of Education, 2007). Additionally, the Ministry of Education (2007, 25) recognized the need to reform traditional pedagogical structures away from "rote learning of scientific contents, with a decontextualized understanding of science, away from everyday life, and unrelated to the historical aspects of science, with little development of scientific skills and critical thinking."

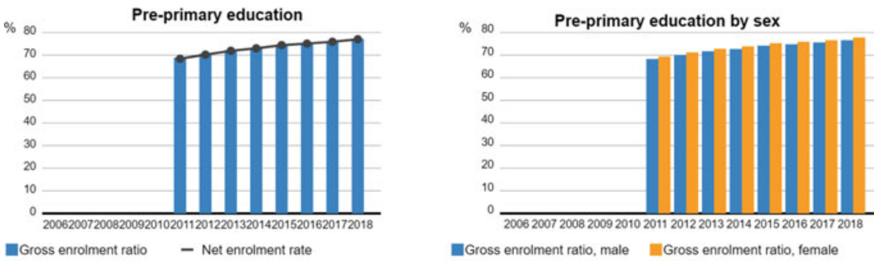
Although the efforts described above address important national pedagogical reforms, Argentine students have obtained low scores in science and mathematics on the international PISA exams (OECD, 2019). This indicates the urgency of improving the quality and equity of education in the country (Nudelman, 2017). According to Valverde and Näslund-Hadley (2011) and Furman et al. (2018), classrooms are often characterized by routine operations such as the memorization of facts and definitions and the mechanical reproduction of concepts and demonstrative practices. In addition, they reported that teachers are generally not well prepared and contend that these variables directly result in young people in Latin America not receiving an appropriate education in mathematics and natural science, and lacking opportunities to develop the necessary tools to adapt to an interconnected world economy. Some progress has been made in school infrastructure across the country to provide access to technologies and laboratories, however, according to Furman et al. (2019), it is necessary to help teachers make good use of these resources. Redesigning educational practices to provide more relevant learning experiences for students, beginning at the earliest levels of education (during Pre-primary, ages 3–5 years old), would undoubtedly cultivate skills needed for success in the future workforce. In addition, providing a more rigorous early years science education curriculum map beginning with Pre-primary experiences may solve the primary student retention problem by intensifying learning environments for children and providing more challenging intellectual assignments that are interesting and require critical thinking. These higher-quality activities ultimately make learning fun and follow a more natural learning process, and also allow all students opportunities for deep thinking that can foster a lifelong appreciation of education and science. The activities also provide a basic grounding of scientific concepts and support development of foundational literacies that lead to success throughout the students' academic life.

19.3 Pre-primary Education in Argentina and Balanced Play

According to reports by the OECD, in 2017, "77% of 3–5-year-olds were enrolled in early childhood education and care programmes and primary education in Argentina, compared to 88% on average across OECD countries" (OECD, 2020, para. 1). However, UNESCO reported that from 2011 to 2018 an increase in pre-primary education enrollment (from 68.9% to 72.2%) occurred, showing an increase in the number of students completing pre-primary education and entering primary school. See Figs. 19.3, 19.4, and 19.5 for a summary of the gross enrollment ratio for pre-primary and primary education as well as the retention statistics through 2018 documented by the UNESCO Institute for Statistics.

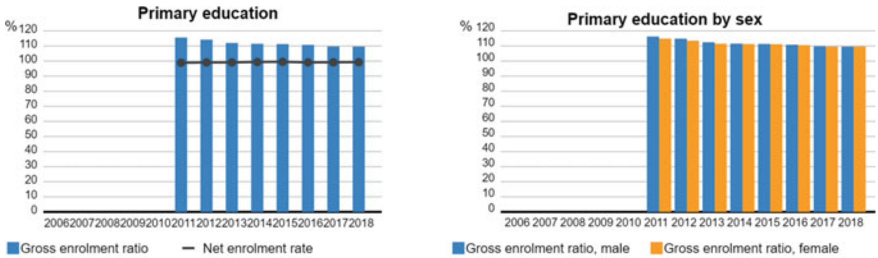
The upward trend in student participation in pre-primary education from 68.9% in 2011 to 77.2% in 2018, presented in Fig. 19.3, with female students slighter higher than males every year during this period, reveals a positive shift toward preparing young learners to enter primary school with basic literacy skills and an interest in learning. However, primary education enrollment during this same period experienced a slight decrease in participation from 115.61% in 2011 to 109.66% in 2018, at a nearly equal rate between female and male students (see Fig. 19.4).

Overall retention statistics revealed a total of 3.1% of repeaters in primary classrooms, with male students (3.2%) slightly higher than females (2.9%), along with a relatively high percentage of students overall completing primary education (94.21%). These data suggest the need for further research into specific reasons why some students leave primary school and what can be done to improve the transition from pre-primary to primary classrooms to stabilize this trend.



PRE-PRIMARY EDUCATION	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gross enrolment ratio (%)										
Total	68.9	70.6	72.2	73.2	74.7	75.3	76.1	77.2	...	...
Female	69.4	71.2	72.8	73.9	75.3	75.9	76.6	77.8	...	...
Male	68.3	70	71.7	72.7	74.2	74.8	75.6	76.6	...	...
Net enrolment rate (%)										
Total	68.4	70.2	71.9	73	74.4	75.1	75.9	77	...	...
Female	69	70.9	72.5	73.6	75	75.7	76.4	77.6	...	...
Male	67.9	69.6	71.4	72.4	73.9	74.5	75.3	76.4	...	...

Fig. 19.3 Argentine student participation in pre-primary education. *Source* UNESCO Institute for Statistics (UIS), Argentina, Participation in Education. http://uis.unesco.org/en/country/ar?theme=education-and-literacy, 2021



PRIMARY EDUCATION	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gross enrolment ratio (%)										
Total	115.61	114.23	112.01	111.46	111.3	110.74	109.74	109.66	...	...
Female	114.92	113.54	111.53	111.34	111.24	110.61	109.63	109.72	...	...
Male	116.29	114.89	112.48	111.57	111.37	110.87	109.85	109.6	...	...
Net enrolment rate (%)										
Total	98.9	99.1	99.1	99.4	99.5	99.1	99.2	99.3	...	...
Female	...	...	...	...	...	...	...	...	...	...
Male	...	...	...	...	...	...	...	...	...	...

Fig. 19.4 Argentine student participation in primary education. *Source* UNESCO Institute for Statistics (UIS), Argentina, Participation in Education. http://uis.unesco.org/en/country/ar?theme=education-and-literacy, 2021

	TOTAL	MALE	FEMALE	
School life expectancy ISCED 1-8 (years)	17.66	16.41	18.93	(2018)
Percentage of repeaters in primary (%)	3.1	3.2	2.9	(2018)
Survival to the last grade of primary (%)	94.21	93.96	94.47	(2017)
Gross intake ratio into the last grade of primary (%)	98.7	99	98.4	(2018)
Effective transition rate from primary to lower secondary general education	99.5	100	99	(2017)

Fig. 19.5 Argentine primary school retention statistics. *Source* UNESCO Institute for Statistics (UIS), Argentina, Progress, and completion in Education. http://uis.unesco.org/en/country/ar?theme=education-and-literacy, 2021

19.3.1 Pre-primary Education and the National Strategy

Initial pre-primary level education in Argentina is a central component of the national strategy for comprehensive early childhood care, recognized as an intentional process that articulates and complements family education. Its main objective is to promote the development of the capacities of young children in a suitable environment with educational and pedagogical references. The influence of early childhood experiences on later school success has also been noted by the American Academy of Pediatrics (2005), and by King (2016).

Early educational experiences at home and in the community, as well as in pre-primary environments, organized around free choice unstructured play time and child-driven play scenarios allow children to explore and experiment on their own. They discover answers to their questions without predetermined rules or guidelines. According to Kenneth R. Ginsburg, M.D., a pediatrician at the Children's Hospital of Philadelphia and author of a special report on the importance of play from the American Academy of Pediatrics, "When parents observe their children in play or join with them in child-driven play, they are given a unique opportunity to see the world from their child's vantage point as the child navigates a world perfectly created just to fit his or her needs. (The word "parent" is used in this report to represent the wide range of adult caregivers who raise children.)" (Ginsburg, 2007, p. 183).

Unstructured play, such as creative play alone or with others, provides opportunities for children to figure things out on their own, satisfying their natural curiosity, while also instilling decision-making and problem-solving skills. However, unstructured play does not mean that children are left alone. Adult supervision is essential, especially for younger preschool children to ensure a safe learning environment and allow for teachable moments related to recognizing danger as well as learning how to keep themselves safe (Qayyum, 2021).

Sandseter and Kleppe (2019) identified eight categories of risky play according to the following variables: play with great heights; play with high speed; play with dangerous tools; play near dangerous elements; rough and tumble play; play where children go exploring alone; play with impact; and vicarious play. While including risky play as a pedagogical practice could be one way of facilitating deep-level learning (Sando et al., 2021), adults must take into consideration the age appropriateness of the play environment to ensure close alignment with the children's developmental and physical literacy skills and subsequently remove all risks from the play environment that could become hazards. We believe in maintaining a balance between structured and unstructured play. Balanced play promotes adults actively participating in child-led activities to provide rules, discipline, and educational continuity, while also ensuring that children freely lead the direction of their own learning. This structure allows children to develop an understanding of how the world works while becoming responsible, independent, and competent decision makers. "As they master their world, play helps children develop new competencies that lead to enhanced confidence and the resiliency they will need to face future challenges" (Ginsburg, 2007, p. 183).

Outdoor spaces provide endless opportunities for balanced play as children interact with and learn from the world around them. Combining unstructured and structured play in these environments promotes curiosity while at the same time provides a sense of purposeful learning. Furthermore, research indicates a tendency for a higher physical activity level during partly structured play in comparison to free play (Tortella et al., 2019, p. 197). The Scandinavian Forest School tradition recognizes the importance of physical activities driving hands-on experiences during unstructured and structured outdoor play. Forest schools, also referred to as "nature-based preschools," "forest kindergartens," or "nature schools," began in Scandinavia in the 1950s, and since that time, the concept has spread to countries across the world (Gomez, 2020; McGurk, 2021). These schools are known for their combined day care and preschool services aimed at fostering environmental stewardship through early childhood experiences in nature.

In Latin America, Argentina and Uruguay led the development of "open-air schools," expanding the pre-primary nature school concept to primary and secondary students and increasing physical education as an additional goal due to the work of Doctor Enrique Romero Brest who promoted outdoor activities in the school courtyard, in the areas next to or surrounding a school where students typically play games or sports, or in nearby green spaces or parks as a means of improving the overall health of Argentine students (Rinaldi, 2020). Nature kindergartens, forest play groups, forest schools and forest kindergartens strive to build a positive, playful, mindful, and respectful relationship with the outdoors while introducing the basic concepts of STEM education. "Once exposed to the delights of nature, children seem to want to find even more around them, even in the most suburban and urban settings" (Musil, 2019, para. 10).

The research literature describes a wide range of benefits to children who engage in combinations of unstructured and structured play in outdoor settings (Chawla, 2015). For example, in studies of preschoolers, links between physical exploration and increased language development of words for actions, forces, and physical objects were shown by children as they investigated nature while adults actively discussed their discoveries with them (Dewar, 2016). Supporting these higher-level conversations, even with the youngest of learners, teaches them inquiry-based learning

Fig. 19.6 Scientific method for preschoolers

strategies and helps them learn how to ask questions and find answers for themselves. Using a modified version of the scientific method for preschoolers works well to extend dialog (Griffin, 2019). The steps begin with encouraging children to ask questions and imagine possible answers or solutions, followed by planning, creating, and improving, when building or constructing something, or simply sharing possible answers and returning to imagine new ideas, depending on the context of the balanced play situation. The pattern repeats itself in a natural fashion as children engage in age-appropriate, content-related discussions (see Fig. 19.6).

As children gain experience in discovery while incorporating science and math all along the way, they inevitably enter elementary classrooms better prepared, with understandings about how to ask questions, better strategies for thinking through potential answers, and actively engaging in collaborative discussions. As Rachel Carson proclaimed:

> I sincerely believe that for the child, and for the parent seeking to guide him [them], it is not half so important to know as to feel. If facts are the seeds that later produce knowledge and wisdom, then the emotions and the impressions of the senses are the fertile soil in which the seeds must grow. The years of early childhood are the time to prepare the soil. Once the emotions have been aroused—a sense of the beautiful, the excitement of the new and the unknown, a feeling of sympathy, pity, admiration or love—then we wish for knowledge about the subject of our emotional response. Once found, it has lasting meaning. It is more important to pave the way for the child to want to know than to put him [them] on a diet of facts he [they] is [are] not ready to assimilate. (1956, p. 46)

19.4 STEM Education, Citizen Science and Early Years Collaborations in Argentina

STEM is an acronym for science, technology, engineering, and mathematics, four disciplines that are closely intertwined in the real world. Through the academic integration of STEM disciplines, students develop key skills such as problem solving, creativity and critical analysis. STEM education is a global concern for economic, social, and political reasons. Many countries around the world are reformulating their educational systems to include the disciplines subsumed by STEM (Bybee, 2013; Li et al., 2020). STEM is not simply a grouping of subject areas or disciplines; instead, it is a movement to develop a deep connection between the subject areas. STEM is a meta discipline that removes the barriers between these four critical content areas, focusing on innovation, designing solutions, and developing problem-solving and critical thinking skills (Kennedy & Odell, 2014; Kennedy & Sundberg, 2020).

In the search for different implementation strategies, the concept of the "STEM Learning Ecosystem" emerged (Cao et al., 2020), focusing on student experiences in formal learning environments such as in schools and universities along with collaborations that result from out-of-school programs, citizen science projects, scientific institutions, the private sector, NGOs, youth organizations, families, the media, games, social media, virtual environments, geospatial technologies (Kerski, 2015), and other innovations mediated by the rapid evolution of digital media. This wide range of learning opportunities provides increasing evidence that individuals develop their understandings of the world and knowledge and interest in science not only at school, but also during out-of-school contexts throughout their lives (Dudo, 2015; Falk & Dierking, 2016; Falk & Needham, 2013). STEM ecosystems must also consider stories of inclusion and exclusion to ensure attractive opportunities for all (Bevan et al., 2018).

Another important contribution to STEM education is citizen science, emerging in this context as a collaborative space in which scientists, professionals, citizens in general, students, and teachers participate together in scientific research processes or in data recording processes through observation or measurement (Cooper et al., 2007). Sharing nature is the perfect venue for young children to experience STEM in action with their caregivers (King, 2016). Citizen science projects tend to be focused activities sponsored by a wide variety of organizations that enable non-scientists to meaningfully contribute to scientific research. It is used to identify research questions, collect and analyze data, interpret results, make new discoveries, develop technologies and applications and others (EPA, 2020). This idea is also used for educational purposes to promote STEM education (Bonney et al., 2016; Toomey & Domroese, 2013). "Engaging the community as well as families helps children find their place in the larger world and connects families with one another" explained King (2016, para. 9). Citizen scientists provide valuable information that would typically not be available due to time, geographic, or resource constraints. Furthermore, research indicates that students participating in citizen science activities have improved their research knowledge and skills (Kobori et al., 2016).

Constructs of citizen science have been a part of the science education framework in Argentina since the early 1990s and include collaborative leadership activities with the United States and other countries resulting in the creation of the international Global Learning and Observations to Benefit the Environment (GLOBE) program. GLOBE is a worldwide program that brings together students of all ages with their teachers, scientists, and community members to promote science and learning about the environment, providing research investigations, and learning activities that involve making scientific measurements in five core fields: atmosphere, biosphere, hydrosphere, soil (pedosphere), and Earth as a system (GLOBE Program, 2020a). Each research area consists of validated measurement protocols and learning activities. The measurement protocols, developed by scientists and educators, allow students around the world to contribute standardized research-quality data. The National Aeronautics and Space Administration (NASA) provides and manages the programmatic infrastructure that coordinates and supports this global community through the Internet and other means. Scientific observations made locally are submitted to the GLOBE data and information system, which currently contains nearly 200 million measurements from 125 countries around the world (GLOBE Program, 2020b).

Argentina was one of the founding countries involved in designing the GLOBE Program, from 1993 to 1994, and was actively involved in identifying and outlining many of the environmental activities implemented by the Program today. According to Dr. Maria del Carmen Galloni, former representative of the Argentine Ministry of Education and the first country coordinator for GLOBE in Argentina, "The fundamental idea is to stimulate in young students the vocation for scientific research and mathematics, with the purpose of extending it in the country, so that all young Argentines can discover their orientations, through a dynamic and creative activity" (Universidad de Ciencias Empresariales y Sociales [UCES], 2004, p. 57). Research activities involving GLOBE in Argentina have historically invited community involvement through collaborative activities spanning from large urban areas, such as in Buenos Aires, to rural environments in Ushuaia, the southernmost city before Antarctica, to Iguazu Falls, at the northern border of Argentina next to Brazil and Paraguay. While GLOBE in Argentina (GLOBE in Argentina, 2013), began with the initial idea of linking students, schools, and scientists, the program significantly expanded its worldwide collaborations with citizen science through the development of mobile applications such as GLOBE Observer (GLOBE Observer, 2020a).

Citizen science arises with the idea of creating effective partnerships between citizens and the scientific community (Bonney et al., 2009; Silvertown, 2009). However, the quality of the data is an important issue to consider, and for this reason, NASA compares data measured by students and citizen scientists with data taken by satellites when passing overhead (Hayden et al., 2019; Kennedy & Henderson, 2003). GLOBE facilitates the study of natural environments in which students live and facilitates sharing their results with scientists via the Internet. It is currently implemented in formal education environments (such as in schools), and in clubs, museums, and other areas of non-formal education.

To engage the youngest of learners, GLOBE developed a suite of science-based storybooks and learning activities called *Elementary GLOBE*, aimed at building a foundation for students in grades K-4 (ages 5–9) leading to more advanced understandings of Earth as a system in subsequent grades (Henderson et al., 2006). *Elementary GLOBE* books are available in multiple languages (Arabic, French, German, Norwegian, and Spanish) and can be downloaded free online (GLOBE Program, 2020c). Each age-appropriate storybook utilizes a science-based, fictional narrative to engage students in the scientific method, and contains teacher notes and classroom learning activities that complement the science covered in each book as well as many of the GLOBE data collection investigation protocols.

The practice of implementing STEM education beginning in early childhood experiences is generally recognized as beneficial since most agree that children naturally use their innate abilities (curiosity, questions, and exploration) to understand the world in which they live (Tippett & Milford, 2017). Offering children appropriate STEM experiences from an early age has been shown to foster later academic success (Campbell et al., 2001; Katz, 2010). However, little has been documented regarding the transfer of information between primary students to their younger siblings at home. Therefore, to examine potential outcomes related to the transfer of information between pre-primary and primary students, as well as education practices promoting child-driven play in support of STEM learning in outdoor environments in Argentina, a research project was conducted utilizing a citizen science application of the GLOBE Program involving preschool children as they engaged in STEM activities with their older siblings in two third-grade classrooms.

19.5 Research Methodology

A research project was designed by the authors of this chapter to examine the implementation of GLOBE atmosphere measurement protocols with primary school students (ages 8–9) and the transfer of knowledge and skills that took place informally to their younger siblings (ages 4–5). Data were collected during a GLOBE unit of study in two third-grade classrooms of the María Auxiliadora Institute (IMA) in the city of Junín de los Andes, Argentina. These Argentine primary students regularly use their observation skills to investigate cloud types as well as cloud coverage and opacity, and record the color of the sky and visibility, among other GLOBE Program investigations and activities. Their observations are recorded on paper, as well as using the GLOBE Observer Clouds application, and then compared to satellite measurements using the HoloGLOBE visualizations application.

The basic characteristics of the GLOBE program allow linking students, families, teachers, community members, and scientists, resulting in our students easily making observations at home with the younger siblings, involving their entire families in their research experiences, and ultimately transferring knowledge and skills informally to their younger siblings. Additionally, students were able to make comparisons of their data with measurements from GLOBE sites around the world to establish differences and similarities. These measurements, made by other students their own age, are shared through the GLOBE Program database.

Since the project occurred shortly before the COVID-19 pandemic, the authors, working collaboratively with the teachers and school leadership, organized a videoconference event for the third-grade students, their younger siblings, and their parents discuss their projects with NASA scientists, allowing free-flowing communication and the sharing of results. Additional discussions concerning global challenges associated with climate change occurred, helping parents and their children understand more about this important crisis. At the end of the investigation, students were exposed to different audiences, professionals, educational community, science fair participants and others, while serving as role models to their younger siblings at home and providing them with authentic scientific experiences leading to their own free choice unstructured play scenarios in their backyard environments as well as child-driven balanced play involving parents and caretakers.

19.5.1 Research Questions

We were interested in gaining a better understanding regarding how young children learn STEM concepts and skills in an informal education environment, especially working together with their older siblings and caretakers. The following questions guided our study:

- How do young children learn STEM concepts related to atmospheric studies in informal learning environments at home with their older siblings, parents, and interactions with others?
- What ideas do young children have related to scientific investigation and how it is carried out?
- What knowledge and skills do third-grade students transfer to their younger siblings through collaborative research activities?
- How can knowledge be shared and transferred to younger siblings and family members at home?

19.5.2 Research Design

Project-based learning (PBL) and problem-based learning (PrBL) are pedagogies employed by teachers to engage students in authentic STEM research, facilitating students to create their own questions, perform their own research, and communicate their results, either through the development of projects addressing questions or problems (Odell & Pedersen, 2020). Two student research projects were carried out applying the problem-based learning (PrBL) approach in two third-grade classrooms at a primary school in Junín de los Andes, Argentina.

The research was carried out in a primary school (total student enrollment = 240), in the city of Junín de los Andes, with 13,126 inhabitants (INDEC, 2012), located in the northwest of the Patagonia region, Argentina, near the border with Chile. Participants included 46 students from two third-grade classrooms (24 females and 22 males) ranging from eight to nine years of age, along with five younger siblings (four females and one male) between the ages of four and five years of age. No additional siblings participated in the study due to family structure limitations (some children only had older siblings, others had siblings younger than one year of age, and most of the students were only children). Table 19.1 depicts student background details.

Communication between school leaders (teachers and project administrators) with the families was established through two methods: (a) use of a formal communication notebook when parental authorizations/permissions were required; and (b) use of an instant messaging group through WhatsApp to enable teachers to share photos of activities carried out by children at school. Both methods were organized before the project began. The instant messaging group also contributed to the dissemination of informal science activities that took place in family settings through sharing photos

Table 19.1 Background information of students

		N students	Ages (students)	*N* younger siblings	Ages (siblings)
Grade 3 A	Males	7	9	0	–
	Females	15	8–9	3	4–5
Grade 3 B	Males	16	8–9	1	4
	Females	8	9	1	4
All Grps		46		5	

of their experiences as well as videos of formal events that took place, such as a videoconference with a NASA scientist and the final video made describing the research carried out by the students.

As a means of answering the research questions, the school administrators, and teachers, working together with the authors, decided to utilize GLOBE Program activities focusing on atmosphere protocols including aerosols, air temperature, clouds, and wind (GLOBE Program, 2020d). During the project, the children used school facilities, such as the computer room and science laboratory, as well as educational mobile applications, such as augmented reality (AR) and virtual reality (VR), 360° videos, and video conferencing with people located outside of Argentina for the first time at school. All students had computers at their homes and all students had access to their parents' smartphones that they used to play games or communicate with others.

19.5.3 STEM Research

To address our research questions, we focused our study on how young children three to six years of age acquired information informally through their third-grade siblings (age 8–9) who participated in a PrBL activity focusing on weather observations. Before initiating the research project, a preconception exploration was carried out to learn about student ideas regarding the water cycle, cloud formation, temperatures, aerosols, and wind. All students had basic notions of these concepts, with the exception of the term "aerosols." However, students did refer to dust, smoke and volcanic ash in the atmosphere and therefore had basic knowledge about aerosols. Forest fires in this region are frequent during the summer and early autumn (Kitzberger, & Veblen, 1997). In 2011, significant amounts of ash fell from the Puyehue Volcano (Easdale & Bruzzone, 2018), and in 2015, the same occurred from the Calbuco Volcano (Van Eaton et al., 2016). The children were familiar with the event that occurred in 2015 which facilitated the understanding of their new vocabulary word "aerosols."

The roles of all project participants were identified after school approval for the project was obtained and prior to initiating activities. The project roles are described below.

- Teachers received training from the GLOBE Program and had the support of specialists trained in GLOBE and STEM education for the duration of the project. Their primary role was to implement a PBL activity implementing a STEM approach for students to investigate real-world issued identified by their students.
- Students developed their research questions collaboratively with their peers. They also communicated with other students and scientists to discuss observations and analyze results. In addition, they taught their younger siblings, parents, and other adults what they learned at school. This activity was carried out of its own free will and spontaneously, without any request from the school.
- Parents and their children, including younger children (age 4–5) and their older siblings (age 8–9), participated as citizen scientists using the GLOBE Observer application to take measurements. The third-grade students served as the expert scientists. Family members learned from their children's explanations and used satellite imagery to compare their observations. When communications were received from the school related to the project, parents asked their children to explain, generating a family conversation about it. All participants (school leaders, GLOBE specialists, students, and their family members) were present at the NASA video conference, however, only students participated while all adults served as observers.
- The interactions of the five preschool children participating as citizen scientists, making observations and records, and discussing their findings, was an important focus of the research project. These children learned from their older siblings when they explained and/or performed the same activities that they did at school and were motivated to think and be involved in the project.

The third-grade students knew very little of the scientific terminology used to describe cloud type since they had not paid attention to the different shapes. Through peer discussions, students created the following questions to guide their research:

- Classroom A students: How does cloud cover influence temperature in Junín de los Andes?
- Classroom B students: How does the color of the sky and visibility change in the presence of aerosols in the atmosphere?

Both investigations were carried out from September 1 to December 6, 2019. See Appendix A for a detailed summary of the daily activities that occurred during the project. Students participated in GLOBE Program activities by taking daily atmosphere measurements at school using the GLOBE Observer Clouds mobile application, and voluntarily with their families taking measurements from their homes. Since the GLOBE Observer citizen science application can be used by anyone, such as the students' parents (Amos et al., 2020), therefore family members entered their own data.

Students recorded cloud type, cloud cover, sky color and condition, visibility, surface condition, air temperature and took photos of the sky towards the four cardinal points (north, south, east, and west), above and below. Their data were shared on the GLOBE Program website and on the GLOBE data visualizations page to compare their findings with other measurements submitted by students, scientists, and citizen scientists at different locations around the world.

Students also examined satellite images on Earthnull School (a visual compilation of winds plotted across the globe, updated every three hours) and HoloGLOBE (an augmented reality App showing real-time weather, earthquakes, fires, surface temperatures and more), and analyzed the size and displacement of Hurricane Dorian, as it entered the Caribbean as a tropical storm and slammed into the Bahamas in September (while the students were engaged in their project) as a Category 5 hurricane using the Worldview software. Web resources utilized are listed below.

- https://www.globe.gov/es/web/mission-earth/overview/teacher-resources/lesson-plans
- https://earth.nullschool.net/
- https://www.globe.gov/documents/18720200/49583420/Hologlobe+Lesson/6eb718e5-4d2f-4ce6-8c2b-f30407519d35?version=1.0
- https://worldview.earthdata.nasa.gov/.

19.5.4 Data Collection

During the development of the classes, video records, field notes, student notebooks, records of atmosphere observations and informal interviews were taken during and after student activities. Figures 19.7 and 19.8 depict outdoor and indoor activities related to their atmospheric study.

Measurements made in collaboration with their families using the GLOBE Observer app were downloaded from the GLOBE database. Surveys completed by

Fig. 19.7 Third-grade students (ages 8–9), identifying clouds and the color of the sky using the GLOBE Cloud Sky Window. GLOBE Cloud Sky Window (GLOBE Program, 2020e)

Fig. 19.8 Third-grade classroom cloud identification activity

parents and teachers were analyzed. After the project ended, additional interviews were conducted with the students, their parents, and the younger siblings. The interviews were semi-structured, flexible, and open to contributions from the interviewees. Statistical software was used for analyses (StatSoft, 2007).

19.5.5 Data Analysis

All data were analyzed by using T-tests to examine differences between the two classes of third-grade students, including potential gender differences. Student learning and transfer to their younger siblings were analyzed. For the first case, data segments were coded, building areas of analysis that included: (1) perception of science and research, (2) acquisition of knowledge, (3) development of skills, and (4) self-confidence as STEM students to teach others. For the second case, the younger siblings, the areas of analysis were: (1) perception of the research, (2) acquisition of specific knowledge, (3) development of skills, and (4) source of access to this knowledge.

For both cases, a 5-point Likert-type scale was used considering the best-rated categorizations with 5 and the least-rated categorizations with 1. Reliability was high with a Cronbach α 0.845 for students and Cronbach α 0.929 for siblings. Scoring differences for siblings were analyzed with the Wilcoxon Matched Pairs Test, a non-parametric method.

19.6 Results

19.6.1 Primary Student Concept and Skills Development

During the project, 30% of the third-grade students attended all classes, 50% missed one class, and 19% missed two class sessions. The teachers sent photos of activities carried out daily to the families to incite evening discussions. All students highlighted that participation in the project was a very different experience or "job" from the one they usually do at school and that they maintained high motivation throughout the project. For the first time in their educational careers, they were given the opportunity to visit the science laboratory to carry out experiments, to visit the computer room where they attended a video conference with NASA scientists, and to use the internet and mobile devices for research purposes (see Fig. 19.9). This technology component of the project was also highlighted by the teachers who explained that most students typically only use the computer and other mobile devices to play games and watch videos.

Due to their age, these young children typically do not have access to their own mobile devices, but instead use their parents' devices to play games, watch movies and YouTube videos. Only 10% of the students reported that they sometimes look for things online, using their parent's devices, to complete school assignments. Students shared their excitement to have had the opportunity, for the first time in their lives,

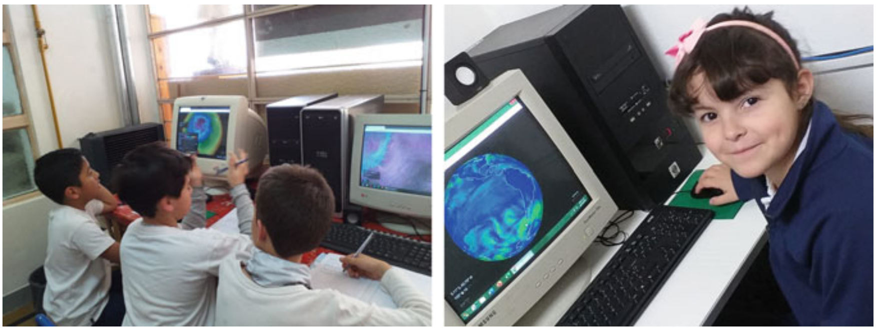


Fig. 19.9 Third-grade students (ages 8–9), discussing visualizations in the computer lab

to view satellite images and visualizations on computers and mobile devices with augmented reality.

The students also highlighted that this was the first time that they conducted investigations and they enjoyed the activities, especially pointing out that it was more motivating to go outside to observe the clouds and record them, go to the laboratory to do experiments, work in the computer room with satellite images, search for sources of heat, measure wind speeds during hurricanes and the amount of dust in the atmosphere, and other activities conducted. Table 19.2 shows the high values obtained in all areas of analysis with little variability.

Regarding comparisons between the areas of analysis (Table 19.2) and between girls and boys (see Table 19.3), significant differences $p < 0.01$ were detected in all four categories (perception of science and research, acquisition of knowledge and relationships between concepts, skill development, and self-confidence as STEM students to teach others).

Specific metadata and comments related to the four categories are described below.

Table 19.2 Descriptive statistics of the areas of analysis

Grade	*N*	1 Means	Std.Dev	2 Means	Std.Dev	3 Means	Std.Dev	4 Means	Std.Dev
3A Females	15	5.0	0.0	4.5	0.5	5.0	0.0	4.5	0.5
3A Males	7	5.0	0.0	5.0	0.0	5.0	0.0	5.0	0.0
3B Females	8	2.9	0.4	5.0	0.0	5.0	0.0	5.0	0.0
3B Males	16	4.0	1.0	5.0	0.0	4.5	0.5	5.0	0.0
All Groups	46	4.3	1.0	4.8	0.4	4.8	0.4	4.8	0.4

(1) Perception of Science and Research. (2) Acquisition of Knowledge. (3) Skill Development. (4) Self-Confidence as STEM Students to Teach Others

Table 19.3 Comparison between groups—test-*t*

Subject	Mean 3A	Mean 3B	t-value	df	*p*
1	5.00	3.63	6.357	44	0.000**
2	4.68	5.00	-3.273	44	0.002**
3	5.00	4.67	3.244	44	0.002**
4	4.68	5.00	−3.273	44	0.002**

**$p < 0.01$—Subject: (1) perception of science and research. (2) acquisition of knowledge. (3) skill development. (4) self-confidence as STEM students to teach others

19.6.1.1 Perception of Science and Research

All students reported that they liked to conduct research, they felt motivated, and their curiosity increased when carrying out scientific processes such as observing, measuring, collecting data and analyzing their data. This item had no differences between boys and girls. This aspect was also highlighted by both teachers and students. Example statements are below.

> It was very motivating for the children and for us. Motivation never decreased. During recess when they were all playing, a girl pointed to a vapor trail [line-shaped clouds produced by aircraft engine exhaust also referred to as contrails, short for "condensation trails"] and everyone stopped playing to look at it… Our students explained to other children at recess that it was a vapor trail and how it was formed. T1 (Teacher)

> I really liked everything... I had never been to a laboratory... I did experiments... I always look at the sky to see what clouds there are, even if I'm not measuring. I also check in my house, on the computer, the heat sources (red dots) to find out if there are fires and the clouds that the satellites show... everything was very nice. S12 (Student, age 9)

When students were asked if they liked STEM topics, most said yes, but some 3B students thought that they still needed to know more to decide if they liked them or not. In response to what information they lacked, students reported that their doubt was due to the use of mathematics to analyze the data, and although they thought that they learned it well for this project, they doubted if they would always succeed.

> I learned a lot of new things in this research... It was very different from everything we do in school... I like science, technology, but... mathematics more or less, but I learned it well in this project. S1 (Student, age 8)

> I am a little afraid of mathematics. I learned this well, it was easy, and I liked it. S16 (Student, age 8)

19.6.1.2 Acquisition of Knowledge and Relationships Between Concepts

This category was one of the highlights of the project for students, parents, and teachers alike. All highlighted that they learned a lot during the project, and they all stressed learning the importance of studying local, regional and global phenomena.

> I look at the hot spots every day with my Dad, before coming to school... if there are fires nearby, the smoke changes the color of the sky... If the sky looks milky, I will look at satellite images to see if there is smoke nearby… I also look at the clouds in the sky and in the satellite images…. S29 (Student, age 9)

> My daughter learned a lot during this project. The whole family learned together with her... At home we all went out to look at the clouds with my daughter and used the GLOBE Observer to record them…. P5 (Parents)

> I learned a lot together with the children…. T2 (Teacher)

> The PrBL pedagogy opens many doors [for students] to access knowledge…. T1 (Teacher)

Table 19.4 Comparison between females and males—test-*t*

Subject	Mean Females	Mean Males	*t*-value	df	*p*
1	4.26	4.30	−0.145	44	0.885
2	4.70	5.00	−3.102	44	0.003**
3	5.00	4.65	3.425	44	0.001**
4	4.70	5.00	−3.102	44	0.003**

**$p < 0.01$—Subject: (1) perception of science and research. (2) acquisition of knowledge. (3) skill development. (4) self-confidence as STEM students to teach others

Some 3A girls responded with difficulty to the relationship between cloud cover and temperature by looking at bar graphs, while other students pointed to these relationships spontaneously. While these girls understood the relationship, they could not interpret it from the data representation in the graphs. However, other charts were well interpreted. See Table 19.4 for details.

19.6.1.3 Skill Development

Students developed skills in the areas of observation, comparison, classification, measurement and recording, and communication, as well as managed to make inferences and predictions of events. They could determine when it would rain according to the type of clouds present or the amount of aerosols in the atmosphere when they found heat sources near their city that could become fires and generate aerosols in the atmosphere. Students reported that their learning was important, citing learning to observe and record their data at school and at home, successfully conduct laboratory experiments and draw conclusions, use satellite imagery and other data sources, such as air traffic activity, to compare with the vapor trails they observed and data reported by other students viewed on the GLOBE Program database, information learned from the videoconference with NASA, and recording videos of their research to share with others.

> I liked working with the computer on the internet, I was measuring the wind speed in Hurricane Dorian with the information that came from the satellites, I also measured it at home…. S35 (Student, age 9)

> I learned to work on the computer with the clouds and also to observe them. With my Mom we look at them every day with the tablet application and register them…. S39 (Student, age 9)

> Children developed many skills by combining real-life examples such as hurricanes, smoke and volcanic ash in the air and then abstraction by going to the internet looking at satellite images, locating their place and observing the same phenomenon... they developed many skills beyond the content… I was surprised at how well they learned to analyze graphics… they managed to express themselves very well by explaining their research on their video…. T1 (Teacher)

> Many internet consultation websites were in English and children automatically translated into Spanish using the translator... they discovered things in satellite images, took records of temperatures, winds, sprays…. T2 (Teacher)

Only some 3B children associated the concept of visibility in the observations with difficulty, but they managed to do it with assistance.

19.6.1.4 Self-Confidence as STEM Students to Teach Others

Children valued their learning, especially when they taught their parents and other adults about clouds, sky color, or how to interpret information displayed in satellite imagery. They felt like "specialists" in something that adults did not know and had an interest in learning. Only some girls in 3A did not teach others, and only made minor comments (without detail) about what they did at school to their families.

Overall, students generally felt they were an important part of a global investigation, especially after speaking via video conference and sharing their results with a NASA scientist who also told them that she used their data in her research. Every time they reported their data, they were aware that the information was shared on the GLOBE Program website and was available for many other students and researchers.

> I taught my Dad everything I am learning in this project. My Dad did not know anything about this... he is proud of me, of everything I learned…. S32 (Student, age 8)

> I showed Hurricane Dorian to my Mom in satellite images, we also measured the wind speed ... she didn't know anything... I explained how I could... I also taught her to observe the clouds and report them with the GLOBE Observer application, she had never done such a thing…. S22 (Student, age 8)

19.6.2 Concepts and Skills Developed by the Younger Siblings

There were no significant differences between the responses of students and their siblings (see Table 19.5) in the areas of analyses related to this project. While the third-grade students (ages 8–9) analyzed the graphs in greater depth than their siblings (ages 4–5), these differences were not significant.

Table 19.5 Comparison between students and their siblings—Wilcoxon Matched Pairs Test

	Valid	T	Z	*p*-level
Student 1 (F) & Sibling 1 (M, age 4)	9	0.000	1.604	0.109
Student 2 (M) & Sibling 2 (F, age 4)	9	6.500	0.270	0.787
Student 3 (M) & Sibling 3 (F, age 5)	9	8.000	0.524	0.600
Student 4 (F) & Sibling 4 (F, age 4)	9	6.000	0.405	0.686
Student 5 (F) & Sibling 5 (F, age 5)	9	9.000	0.314	0.753

(F) Females (M) Males

19.6.2.1 Perception of the Investigation

All the siblings wanted to join the investigations. They were aware that their older siblings and the other third-grade students were observing, recording, experimenting, and doing calculations. They thought that in the future they will know how to calculate and conduct research like the older children. They thought that researching these topics requires experimentation, and consulting satellite images helps research. All the siblings reported watching science programs for children on TV in their homes.

19.6.2.2 Acquisition of Specific Knowledge

The siblings knew the main concepts and relationships that were developed during the project. One girl (age 4) explained the basic types of clouds using the same examples given in class and shared the following explanation.

> some clouds, like cirrus clouds, are like hairs. Cumulus clouds resemble cotton and strata resemble a sandwich…. S-S13 (Sibling, age 4)

All the siblings easily related the concepts and during the interview they eagerly wanted to explain and demonstrate their knowledge as described below.

> the sky is blue, some days it is more or less light blue when there is smoke or dust ... those are the aerosols... when there are cumulus clouds it will rain…. S-S15 (Sibling, age 4)

> I do not need to look at the cell phone to compare the clouds, I know them all... I like contrails, those are left by airplanes, sometimes there are 2 or 3 contrails here…. S-S13 (Sibling, age 4)

> sometimes you can't see the sky because it's all covered in clouds... last week it was like this every day and it was cold... today the color of the sky was very blue because there was no dust or smoke…. S-S31 (Sibling, age 4)

19.6.2.3 Skill Development

All siblings developed observation, comparison, classification, measurement and recording, communication, inferences, and prediction skills. They observed the types of clouds, the color of the sky and estimated the cloud cover with their families. They also consulted satellite images, made measurements of some events (hurricanes and fires). When being showed satellite images on the internet, they could explain what they were seeing hot spots, cloud cover, or smoke. Two girls knew the numbers and knew how to check the temperature of a place. Their comments follow.

> I know the names of almost all the clouds, sometimes I forget some that are a little mixed... the clouds look different depending on where you look at them, I've travelled by plane and I saw them from above, I also look at them every day from home and then we look at the satellite image with my brother and my Mom…. S-S15 (Sibling, age 4)

My sister told me about the hurricanes, we watched one that was being talked about on TV, we saw it in the satellite image... with my sister and my grandmother we measured the wind speed... I don't remember how much it was, but it was strong…. S-S34 (Sibling, age 5)

I know where to look on the internet to see if we have fires nearby… sometimes you see the fires on the computer first and then the smoke in the sky…. S-S46 (Sibling, age 5)

When the sky begins to cover with clouds, we will surely be cold later…. S-S13 (Sibling, age 4)

19.6.2.4 Source of Access to This Knowledge

The young children obtained most of their new knowledge about aerosols, air temperature, clouds, and wind from their older siblings, but in some cases, their parents also provided explanations to satisfy their curiosity. Four students conducted the GLOBE sky color / visibility experiment for their siblings. Below are their comments summarizing what they learned.

I learned with my sister; she would tell me something about the clouds from time to time…. S-S13 (Sibling, age 4)

When we were looking for my brother at school, he would go out telling everything he had learned… When he got home, he would show us the science notebook… we would look at the photos that the Teacher sent… My brother taught my parents new things… me too…. S-S46 (Sibling, age 5)

My brother taught me, but I also spied on his science notebook, without his permission ... I learned many things…. S-S15 (Sibling, age 4)

"My sister read me a story about some children watching clouds..." (reference to two Elementary GLOBE books displayed in Figure 19.10: "Do you know that Clouds have names?" and "What's up in the Atmosphere? Exploring Colors in the Sky."). S-S31 (Sibling, age 4)

19.7 Discussion

The implementation of Project Based Learning (PrBL) with the STEM methodological approach described positively influenced the motivation of the students and their siblings. Children had access to many different resources than what they normally used at school. Working with real-world problems such as observing the sky and comparing their observations to satellite data, working with computers, mobile applications, conducting laboratory experiences, participating in videoconferencing, and making a video of their research. In addition, students presented their research resulting from their projects at the 2020 International Virtual Science Symposium organized by the GLOBE Program (GLOBE Program, 2020f, 2020g). This motivation was extended to their siblings and their families. See Appendix B for information about the student projects and their video submissions.

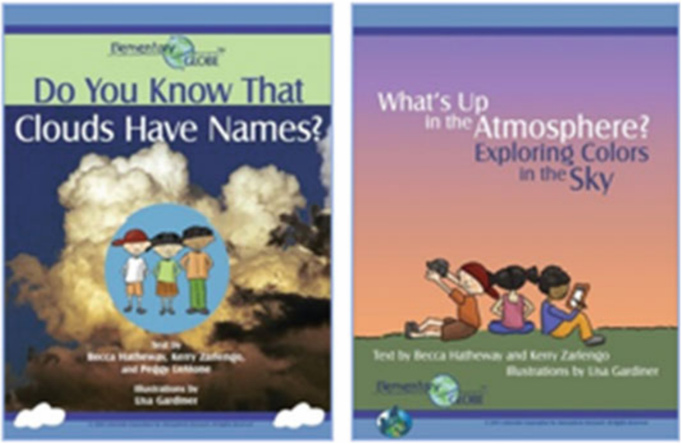


Fig. 19.10 Elementary GLOBE K-4 books covering clouds and air q. *Elementary GLOBE* open access materials (GLOBE Program, 2020c)

As a result of discussions, the younger siblings were able to explain what a hurricane was like, how the wind speed changed at different sites of Hurricane Dorian by measuring satellite images of Earthnull School and HoloGLOBE, and the size of the hurricane and its displacement using the Worldview software. Students also consulted sources of heat and smoke from the Amazon fires and their movement to Argentina. Both events were in the media at the time allowing students to study phenomena as they occurred. These topics were discussed in their homes and the students taught everyone, even the adults. These experiences motivated the young children to observe the sky and clouds in their city and provided insight into the value of validating information by comparing their measurements with data from satellites. All the siblings remembered the names of almost all the clouds. Our data were consistent with other findings indicating that students who participate in the GLOBE Program acquire a deep understanding of the topics investigated, of natural phenomena, and develop research skills and motivation to learn by considering it a pleasant experience (Činčera et al., 2019; Kennedy & Henderson, 2003; Prieto & Chrobak, 2016).

The pictures that the families received from the teachers and research documenting the activities carried out at the school were another motivating factor for the learning of the younger siblings. Many parents said they had learned from their children's explanations, and that conversations at home included all family members. All families reported that their children, including the younger siblings, regularly watch science programs for children on television. This factor could have also positively influenced their motivation to research and learn new information about natural phenomena occurring near their homes.

19.8 Limitations

The number of students participating in this study was small. Therefore, although the study obtained good results, it is not possible to make broad generalizations beyond our findings. More research is required on direct and indirect experiences of students in their early childhood in different socio-economic contexts such as urban and rural settings. In addition, this study was carried out in an urban environment in the Patagonia region. It is suggested that future studies carry out similar research with young children in different regions of Argentina, as well as in other parts of the world, as it would contribute to an understanding of the implementation of PrBL experiences incorporating a STEM approach both in pre-primary classrooms and in areas of citizen science.

19.9 Conclusion

This study analyzed the learning of young children informally with the information they receive at home through their older siblings, their parents, the media, and others. The specific knowledge and skills obtained by the younger siblings indicated informal transfer of knowledge. Our findings revealed that students taught their siblings information they learned in school by implementing PrBL with a STEM approach to study real-world problems. Learning not only occurred with the younger siblings, but also with their parents and older siblings, as observed through their active involvement in making measurements and recording data as citizen scientists. The implementation of PrBL with a STEM focus at school was effective in motivating students and establishing a natural connection between the school and families. The role of the students and the high valuation of their parents influenced the learning of young children. The students carried out the same activities that they did at school in their homes so that their siblings and parents could become involved in their research. Similar findings were reported in kindergarten (Dilek et al., 2020).

The analysis of the interviews suggest that the students and their siblings felt that it was important to know about the state of the atmosphere and the climate, they also thought that their data were valuable and that they were contributing to the knowledge of atmospheric processes by scientists, consistent with other findings (Amos et al., 2020; Bonney et al., 2009; Hedley et al., 2013; Robin et al., 2005). Students feel that they are a part of a larger learning community when they participate in large scale research initiatives (Hayden et al., 2019; Kennedy & Henderson, 2003), reflecting a positive characteristic and outcome of participation in citizen science activities. Similar results were obtained in the application of the GLOBE Program in citizen science activities carried out with children (Penuel & Means, 2004; Shin & Park, 2020).

Motivation is a field of study of great relevance in education. Research has shown that the effective psychological determinants of motivation include the individual's perception, the beliefs and attitudes of the tasks or behavior (it is fun, exciting, it is useful), their self-competence or self-confidence (the individual feels competent to carry out a task or behavior), considers it achievable (evaluates it as easy) and collaboration with others (the presence of people who can help when the individual needs them) (Wigfield et al., 1998). The motivation for science learning refers to the mental state, the driving force, and the willingness to learn a specific science task. It consists of relevance for learning content and goal orientation (Shin et al., 2017). Therefore, it can be said that the students were motivated to learn and felt competent in their learning and capable of teaching siblings to carry out scientific activities outside of school. The younger siblings were motivated to learn science, engaged in balanced play at home involving activities associated with those of a scientist, and are looking forward to future science research and learning when they enter school (kindergarten). Consistent results have been reported in similar research experiences (Samarapungavan et al., 2011; Tippett & Milford, 2017).

By investigating real-world problems, children began to perceive science as fun, exciting, and possible to perform. Our findings are similar to other studies reporting that children's scientific motivation increases when they are exposed to scientific endeavors and implement STEM educational activities (Mantizicopolus et al., 2008; Patrick et al., 2008).

19.10 Recommendations

Although STEM disciplines are increasingly included in the educational experiences offered to children of all ages, more information is needed on how to integrate STEM disciplines in early childhood environments, specifically in preschool and first grade, as well as how to implement STEM disciplines within citizen science efforts. For this reason, additional research in this area is required.

Early STEM education provides very good opportunities for young children to develop twenty-first century skills and a greater understanding of the scientific process, especially in outdoor environments. The Buckinghamshire Council provided a list of recommended activities that encourage early learners to exhibit the characteristics of effective learning (COEL) in outdoor environments (Buckinghamshire Council, 2020), highlighting example activities that link to playing and exploring, creating and thinking critically, and active learning. Additional recommendations we believe lead early learners to fully participate and engage in their learning by thinking, discussing, investigating, and creating include the following:

- Education policymakers, teachers, and trainers should work collaboratively to integrate outdoor STEM activities and practices beyond the playground into preschool (pre-primary) environments.
- Support for the implementation of STEM activities can be carried out by generating associations of scientists, education specialists and teachers (STEM learning

communities) to design and implement STEM practices for young children suitable for formal and informal education settings.

- Implement a link between school and home that works as a support system to develop early science education and helped teachers to carry out STEM practices.
- "STEM activities at home" can be generated to involve families in the learning process of their children. A variety of open access resources are listed below.
  - 11 engaging STEM activities for kids that will foster curiosity: https://www.rasmussen.edu/degrees/education/blog/simple-stem-activities-for-kids/
  - 10 STEM Activities You Can Do At Home: https://kiddieacademy.com/2018/04/10-stem-activities-you-can-do-at-home/
  - Boston Children's Museum—STEM SPROUTS https://bostonchildrensmuseum.org/stem-sprouts
  - Connect with iNaturalist scientists from around the world: https://www.inaturalist.org/
  - OMSI Weekly Science at Home: https://omsi.edu/at-home/weekly-science-activities
  - NASA STEM Engagement: https://www.nasa.gov/stem-at-home-for-students-k-4.html
  - STEM Activities for Kids: https://stemactivitiesforkids.com/
- Our research analyzed the implementation of the GLOBE Program in the classroom context and as citizen science. Other similar programs with different themes can be searched to create STEM implementation opportunities at formal and informal contexts in pre-primary and primary learning environments.
- Future studies may investigate how long-term STEM activities contribute to young children's social, emotional, and language development.

STEM education supports and encourages the development of analytical minds that think critically, solve problems, and are eager to contribute to society. "Particularly in the twenty-first century, but actually always, learning begins and ends with individuals, not institutions. We need to build an education system of the entire community, not based on the structures of these institutions" (Traphagen & Traill, 2014, p. 14). Young children enjoy and learn from exploring the world through STEM experiences. One way to promote child-driven play in support of STEM learning is through providing purposeful learning experiences incorporating balanced play in outdoor environments.

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Appendix A: Daily Activities Table

Days	Topic	Activity	Details	Place
1	Introducing the problem	Preconceptions of the problem and explanation about an investigation Scientific/engineer difference	Multimedia presentation. Basic cloud types. Atmosphere, water cycle. Air pollution Discussion to explore preconceptions Scientific vs engineer drawing. Leonardo da Vinci Bridge[a]	Multimedia classroom
2–3A	Designing a Research Plan: Clouds	Cloud Types: Story[b], Poster[c] Using cloud chart, Sky Viewer[d] and the GLOBE Observer application[e]	How does cloud cover influence air temperature in Junín de los Andes? How did low and dense clouds influence air temperature in September and October 2019? Which clouds were the most common during September and October 2019?	Classroom, playground
2–3B	Designing a Research Plan: Air Quality	Air Quality: Story[f] Using HoloGLOBE[g] application to view satellite images of the day	How do the amount of aerosols influence the color of the sky and visibility? Why the changes in the color of the sky and visibility that occurred in September and October 2019? What is the relationship between cloud cover and the color of the sky?	Classroom, playground

(continued)

(continued)

Days	Topic	Activity	Details	Place
From here began the daily observation of cloud types, coverage, sky color and visibility in the schoolyard by small groups (measurement 5 to 8 min). Watching with GLOBE Observer from their homes with their families (voluntarily, using their parents' phone)				
3	Color of the sky	Lab experiment	Sky Color experiment[h] to interpret colors and visibility. Consultation at HoloGLOBE[g] heat sources	Laboratory
4	Artificial clouds: Contrails	Types of contrails	Types of contrails: To Spread or Not to Spread Activity[i] Recognition of the types of contrails left by airplanes. Air traffic[j]	Classroom
5	Cloud coverage	Estimating cloud coverage	Estimating Cloud Cover Activity: A Simulation[k] Cake and Bar Chart with Percentages	Classroom
6	Preliminary data analysis	First analysis of data from its records on the type and coverage of clouds in the city of Junín de los Andes	Making a bar chart poster (from your own data) with the percentage of each type of cloud and another with the percentage of cloud coverage over a month	Classroom

(continued)

(continued)

Days	Topic	Activity	Details	Place
7	Satellite images	Consult satellite information about the state of the atmosphere (temperatures, winds, aerosols) in different places and dates with Earth nullschoool[l], Worldview[m] and Meteoblue[n]	Consultations for Junín de los Andes and other sites. They also observed large events: (a) Hurricane Dorian and measured wind speed, temperature at different sites. (b) Fires in Russia and the Amazon. CO pollution in China. Dust from the Sahara to Central America and the Amazon. They made searches at different points. Many children spontaneously asked for the links to show their families	Computer room
8	Effect of cloud coverage on temperature	Laboratory experiment Surface temperature	Clear vs Cloudy[o] Experiment Adapted surface[p] temperature, measuring in the experiment and other surfaces in the lab and in the yard	Laboratory and playground
9	Preparation for videoconferencing with NASA	Space agencies. Videoconferencing communication test	Preparation of students for videoconferencing with a NASA scientist. Explanation about space agencies NASA, ESA, CONAE. Discussion on the work of astronauts, satellite space station, scientists on the ground, satellites, and data analysis. Videoconferencing communication practice with the videoconference	Classroom

(continued)

(continued)

Days	Topic	Activity	Details	Place
10	Video conferencing from NASA	Videoconference with Marilé Robles Subject. Discussion of a month's results on cloud types, coverage, sky color, aerosols, etc	In the video conference were together the two groups, Third-grade A and B students. Also, there were parents and directors observing. Activity with regional media impact[q]	Multi-purpose room
11–3A	Comparative analysis of satellite images and field measurements	Data analysis of records taken during September and October 2019. Analysis of satellite images of Earth nullschool[l], Worldview[m] and HoloGLOBE[g]	Record of coincidences with onshore and satellite observations of cloud coverage in Junín de los Andes. Cloud coverage area observation	Computer room
11–3B			Record of coincidences with observations on land and satellites of heat sources, aerosols, and sky color in Junín de los Andes. Cloud coverage area observation	Computer room
12	Research report (written)	Writing the research report in written form in the notebooks	Check the materials and results for writing the report. Group elaboration and writing in the notebooks	Classroom
13	Research report (video script)	Elaboration of a research script to make a report in video format. Recording rehearsal	Preparation of the script. Essay and first video recording of presentations with different students	Classroom
14	Research report (video)	Final video recording	Final recording of the video with the participation of all students explaining different aspects of research	Multimedia room

(continued)

(continued)

Days	Topic	Activity	Details	Place
15	Presentation at IVSS 2020	The teachers subsequently uploaded research reports in both formats to GLOBE-IVSS 2020[r]	Influence of clouds on air temperature in Junín de los Andes GLOBE: https://bit.ly/39OcR0m Influence of aerosols in the color of the sky and visibility in Junín de los Andes. https://bit.ly/39XbrkD	Internet

[a]Leonardo da Vinci's self-supporting bridge https://youtu.be/rwTaGqnuU-I
[b]Clouds Module—Storybook: Do You Know That's Clouds Have Names? https://www.globe.gov/web/elementary-globe/overview/clouds
[c]Clouds Module—Activity Cloudscape.
[d]Sky Viewer https://mynasadata.larc.nasa.gov/lesson-plans/sky-viewer
eGLOBE Observer application and resources https://observer.globe.gov/es/do-globe-observer/clouds
[f]Air Quality Module—Storybook: What's Up in the Atmosphere? Exploring Colors of the Sky https://www.globe.gov/web/elementary-globe/overview/air-quality
[g]HoloGLOBE app https://www.globe.gov/es/web/mission-earth/overview/teacher-resources/lesson-plans
[h]Ski Condition https://scool.larc.nasa.gov/lesson_plans/SkyCondActFULLv2-2.pdf
[i]Contrails—To Spread Or Not To Spread https://bit.ly/3gRXO9z
[j]Air traffic https://www.flightradar24.com/
[k]Cloud coverage estimation https://bit.ly/2RLtFlb
[l]Earth Nullschool https://earth.nullschool.net/
[m]Worldview https://worldview.earthdata.nasa.gov/
[n]Meteoblue https://www.meteoblue.com/es/tiempo/semana/jun%c3%adn-de-los-andes_argentina_3853350
[o]Smith, S. M., & Owens, H. B. (2003). Clouds and the Earth's radiant energy system. Investigating the Climate System. Problem-Based Classroom Modules. *National Aeronautics and Space Administration (NASA)*. 7–10 p.
[p]Surface Temperature Protocol https://www.globe.gov/documents/348614/7537c1bd-ce82-4279-8cc6-4dbe1f2cc5b5
[q]The Morning of Neuquén, NOVEMBER 14, 2019. https://www.lmneuquen.com/alumnos-junin-se-conectaron-la-nasa-n665378
[r]GLOBE IVSS 2020 https://www.globe.gov/news-events/globe-events/virtual-conferences/2020-international-virtual-science-symposium

Appendix B: Student Projects and Presentations

Project 1: Influencia de las nubes en la temperatura del aire en Junín de los Andes

GLOBE Program project link (Link de la publicación en GLOBE): https://bit.ly/39OcR0m

Research report (Informe de investigación): https://bit.ly/2HCxhNW
Student video: https://youtu.be/3if28Vf4AXg

Project 2: Influencia de aerosoles en el color del cielo y visibilidad en Junín de los Andes

GLOBE Program project link (Link de la publicación en GLOBE): https://bit.ly/39XbrkD
Research report (Informe de investigación): https://bit.ly/37BnkuV
Student video: https://youtu.be/3RBWp_uvcew

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Chapter 20
Early Years Informal Science Education Programme in Mauritius: A Systemic Approach by the Rajiv Gandhi Science Centre

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Abstract Children are budding scientists. They are active explorers of the environment and may learn much about the living, material and physical world through play. The inherent curiosity of young children needs to be nurtured and sustained by the adults present in their life: parents and teachers. This would be possible only if these adults are adequately empowered to support science learning opportunities in young children. In this chapter, we describe how the Rajiv Gandhi Science Centre, as a centre for informal science learning, is implementing its early science education programme in Mauritius. We discuss the systemic approach undertaken by the centre through a strategy of collaboration between teachers, parents, children, as well as supervisors of the early childhood education sector. The educational programmes of the centre include a science exhibition by pre-schoolers and continuous professional development of teachers. We attribute our success to the institutional collaborations and support of the Ministry of Education, Tertiary Education, Science and Technology. Finally, we identify some opportunities that the science centre and similar institutions, may explore to support the teaching and learning of science in the early years.

Keywords Science Centres · Informal science education · Mauritius · Continuous Professional Development · Science exhibition · Early years

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20.1 Introduction

There is an increasing understanding and recognition of the power of children's early thinking and learning as well as a belief that science may be a particularly important domain in early childhood (Eshach & Fried, 2005). It serves not only to build a basis for future scientific understanding but also to build essential skills and attitudes for learning. From birth, young children are active explorers of their environment. They learn and construct their knowledge and understanding by doing, questioning and discovery. For example, children may learn about the living world by observing plants and animals in nature and engage in gardening and petting activities. Interaction with the material world may start in the home environment, while learning about the physical world may be developed through play such as swings, slides and ball-playing (Sheridan, 1990).

Children are intuitive scientists (Gopnik, 2010; Johnston, 2013). They have a natural tendency to enjoy experiences in nature by actively engaging themselves with the environment. Experiences which take place outside of the school environment are mainly informal learning experiences.

Though devoid of structure like formal schooling systems, these learning experiences are essential to building scientific process skills, concepts and knowledge. Thus, right from an early age, scientific and mathematical reasoning and conceptual development are ignited. As such, adults have a crucial role to play to nurture this process. Children may interact with adults who play different roles in families and in school environment. Such social interaction with adults sometimes occurs during children's social engagements and when they visit informal learning institutions like science centres and museums, accompanied by parents/relatives and/or teachers. However, the adults themselves need to be fully equipped to support the children in their scientific journey. Science centres act as drivers of informal science education in many communities. Apart from being a place where children may visit science exhibition galleries and enjoy learning through play, several science centres are intricately engaged in supplementing the school education system. In this chapter, we describe how the Rajiv Gandhi Science Centre (RGSC) (see Fig. 20.1), the only science centre in Mauritius, is actively engaged in promoting science in the early years in Mauritius.

The aim of this chapter is to highlight how science centres may support early years' science education using the case of the Rajiv Gandhi Science Centre as an example. We describe the ongoing collaboration between RGSC and other institutions and highlight some programmes of the centre that promote the teaching and learning of science in the early years.

Fig. 20.1 Children visiting the Rajiv Gandhi Science Centre during the National Science Week 2018. The centre houses six exhibition galleries where visitors engage in hands-on exhibits and learn through play

20.2 Activities of RGSC

RGSC is a parastatal body operating under the aegis of the Ministry of Education, Tertiary Education, Science and Technology. One of its objectives is to supplement school education through non-formal and informal education programmes. During the past five years, there has been increasing recognition that the national curriculum of pre-primary schools (3–5 years) should include science as an essential component. The National Curriculum Framework of the Early Childhood Care and Education Authority (ECCEA) stipulates that 'body and environmental awareness' and 'mathematical and logical thinking' should form part of the six main learning areas to be fostered at the pre-primary level. Particular emphasis on advocating for the development of scientific thinking right from pre-primary schools has started in the wake of the decline in the number of students opting for science subjects at the Cambridge GCE O-level and GCE A-level examinations (Maulloo & Naugah, 2017), out of which the intake of biology subjects is alarmingly low.

We believe that if children's love for science and logical thinking skills are triggered, sustained and supported right from an early age, this love for science may burgeon into a longer-lasting interest. This will result in well-developed scientific inquiry skills, required for the later years of their development. We focus on the empowering of adults who play an active role in supporting science learning opportunities in young children: pre-school teachers, pre-school supervisors and parents. In this direction, RGSC has adopted a systemic approach for the Early Childhood Science Education programme. Instead of focusing solely on children, several programmes have been set up by the science centre to support the adults who influence children's life: collaboration with educational authorities, Continuous Professional Development (CPD) of teachers, parents, and children themselves.

20.2.1 Continuous Professional Development of Teachers

In line with the UN Sustainable Development Goal 4, Quality Education, Mauritius aims at ensuring inclusive and equitable quality education. To achieve this goal, it is crucial that teachers are equipped with necessary tools to support children and forge them into valuable assets of society. Thus, teacher training is the core of the education system to develop a culture of achievement and excellence. The Mauritius Institute of Education (MIE) provides professional teacher training programmes for pre-primary, primary and secondary schools. However, post-secondary education is not a pre-requisite for being recruited to teach the early years in Mauritius (3–5 year olds). Several teachers join the service well before they embark on post-secondary studies in education, indicating a limited exposure to science subjects during their formal schooling.

A survey conducted among 132 pre-primary educators during a CPD workshop by the RGSC revealed that 90% of the participants did not opt for science subjects beyond O-Level, including 42% who abandoned after the grade at which science subjects are compulsory (age 15 years) (Kamudu Applasawmy et al., 2016). The same survey highlighted how these Mauritian participants are appealing for more CPDs on hands-on activities specific to science despite their rating of their knowledge of science as sufficient to teach science in the early years. Thus, if inquiry-based science activities are to be introduced in pre-primary classrooms, these educators need more exposure to hands-on science to enhance their Pedagogical Content Knowledge (PCK).

In an attempt to support the teaching of science in the early years, RGSC has implemented a series of workshops on how to teach science creatively in the classroom to empower teachers, enhance their scientific literacy and supplement their science PCK. The staff of RGSC are trained science communicators but are not pedagogically equipped to work directly with young children. Therefore the approach is to target children through their teachers by empowering them during the workshops. The workshop is also an opportunity for teachers who are engaged in the practice to exchange ideas with their peers.

20.2.1.1 The Teacher Workshops

Since 2016, RGSC has been organising highly activity-oriented workshops targeted at pre-primary school teachers and supervisors in the Republic of Mauritius. The activities proposed cover mainly the 'body and environment awareness' and the 'mathematical and logical thinking' areas of the ECCEA National Curriculum Framework.

These hands-on workshops focus on helping the pre-primary teachers engage the children in hands-on science based activities that will help them develop essential science process skills like observation, classification, pattern-seeking, hypothesising, interpretation and prediction. The aim is to empower the teachers (mostly females) to develop their own self-confidence in conducting science investigation and provide them with resources so that they may ulitmately implement in pre-school classrooms.

During these workshops, instructional booklets covering different science topics (for example, Light, Sound, Energy, Electricity, Magnetism and Air), and all the necessary materials are provided to the pre-primary school teachers and supervisors. These experiments make intentional use of low-cost or no-cost materials to ensure that they are budget-friendly and can be easily reproduced in pre-primary schools. This also encourages children to bring their used materials from home, such as shoe boxes, used paper cups, *etc.* so that they embrace the values of reuse and recycle. At the end of these workshops, participants were able to design, share simple group experiments to demonstrate and explain scientific concepts. We also encourage participants to identify challenges that they may face to conduct these hands-on classroom investigations and provide them with possible solutions.

20.2.2 Science Exhibition by Pupils and Teachers of Pre-primary Schools

Education is not just about feeding information. Since the early years, children are observers, and curious about themselves, objects, changes, and phenomena around them. They are always asking questions and trying to make sense of everything. To quench their thirst for knowledge, they are prone to prodding, pulling, tasting, pounding, shaking, and experimenting. From birth, children want to learn, and they naturally seek out problems to solve. Such attitudes and actions indicate that young children engage in scientific thinking and behaviour long before they enter a classroom. Adults need to tap this unique potential by encouraging inquisitivity, observation and questionning among children. In this context the Kiddy Science Fair, which is a joint initiative of the Rajiv Gandhi Science Centre and the Early Childhood Care and Education Authority, is regularly organised at the centre. The event takes the format of a science exhibition designed for and by the teachers and pupils of pre-primary schools during which they display their science-related works to the public.

The objectives of the Kiddy Science Fair are: to encourage teachers and children to engage in science projects at school; to provide a platform for teachers to showcase, disseminate, and share experiences in the field of early childhood education in Mauritius; and, to complement formal education by developing creativity and adopting a "minds-on and hands-on" approach to the learning of science among pre-schoolers.

Fig. 20.2 Group of teachers working collaboratively during hands-on activities

20.2.2.1 The Kiddy Science Fair

During the Kiddy Science Fair, the teachers and supervisors of pre-primary schools in Mauritius have the opportunity to apply their knowledge gained during their CPDs at RGSC to classroom situations (Fig. 20.2).

For approximately three months, the teachers help the pre-schoolers (3–5 year olds) prepare their science projects for the Kiddy Science Fair. The pupils go through a process of active learning of science through hands-on science activities involving group work. They engage in sense-making discussions with their teachers who act as facilitators, which correspond to the student-centred, constructivist Reggio Emilia approach (Edwards et al., 1993).

Science projects presented are in the form of puzzles, games, puppets, models, potted plants, posters, *etc*. Students also develop their artistic, aesthetic and social skills to work while realising their projects. This includes manipulating materials such as scissors, glue, paper, soil, and sand, thereby developing their cognitive thinking, creativity, fine motor skills and emotional skills (Fig. 20.3). Each year more than 120 projects from 100 pre-primary schools are displayed in the exhibition. The exhibition remains open to the public for four days and is attended by a large number of family visitors. This annual display of projects by teachers and pupils has been ongoing since 2015 and has been a success story: a cumulative attendance of more than 11 000 visitors and media coverage including highlights in the national television news, whole page articles in newspapers and TV documentaries broadcasted. During the fifth edition, 158 projects from 156 schools were displayed.

20.2.3 Visit to Galleries

Pre-primary schools and parents with young children are encouraged to use RGSC as a resource centre by organising regular visits to the centre. Organised educational trips on science themes (water, astronomy, environment, *etc.*) can be planned upon request. In the same vein, RGSC encourages pre-primary school pupils to visit the centre

Fig. 20.3 Projects displayed during the Kiddy Science Fair (a) Plant pots made by reusing low cost household materials. (b) Illustration of a water cycle. (c) Poster using handprinting on the theme Reduce, Reuse, Recycle. (d) Model of earth and the night-day cycle. (e) Model of Mauritius island. (f) Plant pots made of old plastic bottles

together with their families to discover science and allows bonding with their family through this shared experience. The science centre houses six exhibition galleries where science learning is minds-on and hands-on. The conceptual development of the exhibition is to foster group learning through a play-based approach. Children are always eager to learn new things through play, puzzles and games. These activities help them to acquire problem-solving skills by training their brains to find quick solutions through the application of the scientific method of observing, hypothesising, predicting and manipulating (Tunnicliffe, 2013).

The exhibits enable children to engage in active as well as exploratory or manipulative play. Figure 20.4 shows a young child engaging with the roller-coaster exhibit whereby the ball is released from a height and moves along a series of humps at high

Fig. 20.4 A four-year old child enjoying, exploring and engaging with the roller coaster exhibit (Photo permission: B. Kamudu)

speed. The child is manipulating the exhibit, developing his fine motor skills while engaging in observation.

Exhibitions at the science centre also aim at fostering family ties where parents guide their children during interaction. In Fig. 20.5, a mother is helping her children with the Tornado exhibit and the children learn collaboratively with each other as they observe the water swirling in the vortex.

Fig. 20.5 A mother guiding her children and encouraging them to observe the vortex formed by the swirling water in the Tornado exhibit (Photo permission: B. Kamudu)

20.3 RGSC's Collaboration with Educational Authorities

With the onset of its early childhood science education programme, RGSC has developed a close collaboration with educational authorities responsible for early childhood education. As such, RGSC has an agreement with the Early Childhood Care and Education Authority (ECCEA), whose function and power are to advise, formulate and implement government policies regarding early years education. ECCEA sets norms and conducts supervision of institutions engaged in early childhood care and education. The institution has a supervisory role over the pre-primary schools, ensuring the safety of children and quality education. If RGSC's strength is in developing hands-on science education programme, it has limited access and resources to reach out to pre-schools. Thus, the full support of the ECCEA ensures that the education programmes reach out to teachers and children. In this line, we first addressed the needs of the supervisors of ECCEA whose role is to reach the grassroots—a total of 851 public and private pre-primary schools in 2019 (Ministry of Education, Tertiary Education, Science and Technology, Education Statistics, 2021). The supervisors of ECCEA are consulted during discussion for the implementation of the Kiddy Science Fair and teacher workshops.

Most importantly, separate training programmes on how to teach science creatively using low cost readily available materials, have been designed specifically to target supervisors. They may, in turn, transmit the information to teachers in schools and ensure that scientific inquiry is brought to the classroom. This train-the-trainer programme of RGSC ensures that a crucial link in the system is not left out. Figure 20.6 is a schematic representation of how RGSC engages with key stakeholders to promote science education in the early years.

The diagram is interpreted as follows:

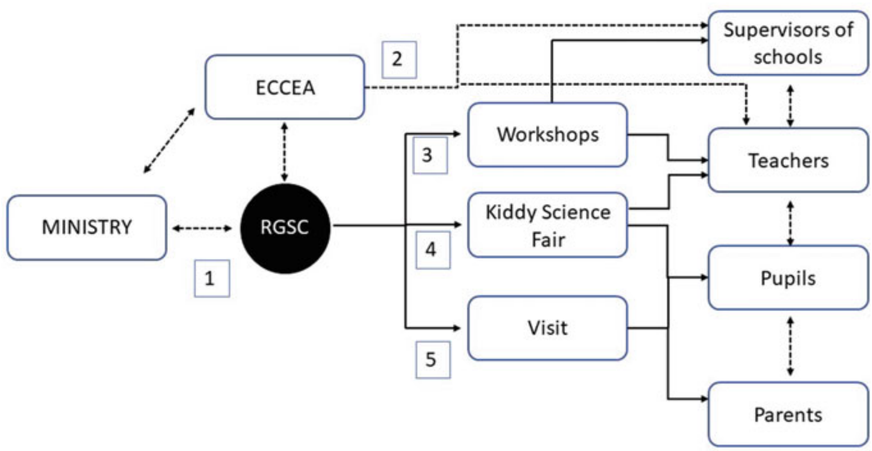

Fig. 20.6 Schematic representation of the systemic approach adopted by RGSC to supplement the teaching and learning of science in the early years

1. Both RGSC and ECCEA are two independent institutions operating under the umbrella of the Ministry of Education, Tertiary Education, Science and Technology, but each of the two institutions has separate mandates. RGSC is mandated to promote science while ECCEA is the supervising authority for early childhood education. RGSC having no control over pre-schools seeks the support of ECCEA for its programmes. ECCEA being also responsible for the delivery of the pre-primary curriculum, solicits the help of RGSC for science components.
2. ECCEA employs supervisors who closely follow up with pre-primary schools as they have direct access to schools and teachers.
3. RGSC organises hands-on training workshops targeting teachers and supervisors.
4. Teachers and supervisors use the knowledge and skills gained during the training workshops to develop the Kiddy Science Fair. The Kiddy Science Fair involves the participation of parents, teachers and children.
5. RGSC has exhibition galleries open for visits. We receive family and specialised school visits.

Thus, RGSC has an all-inclusive systemic approach reaching out to children, families, teachers as well as school supervisors. Institutional collaboration between ECCEA and RGSC is fully supported by the Ministry of Education, Tertiary Education, Science and Technology.

20.4 Conclusion

This chapter highlighted the role of RGSC in supporting the teaching and learning of science in the early years. The success of the early years' science education programme of the RGSC is attributed to the institutional collaboration and the all-inclusive approach which targets children through their teachers, the school supervisors from the ECCEA and the involvement of parents in following up the children's progress.

While numerous seminars and workshops for educators are regularly organised by several insitutions in Mauritius, a large number of these workshops emphasise on curriculum and assessment. CPDs for teachers in the early years are less frequent compared to those designed for educators of primary and secondary schools. Furthermore, CPDs that emphasise teaching STEM in the early years using hands-on and minds-on approach remain limited. RGSC has taken the initiative to enhance STEM education in the early years, which is part of its strategy to supplement formal school education. As a science centre in a small island developing country, RGSC has limited resources in terms of staff and logistics to reach out to all pre-primary schools in Mauritius. Yet, our strength lies in our ability to develop science educational resources that support teaching and learning. Institutional collaboration is crucial for our success in reaching out to this sector. Subsequently, there is a need for a national policy on STEM education in the early years to contribute holistically to the development of the education sector in the Republic of Mauritius.

20.5 Recommendations

Setting up educational programmes by a science centre is good; but it is best if the impact of the programmes is documented. The successes and challenges of RGSC deserve to be shared among a wider community. It is recommended that evaluation of the effectiveness of the educational programmes become increasingly embedded in the activities of RGSC and other like-minded institutions.

RGSC is investing resources in conducting workshops for educators and developing programmes such as Kiddy Science Fair to encourage the implementation of workshop activities in classrooms. However, little is known to what extent educators are implementing their knowledge gained from the workshops on inquiry-based STEM activities in their classrooms. Identifying and addressing the challenges faced by educators are also essential. It is proposed that the development of structured CPDs that are not one-off events but are extended over sessions spread across the year. This will better foster dialogue among the RGSC, the ECCEA and the relevant policy makers.

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She has been a Senior Adviser at the Ministry of Environment. She was a delegate who accompanied the present Minister of Education to the Science, Technology and Society Forum, held in Kyoto, Japan in 2015.

Bhamini Kamudu Applasawmy is attached to the education department of the RGSC for the past 12 years. She has played a key role in designing and implementing science education programmes for diverse audiences, which includes the development of educator workshops and the Kiddy Science Fair. She is a strong advocate for the recognition of the undisputable contribution of science centres and museums to science education. Bhamini holds a BSc (Hons) in Biology, MRes in Research Methodology and a PhD in Education. Her research interests are ‘interest and learning in informal learning contexts’, ‘science in the early years’ and ‘techniques for investigating museum experiences’.

Li Kim Khiook is a Resource Officer/Senior Resource Officer at the Rajiv Gandhi Science Centre since 2018. Part of his duties is to plan, organise and conduct non-formal educational programmes in the hope of making science accessible to all. He believes that to impart knowledge and instil enthusiasm and wonder for science to the public is so fulfilling that sometimes, he even forgets that it is work. Before working in science popularisation, Ian spent all his formative years studying sciences since he was a schoolboy and is a holder of a MSc in Plant Biology and Biotechnology from the University of Bordeaux, France. He has previously worked as a researcher studying grapevines and he has co-authored several peer reviewed scientific articles. Mr. Li Kim Khiook has been the coordinator of several projects like the Kiddy Science Fair and the Science Quest Competition and worked on conceptualising and developing Science Exhibition Galleries for the Rajiv Gandhi Science Centre.

Sookdeo Rungoo holds a BSc and MSc degree in Physics. He taught Physics to secondary level students for six years before joining the Rajiv Gandhi Science Centre in 1999. As Manager/Curator at RGSC he is specifically trained to run a Science Centre and exposed in areas like exhibition design, conceptual development of interactive participatory exhibits, exhibit testing, animation techniques, development of tailor-made educational programmes, Museum management techniques, evaluation of exhibits, visitor survey analysis and fabrication of exhibits and displays. During the last twenty years at RGSC he has planned, designed and conducted several tailor made programmes to various categories of students and the general public. He is dynamic, team-spirited and result oriented who utilises his combination of problem solving and analytical skills and experiences for the promotion of science and technology to all the segment of the population.

Aman Kumar Maulloo is the Director of the Rajiv Gandhi Science Centre since June 2007. He holds a PhD in Operational Research. At the Rajiv Gandhi Science Centre he is leaving no stone unturned to promote science and technology to all segments of the population by developing custom-made activities, encouraging hands-on science, and advocating a reasearch-oriented approach. This approach has led RGSC to be the Grand Winner of the National Productivity and Quality Convention in 2019 and 2020/21, and the team won Silver Award in the ICQCC'11 held in Tokyo, Japan in 2019. Strong local, regional and international collaborations enable RGSC to keep pace with the evolution of S&T. Dr Maulloo has a number of publications in high impact Journals and has edited a book entitled "Enhancing Change Through Science Centres."

Chapter 21
Diverse STEM Interest Development Pathways in Early Childhood

Scott Pattison and Smirla Ramos Montañez

Abstract As educators and researchers focused on science, technology, engineering, and mathematics (STEM) learning, we often adopt a relatively narrow view of the STEM domains, based primarily on how these topics are defined and taught in school. The concept of play, however, invites us to broaden this perspective and explore the diverse and interdisciplinary ways that children and their families engage with STEM in their everyday lives. Over the last several years, the Head Start on Engineering (HSE) initiative, based in Portland, Oregon, USA, has been developing a family-based program to engage preschool-age children (3–5 years old) and their families from low-income communities in the engineering design process and simultaneously study how these experiences support long-term family interests related to engineering. In this chapter, we describe findings from a retrospective interview study with parents one to two years after they participated in HSE. Through qualitative analysis of the interviews, three distinct interest pathways emerged: (a) engineering focused, (b) prior interest focused, and (c) family values focused. The findings problematize traditional approaches to studying STEM-related interests and highlight the importance of understanding the complex ways families make sense of and engage with STEM through play and other informal learning experiences.

Keywords Engineering · STEM · Interest development · Early childhood · Family learning

21.1 Introduction

Strong support for learning and development in early childhood creates a foundation for lifelong success (IOM & NRC, 2012; NRC, 2015). Science, technology, engineering, and mathematics (STEM) are critical topics in these early years (McClure

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et al., 2017; NASEM, 2016; NRC, 2001). Providing quality STEM learning opportunities for young children and their families prepares children for STEM education in school and, more importantly, instills a passion and interest in these topics that motivates lifelong STEM engagement (NRC, 2007; Renninger et al., 2015). Furthermore, practicing STEM skills and engaging with STEM topics can support a wide range of developmental domains for young children that are essential for success in school, work, and life, such as problem-solving, executive function, mastery motivation, and socioemotional learning (Gold et al., 2021; McClure et al., 2017).

A primary way that children encounter STEM before they enter the K-12 education system is through informal family- and play-based learning experiences (Gopnik et al., 2001; NRC, 2009). The concept of play in particular draws attention to the many ways that children and their families learn through experiences that are not explicitly didactic but nonetheless provide rich opportunities for STEM learning and child development more broadly (Fleer, 2019; Lai et al., 2018; Luke et al., 2017; Rogoff et al., 2016; Yogman et al., 2018). Research on children's play, family learning, and informal STEM education highlights the many ways that young children and their families engage in STEM practices, learn about STEM concepts, and develop STEM-related interests through everyday experiences. For example, families may discuss biological concepts during walks outdoors (Marin & Bang, 2018; Zimmerman & McClain, 2016) or engage in engineering design practices while building with blocks and other everyday materials (Bairaktarova et al., 2011; Gold, 2017). Studies of play also highlight how these concepts are deeply cultural in nature (Gaskins, 2008; Rogoff, 2003). The ways that families think about and value play, learning, and STEM vary greatly across and within cultural groups (Rogoff et al., 2003; Roopnarine & Davidson, 2015; Vandermaas-Peeler et al., 2019). And these varying beliefs and values in turn shape how young children and their families experience learning opportunities and connect these to future experiences (Garibay, 2009; Gaskins, 2008; Pea & Martin, 2010).

In our work, we are interested in the unique ways that *families with young children develop and pursue long-term interests related to STEM topics and skills through these everyday, family-based experiences*. Through our research and family engagement efforts, we focus on the ways young children develop interests in topics and activities related to STEM and how these interests develop reciprocally between children and other family members, using the family as our unit of analysis (Pattison et al., 2016, 2020; Pattison, Núñez et al., 2018; Pattison, Weiss et al., 2018). In the long term, we hope to better understand how STEM-related interests develop in early childhood, the unique ways that these interest development patterns are shaped by family beliefs, experiences, and values, and the types of educational resources that can support long-term interest development, especially for families from communities that have traditionally been marginalized in STEM education.

In this chapter, we share findings from retrospective interviews with 18 parents one to two years after they had participated with their children in a five-month early childhood engineering engagement program for low-income families based in Portland, OR, USA. At the time of the program, the children were preschool age (3–5 years old). Using engineering as a case study for our broader focus on

STEM-related interest development, we reflected with parents on the unique ways that children and their families had extended the interests sparked or reinforced in the program through their ongoing, family learning experiences. Based on our in-depth qualitative analysis of the interviews, we describe the different interests that emerged for families from the engineering-based program and explore how these findings broaden our perspective on the way STEM is reflected in early childhood, family- and play-based learning.

21.2 Study Context

Our research on early childhood family interest development has emerged as part of the ongoing Head Start Engineering (HSE) program—a collaborative initiative led by TERC in partnership with Mt. Hood Community College (MHCC) Head Start, University of Notre Dame, and the Oregon Museum of Science and Industry (https://hse.terc.edu). HSE is a multi-component, bilingual (Spanish and English), family-centered program designed to engage preschool children and their families from low-income backgrounds in the engineering design process. The overarching goal of HSE is to build on existing family knowledge and assets and help families develop long-term interests in engineering and science so that they will have the skills, knowledge, and confidence they need to be successful in an increasingly STEM-rich world.

The program focuses on the engineering design process, rather than the field of engineering, as a topic and skill that is highly relevant to the lives of families and early childhood play (Bairaktarova et al., 2011; NASEM, 2020; Tõugu et al., 2017). In the program, engineering is described as "designing and testing ideas to solve problems in work and life" and the engineering design process is introduced as an iterative cycle: ask, imagine, plan, create, and improve (Cunningham, 2018) (see Fig. 21.1). The ask step involves understanding the engineering design problem and what you need to solve it. The image step involves brainstorming as many possible solutions and designs as you can. Planning is when you select a design and determine how to build it and what materials you need. Create is when you both build and test your design to see how well it solves the original design problem. And finally, the improve step involves making changes based on what was learned through the testing process. Although this cycle is an oversimplification of the process used by engineers (Crismond & Adams, 2012), it provides a useful model to introduce families to engineering design and make connections to the ways they already use this process throughout their lives. It also emphasizes that engineering design is an ongoing, iterative process of continuously planning, testing, and improving.

HSE is integrated into Head Start, which is a national early childhood program in the USA run by the U.S. Department of Health and Human Services and designed to promote school readiness for young children (birth to age five) from low-income families (below the federal poverty line) through childcare centers, home visiting

Fig. 21.1 Overview of the bilingual (Spanish/English) engineering design process used in the Head Start on Engineering program and adapted with permission from Engineering is Elementary (Cunningham, 2018)

programs, and other parent engagement strategies (Ellsworth & Ames, 1998). Participation in Head Start is free, although availability may be limited in some regions. Locally, the MHCC Head Start program supports a diverse group of families from different cultural backgrounds, with a particular focus on families that identify as Hispanic/Latino. At the time of the current study, 44% MHCC Head Start families identified as Hispanic/Latino and 28% reported their primary language as Spanish.

The approximately five-month HSE program includes a three-part evening parent workshop series, four take-home family activity kits introduced during the workshops, classroom extensions mirroring the take-home activities, home visits, online support videos, and a culminating science center field trip (Pattison, Núñez et al., 2018; Pattison, Weiss et al., 2018). Families are recruited for HSE through fliers, announcements at parent meetings and other Head Start events, and by Head Start teachers and staff. The program is free for participants, and all parent workshops include childcare and dinner. All family members are encouraged to attend the events, although most participants are mothers and their preschool-age children enrolled in Head Start. Throughout the process, Head Start staff are provided training related to early childhood engineering education and are engaged as collaborators in program development and implementation.

The backbone of HSE is the take-home family activity kits that engage parents and children with the engineering design process through open-ended design challenges set in imaginative story contexts (see Fig. 21.2). Each activity kit includes a children's book, activity materials, and a parent facilitation guide. For example, the Fox and Hen activity kit, based on the book, *Oh No, a Fox!* (Stoeke, 2014), prompts families to build a structure with foam blocks to protect a hen and her chicks from a 1-foot-tall fox. In another activity, focused on process engineering, families are challenged to work together to create a process for building as many tacos as they can in 1 minute using felt ingredients and following different tacos recipes. One activity kit is introduced to families at each parent workshop, during which parents also learn about the engineering design process, share strategies for using the kits, and explore how engineering connects to everyday problem solving and children's play. Each family receives their own copy of the kits to keep and is supported throughout the year with additional resources, such as online videos, home visits, and a trip to the local science center.

The data presented in this chapter is based on retrospective, home-based interviews conducted in the spring of 2019 with 18 families who had previously participated in the HSE program one to two years earlier. The goal of the interviews was to understand how families had remained engaged and interested, if at all, in the engineering-related topics and activities from the program and what factors might have influenced their ongoing engagement. Ten of the interviews were conducted in English and eight were conducted in Spanish. Based on their eligibility for Head Start, all families had household incomes below the U.S. federal poverty line during their participation in HSE. At the time of the interviews, the children who had participated in the program ranged from 5 to 7 years old. When asked to self-identify their race and ethnicity through an open-ended question, ten participants identified

Fig. 21.2 A family engaging with the build-a-nest engineering activity from the HSE program (Photo ©TERC 2021)

as Latino or Hispanic, four as White or Caucasian, and one as African American. Three of the participants identified with multiple racial and ethnic categories (e.g., "White, Hispanic, Native American").

Data from the interviews were analyzed at two levels through an inductive, qualitative approach (Creswell, 2013; Patton, 2015). First, drawing from techniques in constructivist grounded theory (Charmaz, 2006), we iteratively reviewed the interviews to develop a code book that was used to systematically analyze the data and identity themes and patterns relevant to the research questions. Next, using a multiple case study approach (Yin, 2018), we developed narrative descriptions of the interest development stories shared by each family during the interviews to complement the coding analysis and identify broader patterns across families and over time (see Pattison & Ramos Montañez, 2021).

21.3 Theoretical Perspectives

Our long-term relationship with HSE participants has provided unique insights into how families develop and extend their interests related to the engineering design process and other STEM topics and practices, both during and after the program. Although conceptualizations differ, *interest* is generally understood to include both the spark of emotion we feel when we are excited or compelled to engage with something in a particular moment, as well as the more enduring motivation to re-engage with an object, activity, or topic that we may begin to associate with we who we are as a person (Ainley, 2019; Renninger & Hidi, 2016). Through this ongoing process of interest development, the positive emotion of interest becomes linked to a constellation of related constructs, including knowledge and values, all of which are influenced by new experiences and, in turn, motivate further engagement inside and outside of school (Azevedo, 2011, 2015; Gottfried et al., 2016).

Our perspective on interest development in early childhood draws from sociocultural frameworks (Bronfenbrenner, 1979; Rogoff, 2003; Vygotsky, 1978) and systems theories (Broderick, 1993; Cox & Paley, 1997; Hutchins, 2000) to conceptualize interest as a family-level, systems phenomenon. In early childhood, learning and development are arguably best conceptualized as multi-directional and distributed (NRC, 2000; Sameroff, 2009), with parents and other significant adults changing and learning in parallel with children and providing scaffolding and support as children gradually develop more skills, knowledge, and autonomy (NASEM, 2016; Rogoff et al., 1993; Vygotsky, 1978). Based on these perspectives, we define the *family interest development system* as parents' and children's interrelated predispositions (stated and enacted) to reengage with a focus of interest over time, as well as the connected set of beliefs, values, knowledge, and skills that influence and are influenced by this reengagement and are distributed across family members. From this perspective, these distributed aspects all influence family interest, and the sum of the aspects better characterizes the interest system compared to traits of parents or children considered independently (Pattison et al., 2016; Pattison, Núñez et al., 2018; Pattison, Weiss et al., 2018).

We also take a broad perspective on engineering-related interest development, acknowledging the unique ways that families themselves may define engineering, connect engineering design to their beliefs and experiences, and extend their interests developed and reinforced through the program. Interest studies typically use the researcher's own pre-defined domain framework, such science content, to investigate interest development (Renninger et al., 2015). However, as noted, the notion of play highlights the emergent, multi-disciplinary, and pragmatic ways that children and their families encounter and use STEM ideas and practices as part of their everyday lives (Bairaktarova et al., 2011; Fleer, 2019; Gomes & Fleer, 2019; Kliman, 2006). From a methodological and analytic perspective, this broad conceptualization of engineering-related interest required us to be sensitive to not only our definitions of engineering and how these were manifested in families' experiences, but also the unexpected ways that families connected with or extended their experiences with the HSE program and how these motivated ongoing patters of re-engagement and interest development. This conceptualization also aligns with asset-based perspectives on learning and education that focus attention on the existing STEM-related knowledge, skills, and interests that families bring with them to any experience and the critical importance of understanding and supporting these assets to create more equitable STEM education systems (Torres et al., 2018; Yosso, 2005).

21.4 Diverse STEM Interest Pathways

In the retrospective interviews, parents described a variety of ways in which their families had extended their interests since the HSE program. In this section, we provide a brief overview of three distinct interest pathways that emerged from the study and that illustrate the diverse ways that families interpret and extend their informal STEM learning experiences. These pathways are summarized in Table 21.1.

Table 21.1 Summary of family interest pathways

Interest category	Description
Engineering focused	The family increased their value for engineering, expanded their awareness of the relevance of engineering, and began to incorporate the engineering design process into everyday life
Prior interest focused	The family discussed how the HSE program supported and deepened an existing interest. These stories were often about child's continued interest in building or construction
Family values focused	The family built on ideas or activities from the HSE program in ways that extended or reinforced existing family values and beliefs, such as spending more time together or seeking out new experiences and adventures

During the interviews, some families discussed the ways they had continued to engage with and think about the engineering design process that was highlighted in the HSE program, including connections between engineering design and their children's play. Other families talked more about how the program had reinforced or extended prior interests that their children brought with them to the program, such as a love of building and creating. And a third group of families talked about how the program had connected with and helped them reinforce broader family interests and values, such as spending time together as a family or promoting children's creativity and imagination. We describe each of these groups in more detail below.

21.4.1 Pathway 1: Developing Engineering-Related Interests

> He's exploring more in the engineering world, now that we know it's not just for adults. Since HSE, we have had more awareness of the steps of engineering. We talk about it quite a bit. A lot of the time, when we are building, we talk about the steps. (Family 9)

In the first group that emerged from the analysis, families described long-term interests that were most directly relevant to the STEM focus of the program: engineering and problem-solving. During the retrospective interviews, these parents talked about how the program experience had helped them increase their value for engineering, expand their awareness of the relevance of engineering, and incorporate the engineering design process into everyday life, such as household chores, family play, and arts and crafts.

In the quote above from Katie,[1] the mother highlighted her awareness of the engineering design cycle and how this relates to everything they do, including building, problem-solving, planning family trips, art, and more. She felt that the HSE program was very impactful, introducing her to the engineering design process and helping her realize how engineering is relevant to her son's learning and development. She reported that she and her son had continued to use the HSE materials and seek out new engineering-related activities and experiences, such as science center visits, building materials like Legos, and engineering-related board games. She also implied that the family has incorporated the idea of engineering into their existing interests, connecting engineering to science and using the engineering design process to be more thoughtful about how they go about building and problem-solving. Katie described how the program changed her perspective on engineering, provided her with a new way of thinking about how she engages in play with her son, and even positioned her as a teacher of engineering for others. For example, she described sharing engineering-related activities and the engineering design process at her son's school and afterschool club.

Some families in this group explicitly used the term engineering in their retrospective interviews, similar to Katie above. Others, however, talked more broadly

[1] All names used in this chapter are pseudonyms.

about problem-solving. For example, when describing the impacts of the program, Molly (Family 21) focused on her daughter's increased interest in problem-solving and other broader outcomes, such as being more creative, finding different ways to play, thinking outside the box, trying new things, and not giving up. She mentioned that the program had expanded her ideas of engineering and connected it to the idea of problem-solving: "*The program overall was a really good opportunity to involve the kids in the foundation of engineering and problem-solving at a really young age. It did not seem like my concept of engineering at first. But it's really important—it opens their minds to different things. I can only relate it to problem-solving skills. If they have an idea, they can fill in the blanks and make it happen.*"

What was most striking about this group of families was the way that they all emphasized their recognition of the relevance of engineering process to everyday life and subsequently found ways of further incorporating and highlighting engineering in their family learning experiences and routines, including the ways that they talked about playing with their children. In our past work, we have described this recognition as potentially a critical shift for STEM-related interest development—allowing families to see the relevance of engineering to everyday life and opening up new opportunities for extending engineering-related interests (Pattison et al., 2020; Pattison, Núñez et al., 2018; Pattison, Weiss et al., 2018). For Katie, her family not only found ways to more explicitly incorporate the engineering design process in their play, but she also discussed how she applies the engineering design cycle in her own life (e.g., her art and tattoo practice) and has taken on a teaching role, sharing engineering and the engineering design process at her son's school and afterschool club. Similarly, for Francisca (Family 2), the engineering cycle has also provided a different way of engaging activities by breaking the activity in steps. As she noted, *"Siempre estamos haciendo ingeniería, siempre. Eso se me ha quedado en la mente siempre y podemos lograr hacer ingeniería." [We are always doing engineering. This has always stuck in my mind, and that we can do engineering ourselves.]* The mother also described the ways she thinks about the engineering process as she plays with her child, such as making a car track:

> "Bueno, a veces cuando tengo que ensenarle a mi niño como hacer la pista de carro lo llevo paso a paso. Le digo imagínate como las puede hacer, no tienes que hacerla de la misma manera que está en la foto de la caja. Cuando la construye lo invito a que piense si lo puede mejorar y le digo que si que puede mejorar. A veces le cuesta trabajo a él, pero seguimos intentando." [At times when I have to show my son how to make the car track, I take him step by step. I tell him to imagine how you can make it. You don't have to do it the same way as in the photo on the box. When he's building, I encourage him to think about how he can improve the design, and I tell him that yes, he can make it better! Sometimes it's difficult for him, but we keep trying.] (Family 2)

21.4.2 Pathway 2—Extending Prior Interests

> He really liked building before. That's why the teacher suggested the HSE program to us. He really enjoyed all the activities. It got him going with trying to build with other things and materials. For example, we got him those magnetic blocks. He'll build houses, parking for cars, and more. If you can build it from foam blocks, you can build it from other things! This has continued through kindergarten. He will come home and say, 'I have an idea,' and start taking out his building supplies from beneath his bed. (Family 12)

A second group of families talked less about the way the program has initiated a new area of interest related to the engineering design process but instead focused on the ways that the program had connected with, reinforced, and extended prior child interests within the family. Two families were particularly explicit about how the program had extended and deepened their children's prior interests, and in both cases these prior interests were related to building and making (see Fig. 21.3). For Family 12, quoted above, Luciana connected the HSE program experience to her son's ongoing interest in building, which they have tried to support with new resources like magnetic tiles. She stressed how her son's interest in building was present but that it evolved and deepened throughout HSE and subsequent experiences. If fact, as she mentioned, their Head Start teacher specifically recommended them for the program because of his interest. The program seemed to also connect with and help extend several other areas of interest for this family. For example, Luciana associated the HSE experience with science and talked about wanting to get more hands-on science activities for her kids. She also talked about the impact of the program in terms of their ongoing use of the activities and supporting existing family interests related to building, crafts, and hands-on exploration. She said one broad change has been

Fig. 21.3 For several families, the HSE program extended and deepened existing interests related to building and making (Photo ©TERC 2021)

the motivation to do more activities with her children like the HSE activity kits or activities based on books.

Janice (Family 25) similarly described how her son Chris had always been into building and how the program extended and deepened this interest, especially motivating her son to build more specific things, rather than just towers: *"He'll build helicopter pads, trains, and other things with the sets at his therapist office. Legos are a favorite. He just started getting interested in Legos and using his imagination to build. Since the HSE activities, he's really started making more designs and play structures instead of just higher or taller. He makes items with them."* Although there was no mention during the interview of the family continuing to use the HSE activities and materials, Janice talked about providing a variety of new experiences and resources for her son's love of building, finding other hands-on activities or programs for him, and regularly talking about how things work. She said that through the program her son had been more motivated to ask questions. In turn, she described her job as helping him *"understand how things work and why."*

Like many families in the study, both parents from these two families also connected their own prior interests to their children's interest stories. Luciana (Family 12) talked about her love of building and how she shared this interest with her children: "*I personally like building. My husband says I'm crazy. I like to buy things from Ikea and put them together. And my kids help—they love it! We got them an air hockey table for Christmas. They loved building it. Loved learning how things worked.*" And although she didn't make an explicit connection to an interest in building, she also mentioned her husband's job fixing cars as another possible family influence. In the same way, Janice (Family 25) highlighted her dad's profession and her own love of building and thinking about how things work: "*My dad builds tow trucks. So, things like angles, how to lift things. This has always been part of my life. These things are really interesting to me because they are involved in daily life.*" According to her, the family interest in engineering and building, related to her father's tow truck business, seems to have been an important influence on the ongoing connection to the program.

21.4.3 Pathway 3—Reinforcing Family Values

> Creo que la parte que nos quedamos después de todo eso fue estar en familia y tener la costumbre de trabajar esto por las noches. Cuando nos vamos a acostar, leer libros y pensar en cosas que podemos hacer siempre relacionado a los libros. [I think that the part (of the program) that stayed with us was spending time together as a family, creating that habit of working on these activities at night. Before we go to bed, we read books and think about what we can do related to those books.]. (Family 27)

A third group of families spoke about the ways the HSE program had connected with and helped them reinforce broader family values, beliefs, and interests beyond engineering or building. In the quote above, Lorena (Family 27) talked about the importance of family engagement and how she appreciates activities that support the family spending time together. This is a value she emphasized throughout her interview. As she said, *"Tratamos de practicar eso para que ellos sepan que estamos juntos y siempre con ellos." [We try to practice this so that our kids know that we are together and that we'll always be with them.]*

Similar to other families in this group, Lorena and her family have continued to prioritize activities, interests, and other opportunities that align with this goal. Many families discussed these opportunities as the reason why they value spending time together. Some of the opportunities included preparing meals together, eating dinner at the same table, going out on special trips every weekend, starting a weekly movie night, and playing with puzzles and board games. Reasons for valuing time together were varied. Some families spoke about how they enjoyed spending time with each other or how spending time together allowed parents to see their children develop. Other parents mentioned the importance of teaching their kids to value spending time together, especially since some of them did not have those opportunities when they were children themselves. Some parents also talked about how it could be challenging to spend time together due to their busy schedules, differing interests among family members, or other life circumstances.

For some families in this group, it was important to reinforce the value of not only spending time together but also seeking new experiences and adventures. Karina (Family 11), for example, shared that her family likes to go on adventures, partly because they can always learn something new or visit places they have never been to. She also talked about how this is especially important for her children because she doesn't want them to feel restricted or limited. She emphasized that trying new things allows the children to get out of their routine and gain different experiences:

> Nos gusta salir de aventuras, manejar hasta llegar a un sitio que no hemos ido. Siempre queremos explora nuevas cosas. Siempre que veo algo nos gusta intentarlo, aunque sea diferente. Quiero que sigamos saliendo de la rutina, que los niños vean cosas diferentes y nuevas. El año pasado tomamos un viaje a Florence y fuimos a unas cuevas. No lo planificamos solo lo hicimos. Quiero seguir hacienda esas cosas, que no se limiten." [We like to go on adventures, like driving to a place we have never visited before. We always want to explore new things. Every time I see something new, we want to try it, even if it's different. I want us to keep getting out of the routine, for the kids to see different and new things. Last year we took a trip to Florence and we visited some caves. We didn't plan it, we just did it. I want to keep doing things like that. I don't want them (kids) to limit themselves.]. (Family 11)

After the program, Karina and her family have continued to seek new experiences and opportunities for their family to learn new things. Among these experiences, they had started frequently attending the local science center and library. The family even involved their whole neighborhood in a play based on a book that they liked. When speaking about engineering specifically, Karina said the family was always imagining and creating and that they had used some of the engineering skills they learned in the program to solve everyday problems, like fixing a broken leg on their couch.

Families like the ones mentioned above may have initially connected with the HSE program because it aligned well with their family values and beliefs and provided an opportunity to reinforce these. Through the interviews, we observed how these values and beliefs also supported ongoing interest development related to engineering or HSE. For example, many families had continued to engage with engineering or program materials because they created an opportunity to spend time together as a family. When Shaila (Family 35) reflected on what had stuck with her from the HSE program, she spoke about the experience being a source of inspiration for family engagement: *"I've learned to participate with him and to see his strengths and weaknesses. That's when family game night came out. It came after the program, looking for more activities to do with the kids. The kids all wanted to be involved. The program helped me with that focus, and we all got to laugh!"*

Other families have incorporated the program activities or the engineering process into their daily routines for similar reasons. Families that expressed a value for adventure talked about using ideas or materials from the program to inspire new adventures or provide novel opportunities for their children. These families in general enjoyed the challenge aspect of the engineering activities and built confidence about the way they approached those challenges, eventually applying that knowledge to everyday problem-solving situations. For example, Francisca (Family 2) shared her perspective on this: *"Creo que a veces esos retos o pequeños desafíos que se nos presentan y las habilidades, nos han ayudado a salir adelante. La confianza que tenemos también nos ha ayudado." [I think sometimes these challenges that present themselves, even if small, and the skills we have learned have helped us move forward. The confidence that we have gained has helped us too.]* Like several other parents, Francisca also talked about her realization that there are multiple solutions to problems and that "failure" or "mistakes" are an important part of the engineering and problem-solving process: *"Aprendimos que siempre hay diferentes maneras de hacerlo todo, no hay solamente una manera. No tenemos que estresarnos tratando de hacer las cosas bien, podemos cometer errores." [We learned that there are many ways to do things, there is more than one solution. We don't have to be stressed trying to do things correctly. We can make mistakes.]*

21.5 Conclusion

In this chapter, we presented findings from retrospective interviews with 18 parents one to two years after they participated with their children in an early childhood informal engineering education program for preschool-age children (3–5 years) and their families integrated into Head Start. Moving beyond a traditional focus on the STEM disciplines, we explored the unique ways that families extended the interests sparked or reinforced by the HSE program through their ongoing informal and playful learning experiences outside of school. Although some families connected strongly with the engineering content of the program and built long-term interest pathways related to the engineering design process, other families focused more on the ways that the program extended prior interests that already existed in the family. In addition, some families also extended their experiences in even broader ways, using program elements to connect with, reinforce, and extend core family values.

Viewing child development and family learning holistically, we argue that none of these interest pathways represent either program successes or failures. All are important and valid ways that families built on their experiences based on their own values, interests, and goals. Research has repeatedly shown that what learners bring with them to an experience deeply influences the learning process and outcomes (NRC, 2000, 2009). Furthermore, the outcomes of a program may ultimately connect to STEM in unexpected and surprising ways. For example, retrospective interviews with adults, including scientists and engineers, highlight how STEM-related interests begin early, through the support of family and friends, are sparked and extended in unique ways that differ for each individual, and can ultimately lead to ongoing engagement with STEM through education, work, or hobbies (Corin et al., 2018; Crowley et al., 2015; McCreedy & Dierking, 2013).

Theoretically, these findings have important implications for understanding interest development in early childhood and the intersection with play. Researchers studying STEM interest development have variously focused on interests related to STEM domains, interests based on preferred modes of engagement, and interests that build on and connect with prior focus areas in complex ways (Alexander et al., 2015; Azevedo, 2011; Barron, 2006, 2010; Chesworth, 2016; Renninger et al., 2015). This study highlights how all three of these perspectives may be true, and how the complex, playful learning processes of families defy traditional categories of STEM domains or practices. So that educators and researchers can understand how families engage with and develop interests related to STEM, it is critical to acknowledge this complexity and continue to explore the diverse ways that both STEM-related experiences influence families and how families, in turn, shape the outcomes of these experiences.

Similarly, as educators and practitioners grapple with these complexities, we suggest they focus on two key areas. The first is developing relationships and connections to the families and the communities they serve. Understanding the knowledge, practices, and values that families bring with them to different learning experiences will help educators create programs that build on families' assets and empower parents to engage their children in STEM (Rendón et al., 2014; Torres et al., 2018). Play is an important way that parents can engage their children with STEM topics. However, families may not recognize, value, or be aware of the potential for connecting play and other home-based activities with STEM (Gaskins, 2008; Vandermaas-Peeler et al., 2019). Building deep, sustained relations with communities is an important way for educators to gain insights into these connections and better understand the needs and interests of families.

The second area of focus involves the ways educators conceptualize interest development and STEM engagement for families. In the work presented here, it was critical for us to take into account the family as a system and the ways parents, children, and other family members collectively shape interest development. It was also important to broaden our perspective on engineering to acknowledge the different ways families define, engage, and connect to engineering in their lives. In the same way, educators can create programs and learning experiences that consider the roles of children, parents, and other families and not only make STEM knowledge and practices accessible but also highlight the STEM-related knowledge and skills that already exist within families. By mirroring the more holistic and inclusive ways the families encounter STEM through play and everyday learning, educators can support a more equitable and relevant vision of STEM education for all.

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Chapter 22
Sparking Imaginations: Exploring Science Teachers' Perspectives and Experiences of Play and Early Learning at Dioramas

Jamie Wallace and Jenny D. Ingber

Abstract In this chapter, we explore early childhood educators' experiences and perceptions of young children's play and learning at dioramas, portrayals of frozen moments in time depicting three-dimensional scenes of the natural world. In this study, we interviewed ten early childhood educators at the American Museum of Natural History in New York. Through teachers' perspectives and experiences, we explore examples of play-based, diorama-based science learning activities. Findings suggest that play and learning at or inspired by dioramas looks different across classes and contexts but is perceived as vital in sparking imagination and creativity for young children when integrated into experiences, and affords unique opportunities for role play, games, and discovery. We provide examples of teachers' perceptions of the affordances of dioramas for play and learning, as well as a variety of pedagogical approaches and strategies teachers' use to bring to life dioramas and the science concepts represented within them. This study highlights how dioramas can be integral in play-based science learning—making museums that are not traditionally designed for children into places for play.

Keywords Play · Diorama · Museum · Early childhood · Science education · Teacher perspectives

22.1 Introduction

Considerable research across the United States and internationally examines the beneficial aspects, importance of, and contribution of play in early learning (Hirsh-Pasek & Golinkoff, 2008; UNICEF, 2018; Zosh et al., 2017) and development (Akman & Ozgul, 2015; Sahlberg & Doyle, 2019; Whitebread et al., 2017). In fact, play has often been viewed as a vehicle, medium, and even strategy through which

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children learn and develop (Bergen, 2009; UNICEF, 2018) and make sense of the world (Shine & Acosta, 2000). Despite the advantages of play in early childhood education, studies indicate that play is diminishing at an alarming pace from classrooms in the United States (Miller & Almon, 2009; Nicolopoulou, 2010; Zosh et al., 2013). This trend of a reduction in play nationwide has been concurrent with a variety of policy changes in schooling. Seeing implications from a growing emphasis on academic instruction, beginning as young as three years old, and standardized assessment among school-aged children, there is a call to return and restore play-based experiences in educational environments (Miller & Almon, 2009; Nicolopoulou, 2010; Reuter & Leuchter, 2020; Sahlberg & Doyle, 2019; Wineberg & Chicquette, 2009). There is widespread recognition that high-quality prekindergarten (pre-K) for four-year-olds has long term benefits for children and society (Wechsler et al., 2016). Thus, state- and city-funded pre-K has become more prolific and standards-oriented. New York City—the context of our study—offers universal pre-K for four-year-olds. Standards for pre-K learning in New York State include physical, social, emotional, communication, and cognitive domains (NYSED, 2019). While "play and engagement in learning" is included in these standards, parents often maintain conceptions of school and learning that focus on academic skills and do not recognize the importance of play in the learning process (Liang et al., 2020); thus, a widespread understanding of the value of play in young children's learning needs is to be encouraged amongst educators and parents alike.

Joining the argument, we advocate that play is critical for early learning and we further support the use of play in young children's learning of the natural sciences. Our research is set in an informal learning environment—a museum. As Adams and Kanter (2011) argue, "play in informal spaces can be thoughtfully designed to simultaneously build bridges to and support the goals of formal science education" (p. 206) and that play-based contexts can spark science learning. Informed by theories of play and early science learning in informal environments, we explore teachers' experiences and perspectives on the role of dioramas in play and learning in early childhood classes (ages 2–7) in a large natural history museum. Through teachers' voices, we examine the role of dioramas in play and early learning and explore what it can look like in class settings. Situated at the American Museum of Natural History (AMNH) in New York City, teaching and learning takes place amongst iconic dioramas portraying animals in their natural habitats and representing places and cultures from around the world (see Fig. 22.1). The dioramas provide a window into another time, another place, another perspective; and provides the setting and context for this study. At AMNH, a typical habitat diorama portrays a frozen moment in time that is three-dimensional, using models or taxidermied animals to depict a scene in nature and tells a story through what can be seen close up as well as in the background (Haraway, 1984; Quinn, 2006). We begin this chapter with a review of literature as it relates to play, early childhood science learning, and dioramas. Next, we describe the Museum and educational programs in which the study takes place, before delving into the qualitative study design and findings on: (1) how teachers describe the ways in which children play and learn with dioramas in their classes; (2) teachers' perceptions of the affordances that dioramas provide for play

Fig. 22.1 Children at the Wading Birds Diorama (Photo J. Ingber)

and learning; and (3) the strategies and pedagogical approaches they use to promote play and learning at dioramas. We conclude with a discussion and provide a set of pedagogical approaches to consider when bringing children to explore, wonder, and play with dioramas.

22.2 Literature Review: Dioramas and Learning About the Natural World Through Play

With little prior research on how children play in natural history museums specifically in relation to dioramas, we draw from literature in three areas to inform this study: (1) early childhood learning and play; (2) early science learning; and (3) learning and interacting with dioramas.

Young children make sense of the world through play (Hadani & Rood, 2018; Samuelsson & Carlsson, 2008; Shine & Acosta, 2000). Theorists on early learning describe attributes of play in a variety of ways. Piaget focused on types of play for young learners including imaginary, sensorimotor, and games with rules in relation to early development of cognitive skills (Akman & Ozgul, 2015). Vygotsky emphasized the structure of rules in play, particularly around pretend play which commonly encompasses imaginary events and role play (Akman & Ozgul, 2015). In Montessori's method of playful learning, children are able to self-select activities with a degree of freedom and teacher guidance (Lillard, 2013). Zosh and colleagues (2013, 2017) group free play, guided play, and games under the umbrella of 'playful learning,' encompassing physical and board games, pretend play, role play, and play with objects. Arguing for the addition of guided play into early learning curricula as an alternative to didactic instruction and an intrinsic connection between play and learning where play is child guided but adult initiated, Weisberg and colleagues (2015) cite examples of toys available for play that are teacher selected and children's free exploration at a museum exhibit.

As discussed in UNICEF's 2018 study, "play is considered children's 'work' and is the vehicle through which children acquire knowledge and skills… The role of teachers and other adults in the room/environment is to enable and scaffold playful experiences and learning" (p. 10). Part of the role of teachers and adults is to establish an environment for young children to play. This requires considerable planning and experiences, to allow for children to spontaneously interact, and draw on or connect to their ideas and curiosities (2018). In the UNICEF study, adults adopt the role of facilitator to continue and connect children's learning through "recognizing, initiating, guiding, and scaffolding playful experiences, in support of children's agency" (2018, p. 11). However, various scholars argue it is not enough for teachers or adults to design or set up play experiences; as children express curiosity in activities in which others participate; it is essential that teachers and adults join in, support, and are playful as well (Fleer, 2019; Henderson & Atencio, 2007; Shine & Acosta, 2000).

The ways in which play has been described for teaching and learning, generally, also justifies its integration in early science education. Arguing the importance of time and places dedicated to play and exploration in promoting implicit learning in science, Trundle and Smith (2017) describe the usefulness of designated stations where early learners can make their own meanings from interactions with objects, tools, manipulatives, and other children. Role play, often a component of pretend play according to Vygotsky (Akman & Ozgul, 2015) or of dramatic play (Worch et al., 2009), has been found to increase motivation and deepen student understanding in science classrooms (Aubusson et al., 1997; Worch et al., 2009) and is effective in developing multiple perspectives (Howes & Cruz, 2009). In fact, many scholars agree that one way that children make sense of their world is through stories (Hendy & Toon, 2001) and that acting out, dramatizing, or mimicry in which children play act the stories can be especially valuable for cognitive and socio-emotional development (Alghamdi et al., 2020; Wright et al., 2008). Fleer (2019) argues that guided imaginative play that explores the natural world provides an optimal opportunity for teaching and learning science. Drawing on previous studies adopting cultural-historical approaches, Fleer contends that engaging in role play can draw out characteristics of curiosity and wonder and also finds that role play around science concepts by children together with teachers can result in "more authentic science learning" (p. 1259). Similarly, other studies emphasize the importance of drawing on imaginative play as the entry-point for science instruction (Trundle & Smith, 2017). For younger children, play can be seen as a vehicle through which they reveal and demonstrate their thinking of the world through expression in a way that is observable to others. As Henderson and Atencio attest, "play-based inquiry is understood as a fundamental mediator of children's learning as they engage in their activity" (2007, p. 246).

Play, particularly guided play, is effective for science, technology, engineering, and mathematics (STEM) education and more play opportunities need to be integrated into teaching and learning especially in early years, based on a comprehensive review of 150 empirical studies conducted by the Bay Area Discovery Museum (Hadani & Rood, 2018). For instance, studies show that pretend play is linked to counterfactual reasoning—essential to thinking related to scientific inquiry—and exploratory play can help support children in constructing explanations and causal learning (Hadani & Rood, 2018). Similarly, connections between guided play and deeper conceptual learning and developing specific STEM skills such as spatial reasoning were also identified in the review of existing literature. These findings reveal an opportunity for young children, through play, to build foundational knowledge, practices, and skills that align with a shift in science education increasingly centered on children's sense-making of everyday phenomena (cf. Furtak & Penuel, 2019; Hadani & Rood, 2018; NGSS Lead States, 2013; NRC, 2012). Informal institutions, such as museums, zoos, and gardens, are uniquely positioned to offer children first-hand experiences with science and everyday phenomena and provide a context for children's exploration and sense-making regarding how things work (NRC, 2009).

Frequently based in natural history museums, dioramas are invaluable assets for learning science (Quinn, 2006), as they offer opportunities to observe science in action (Gkouskou & Tunnicliffe, 2017), and provide multiple entry points to learn about the natural world (Scheersoi & Tunnicliffe, 2019a, b). Historically, dioramas have been portrayals of a frozen moment in time, a curatorial depiction or constructed reality of a scene designed to share a story (Reiss & Tunnicliffe, 2011). Recently in museums, more emphasis has been placed on a visitor-centered approach, situating the visitor at the center of the experience (Samis & Michaelson, 2016) and focusing on the prior knowledge and lived experiences that they bring to their interpretations of dioramas (Reiss & Tunnicliffe, 2011).

Over the past decade, some studies have emerged exploring teaching and pedagogy at dioramas. We have learned, for instance, how listening to conversations at dioramas can help teachers think about areas of knowledge to tap into and make connections with newcomer students (Macdonald et al., 2019), and how dioramas can be used for making observations, sketching, reflection, and discussions with novice teachers (Trowbridge, 2019). In these studies, teachers act as mediators and facilitators in learning at dioramas (Tunnicliffe & Scheersoi, 2015). Yet, more studies are needed to gain a deeper understanding of pedagogy that teachers use with specific populations of students integrating the multidimensionality and power of dioramas as an educational tool (Macdonald et al., 2019).

While studies have explored how teachers interact with dioramas to support learning, few examine children's play and interactions with dioramas. A notable exception, Washinawatok and colleagues (2017) studied children's play behavior when designing forest dioramas in a classroom setting across three US populations. In this study, researchers found the diorama project offered numerous affordances:

> The diorama task permitted us to probe young children's knowledge in a novel way, using children's spontaneous talk and play as a window into their knowledge. It offers an opportunity to observe how children from each community engineer interactions in the natural world, including animals' interactions with other animals, with plants... and with natural kinds (water and rocks); it also provides an indirect assessment of ecological knowledge. (p. 620)

They also found that children incorporated both realistic and imaginary play and talk with habitat dioramas, and enacted ecological relationships and perspective taking of animals (Washinawatok et al., 2017).

As wildlife artist Stephen Quinn documented, AMNH has "played a leading role in the development of the habitat diorama as a tool for science education" (2006, p. 10). Dioramas offer unique opportunities for children to engage in learning and meaning-making because they can prompt questions and stories, elicit emotions, or even spark discovery and imagination. However, research on young learners' exploration and experiences in informal learning settings is a growing field (Washinawatok et al., 2017) and there is very little in the literature focused on play and early learning at dioramas. Given the affordances of the dioramas and the early learning programs at AMNH, we are in a unique position to help explore and shed light on this area that is prime for research.

Imagination and fantasy can play a role for visitors and learners alike at dioramas (Tunnicliffe, 2015). Multiple researchers connect this imagination and fantasy at dioramas with the power of narratives and storytelling (Cotumaccio, 2015; Dunmall, 2015). Taking this notion a step further, Dunmall (2015) explains that storytelling at dioramas can include dramatization, acting out, call and response games, using objects, and even the design of arts and crafts; and it is this type of more active engagement and interactive behavior at dioramas that provide powerful pathways to sense making of the exhibits and displays. In fact, engaging in play can help children remember and extend their sense-making experiences in museums later on (Krakowski, 2012).

In this qualitative study, we explore teachers' perspectives and experiences of play and learning at and with dioramas in their early childhood classes. The model that we examine includes roles for both the teacher and accompanying adult (e.g., parent, caregiver) in children's play. In line with an approach common amongst the Reggio Emilia school, teachers, together with parents and children, act as collaborators and co-learners, engaging in reciprocal exchanges and collective socially constructed experiences while guiding and facilitating (Hewett, 2001). Another unique aspect of the model is that the play-based setting is an environment that customarily was not designed with children in mind—dioramas at a natural history museum. We wonder, if play "helps children make sense of the world" (Shine & Acosta, 2000), also a goal of science museums through discovery and interpretation, what opportunities and affordances do dioramas provide?

22.3 Context and Setting

The natural history museum is one of many informal science learning environments in which visitors and families come to explore, observe, and learn about the natural sciences. Some of these institutions feature iconic dioramas, each an artistic and scientific representation of a unique place with a story to tell. At AMNH, habitat dioramas portray a three-dimensional scene of the natural world consisting of taxidermy animals, a foreground, and a panoramic painting in the background (Quinn, 2006). The habitat dioramas depict science phenomena from around the world, that can be observed by and accessible for young children who might never have left New York (Ingber et al., 2020). These frozen moments in time or "windows on nature" are fundamental to the landscape that each early childhood class explores.

The suite of programs focused on children and family learning (ages 2–11), designed and implemented by the early and elementary childhood educators at AMNH, have goals in four primary areas: (1) learning about science and nature; (2) supporting young children's development and life-long learning; (3) building community among children and adults in the class; and (4) introducing the Museum as a context for learning and for family time. In order to achieve these goals, the early and elementary childhood classes and learning spaces are built upon six design principles (see Fig. 22.2). There are a variety of programs delivered by the early and elementary childhood educators that each attend to a majority, if not all, of these principles and goals. Programs for early childhood include year-long preschool classes which meet weekly for 2–5-year-olds with parents or caregivers, multi-year classes that meet weekly for 3–11-year-olds, and summer camps for 6–11-year-olds. Strategies used in class learning experiences across programs—such as "expeditions" to dioramas, parent/child conversation prompts, and role-playing animal behaviors—as well as the structure of classes are built upon these principles.

Most early childhood classes at the Museum follow a similar structure: free exploration, rug meeting, "expedition" to dioramas in halls and galleries, and a science-related art project or experiment. In this model, teachers, children, and their accompanying adults (parents or caregivers) participate together in play and learning experiences. In each early childhood class, dioramas are integrated and woven throughout the lesson. Nearly every class includes an expedition in which teachers, children, and accompanying adults visit between 1–4 dioramas. The dioramas are carefully selected as an integral part of the lesson, thus children have regular access and become familiar with dioramas throughout the Museum. It is important to note that the early and elementary childhood education goals are also supported within a space in the Museum specifically designed for children to explore, discover, and play, called the Discovery Room (often referred to as children's "gateway into the Museum" as there are toys, objects, live animals, and puzzles to provoke curiosity and build foundational knowledge to motivate interest and learning throughout the Museum).

Fig. 22.2 AMNH Design Principles (Courtesy of Ingber et al., 2019)

22.4 Study Design: Methods, Data, Analysis

In this study, we worked with early childhood teachers at AMNH. Using qualitative methods, we examine the following questions: (1) How do teachers describe the ways in which children play and learn with dioramas during their classes?, (2) What do teachers perceive as the affordances and opportunities that dioramas provide for

Table 22.1 Participant information

Early Childhood Educators (N = *10)*				
Background prior to the AMNH	*Formal education*		*Informal education*	
	4		6	
Years in Education	0–5	6–10	11–15	16–20+
	0	4	3	2
Years at AMNH	0–5	6–10	11–15	16–20+
	2	4	2	1

children's play and learning?, and (3) What strategies and pedagogical decisions do teachers make to promote play and learning at dioramas?

22.4.1 Sampling and Participants

The analysis in this chapter is based on interviews with early childhood educators employed at AMNH. Twelve early childhood teachers were identified, all of whom were recruited through email and at a department meeting, and 10 participated. Participating teachers present a wide range of backgrounds prior to working at AMNH based on experience and/or education, from specializations in science, science education, and early childhood, to museum pedagogy and teaching in informal settings. The commonality across participants is that they all work at the same museum teaching early childhood classes. At the time of data collection, teachers' experience teaching at AMNH spans from less than 1 year to more than 20 years, and all have at least 6 years of experience in education (Table 22.1). Throughout their time at AMNH, most of the teachers have taught in various early childhood classes and worked with different age groups. Teachers co-teach classes in which an inherent mentorship is implicitly built into the structure where those who are more veteran at AMNH are paired with teachers who are more recent at the Museum.

22.4.2 Methods, Data Sources, and Analysis

We conducted ten interviews with early childhood educators to explore young children's play and learning in relation to dioramas. Each participant engaged in one interview, approximately 35–50 min, which took place virtually in spring 2020. We used a semi-structured interview protocol and developed questions to learn more about teachers' experiences with play and learning at dioramas, perspectives about play, and perceptions of the role that dioramas can take in play and learning. We conducted background research using the Museum's digital archives, annual reports, and related resources to provide additional context for the dioramas that teachers presented in their interviews. Data sources also include teacher artifacts and program documents, such as lesson plans and photos. Memos, generated throughout the study, became a data source as well as an analytical tool (Creswell, 2013).

Our analysis is based primarily on the teacher interviews, which were recorded and transcribed verbatim. After removing identifiable information and using pseudonyms to protect confidentiality, we uploaded transcripts into the qualitative data analysis program, Dedoose (SocioCultural Research Consultants, LLC, 2018). We applied an open coding method to learn what themes naturally emerged from the data drawing on a constructivist grounded theory approach to help guide our learning and making sense of the data (Charmaz, 2006). Examples of codes applied during analysis include "type of play," and "diorama - view, role, purpose." We anticipated that we would see different types of play emerge from the data, given the variety of classes and ages across the early learning continuum at AMNH. We also bring to the analysis our backgrounds as researchers and educators in informal and formal learning settings. One author, Jamie, has a background in anthropology and museum ethnography and works in educational research and evaluation primarily focused on teacher education, while the other author, Jenny, has expertise in early science learning. We have both worked in education together at the Museum for years with the teachers in this study. In addition, both of us have strong connections to progressive, learner-centered, equitable education, and a developmental-interaction approach (Nager & Shapiro, 2000). Participating teachers also engaged in a member check to strengthen trustworthiness and ensure validity.

22.4.3 Study Design Shifts Due to Pandemic

This study was originally designed to focus on children's experiences with play and learning at dioramas, investigating "in what ways children's play at dioramas makes visible their sense making about the natural world?" Data collection, including observations and interviews with children and parents, was scheduled for winter 2020. Given circumstances related to the COVID-19 pandemic, it quickly became evident that the study had to be reimagined if it were to actually take place. Thus, we shifted focus to capture the experiences and perspectives of early childhood educators at the Museum. Teacher interviews were conducted online during the Museum closure due to the pandemic, when staff worked remotely. We are incredibly appreciative of the willingness and generosity of time that teachers dedicated and their interest in the study, especially given the uncertain and challenging time with staff reductions, furloughs, and layoffs. As interviews were online, many of the teachers featured various dioramas as virtual backgrounds and referred to them during our discussions.

22.5 Emperor Penguins and Parental Care Vignette

To share our findings, we begin with a vignette to help visualize an example of what play can look like at dioramas in early learning classes. The vignette below is an amalgam of four teachers' recollections and experiences with the same lesson about emperor penguins and parental care across classes. It is intended to provide a detailed picture of how play and learning can happen at or be inspired by dioramas. This lesson on penguins and parental care was perceived as "really playful" and a favorite amongst teachers. The vignette illustrates how play-based activities are designed into free exploration, rug time, and expeditions to dioramas. While these are three distinct segments, the penguin lesson reveals how storyline and play can flow seamlessly throughout the facilitation. Later in the chapter, we analyze teachers' descriptions of their use of dioramas to highlight multiple examples of play and learning as well as examples of their perceptions of affordances of dioramas for play and learning. Thus, we use the vignette as a tool that ties together an example of play (role play), grounded in affordances of dioramas (storytelling), guided by facilitation moves and mediated by objects.

22.5.1 Emperor Penguins and Parental Care Lesson (2–6-Year-Olds)

Upon entering the classroom, tables are set up for free exploration time. Children and accompanying adults can move freely across stations throughout the classroom. At the stations, they explore landscapes with animal figurines, to books, puzzles, and domino pieces. The first table is designed to reflect climates where penguins live, featuring a chunk of ice and tons of little penguin manipulatives. Children play with the ice and slide penguins on their bellies. A little girl plays with her father at a table with pretend ice made out of styrofoam and a blue board representing water. The little girl calls out, "Don't let the baby fall in the water, don't let the baby fall in the water! The baby is going to fall in the water and the baby cannot fall in the water" (Fig. 22.3).

Everyone moves to the rug area to hear the story of the emperor penguin and simultaneously act out or role play the behaviors of the penguin using a styrofoam or plastic egg, plush penguin, and their bodies. In the story, the mommy penguin lays an egg and passes the egg to the daddy to care for while she goes out to find food. Teachers first stand and try to pass the styrofoam egg back and forth, modeling, pretending, and demonstrating how the mommy penguin transfers the egg to the daddy; the children then do the same with their adult partner or a peer.

Mimicking a storm in Antarctica, the class stands up pretending to be daddy emperor penguins, huddling close together to brave the cold while protecting their eggs, careful not to drop them. Penguins in the middle of the circle are warmer, so children standing in the center come out and those on the outside have a chance to move inside the circle. One teacher says, "Ok the wind is blowing this way, let's

Fig. 22.3 Station during Penguin lesson (Photo B. Casado)

huddle this way. Oh no no no, the wind is coming this way" and everyone leans the huddle in the other direction. In tandem with the story, suddenly there's the sound of a knock. Children and adults ask, "Do you hear something?" The sound of the knock initiates the egg cracking and the hatching of a baby penguin. Teachers quickly exchange the styrofoam eggs with plush baby penguins that children care for and continue to act out the story. When the mommy penguin returns from fishing for food, she recognizes and reunites with her baby chick that she has never met through a call and response of chirping; teachers, children, and adults "chirp chirp chirp" together.

Teachers stand up and children follow, carrying their plushy penguins, waddling together through the halls pretending as if they don't have knees and move from side to side, flapping their wings. Together they reach the King Penguins diorama in the Hall of Birds of the World. At the diorama, teachers pose questions, "What do you see? What do you notice? How do baby penguins get their food?" "Oh, I see the baby penguin is eating," says one child. Another child shares, "That baby penguin is being fed by its mom! I don't do that—my parent doesn't shove food in my mouth." Adults help children with flashlights, guiding and giving suggestions, such as "Let's look at this [penguin] parent." Children and adults search the diorama to find a penguin that resembles their doll and play a little family, caring for their offspring. Finding a baby penguin eating from inside the beak of its parent, children use their hands to feed their plush babies, opening their mouths and putting their beak inside based on what they see in the diorama. Teachers say, "Stretch your wings or waddle … keep your eggs safe…" as the group returns to the classroom (Fig. 22.4).

22.5.2 Deconstructing Facilitation Moves in the Vignette

In the lesson illustrated in the vignette, we highlight "facilitation moves" to point out the use of questions, the demonstration or modeling of an action, or the dialogue, for

Fig. 22.4 King Penguins diorama in Hall of Birds of the World (Photo J. Wallace)

example, that is meant to engage children in the lesson. The facilitation moves often vary from teacher to teacher.

In this example, teachers used play in a myriad of ways to engage children as well as teach and assess their understanding of penguin parental care. Teachers first set the stage, providing the setting in which children could play and freely explore habitats where penguins live (e.g., ice and water table), then through storytelling initiated pretend play of family interactions and parental care, which led to the visual representation of the King Penguins diorama where children continued acting out the behaviors and actions they observed, and then kinesthetically waddled back to the classroom. The teachers modeled movements acting out the pretend or imagined situation as penguins, such as first demonstrating how to transfer an egg between your feet or waddling; also indicating that this was safe and accepted behavior. They used the storyline from the book to guide the pretend play. They also continually posed questions to students, inviting them to "be penguins" and embody the physical characteristics as well as drawing on empathy to consider how the daddy penguin might feel in the situation and bring that into their role. During the role play, children are thus encouraged to adopt the perspective of a daddy emperor penguin and enact the story through that lens. In their facilitation, teachers were able to extend the pretend play across settings, moving from the rug in the classroom to the diorama in the hall using physical movement as well as objects like penguin hatchlings and eggs. In addition to movement (e.g., waddling), teachers drew on multiple senses such as touch (e.g., sensory bins with ice and water, eggs, plush penguins), sound (e.g., chirping, knocking), and sight (e.g., observing mother penguins feed their chicks in the diorama) to enhance the experience and imagination.

Teachers observed during free exploration and informally assessed how the little girl drew on prior knowledge about penguins when playing with her father. Reflecting on that example, one teacher commented, "They get it, they understand that the baby needed to be protected. The baby had to be with the daddy or the mommy because if it goes in the water it might die." At the diorama, teachers posed open-ended questions to support children in continuing the narrative and extending the story in relation to parental care or familial connections and supported children in noticing and acting out what they observed using objects. The conversation at the diorama was based on observing similarities and differences between the penguin and the learner, explicitly making connections back to the child.

Thinking about children's responses to the lesson, a teacher shared, "*Typically they're really excited, it's a lot of fun. They love the penguins already; they have a lot of empathy for them. They think they're really cute. They often know about them already…and through the play I feel they come up with more questions, they want to play more, they ask to waddle back to the classroom, they want to bring their birds with them.*"

As the vignette is an amalgam of multiple teachers' experiences with the same lesson, the data collected were rich and multi-faceted. Thus, embedded within the story and the compilation of experiences, we had the opportunity to unpack facilitation moves reported. Next, we delve into the approaches that teachers adopt and what they perceive to be the affordances that dioramas provide for play and learning.

22.6 Exploring Teachers' Examples of Play and Learning at Dioramas in Early Childhood Classes

The vignette offers insights into several of the themes that emerged from teachers' descriptions of how dioramas are incorporated into play and learning in their classes. Teachers provided nearly 30 unique examples of play and learning with dioramas and 9 examples were referenced by multiple teachers. We use teachers' examples, inclusive of the vignette, to illustrate how dioramas play a role in classes, and their perceptions of children's responses to the activities. They shared strategies and approaches for facilitating play-based experience incorporating dioramas, as well as the roles of adults and children in initiating play. In our analysis, it became apparent that the examples that teachers described characterized distinct types of play-based activities. We offer an organization in which to explore particular examples of play-based activities at or inspired by dioramas by outlining eight categories based on teachers' descriptions. Play-based activities can fall into multiple categories, and overlaps exist across categories; this is not exhaustive but based solely on the examples teachers shared during interviews.

22.6.1 Role Play During the Expedition

In classes at AMNH, children, teachers, and accompanying adults act like scientists and go on an "expedition" (or "adventure" depending on the class) to dioramas. Embodying their role as young scientists, children wear expedition vests and bring science tools such as flashlights and hand lenses to support their investigation and discovery. In this manner, teachers incorporate role play through which children engage in exploration and inquiry to learn about a particular animal, environment, or phenomenon. Objects and scientific tools play an important role in physically embodying and enacting that role play, as well as emphasizing what scientists do in their work. Teachers shared examples of getting ready for an expedition, adopting the perspective of a scientist and preparing like scientists with tools needed to explore. At times, teachers incorporate an activity where students create binoculars out of toilet paper tubes that become a tool they use on their expedition, tapping into science learning and imaginative role play. As Amari shared, "That is definitely sort of a playful tool, because they're obviously not real binoculars. They're not going to magnify anything, but they do sort of help focus the attention." In describing tools that scientists need for expeditions, Rory connected play with embodied learning, "Oh dramatic play—the role of 'I'm in my expedition outfit.' When we put our vest and our flashlight on, we go to dioramas and we learn about animals and science…And that is your mindset, 'I am doing science!'" Students are asked to become scientists and see the world through that perspective. Blaire described how, in a lesson on butterflies, 3–4-year-olds transform into scientists on their expedition to the Dzanga-Sangha. The Dzanga-Sangha is a walk-through immersive diorama, recreating a portion of a rainforest in the Central African Republic (see Fig. 22.5). Innovative in design and countering the typical static display, the glass barrier of the diorama is removed allowing visitors to interact and move through the space encountering moving images, sounds, smells, plants, and animals in the environment (AMNH Annual Report, 1998). "You can literally walk into the rainforest." Blaire described, in the Dzanga-Sangha it's the young scientist's job to look for animals and find evidence, such as elephant dung and footprints, to discover what butterflies do while "Trying to make it as fun and fantasy and pretend play as possible."

22.6.2 Role Play and Acting Out the Story

This category involves a collective, shared play experience amongst children, teachers, and accompanying adults, as well as embodied learning related to a science concept, and often takes place at dioramas or in the classroom pre- or post-expedition. This involves physical gestures and movements in which children role play and embody a specific animal or interaction, often following a particular storyline. In both role playing categories, emphasis is placed on the importance of noticing, observing, and asking questions at dioramas. The emperor penguin vignette included this form

Fig. 22.5 The Dzanga-Sangha rain forest diorama in Hall of Biodiversity (Photo S. Moshenberg)

of play as everyone in the room became penguins caring for their eggs/chicks. "We try to do a lot of that [with] a lot of dioramas, almost all if not all, to have them act it out… By seeing what's behind the glass… and by acting out what is happening… [it] shows us that they understand, they get it," Marlo reflected. Four teachers described an example of play that took place in front of the Water Hole diorama in the Akeley Hall of African Mammals, which was integrated into multiple classes (see Fig. 22.6). The scene at the Water Hole depicts zebra, giraffe, gazelles, and eland families in the Kenyan savannah gathered to drink surrounded by the river, acacia trees, and doum palms.

The portrayal is serene and not necessarily reminiscent of other watering holes, which are often places with great danger looming where predatory lions, leopards, or hyenas await (Quinn, 2006). In the hall, the Water Hole is situated near Buffalo, Lion, and Gorilla dioramas. In classes for 2–5 year-olds, teachers join children and adults in pretending to be giraffes drinking at the water hole, playing out the scene through the perspective of a giraffe. Ellis shared her instructional approach, "We always have them start to observe the diorama and talk about what they're noticing. And then from there you can maybe do the acting out part." Tobin described how she asks open-ended questions and brings in children, adults, and teachers to enact and imagine the scene,

> We would go over to the watering hole and we would look for all of the animal babies that are there, since it's the animal babies class. 'What do you notice? What do you think is happening?...' Children voice that [animals are] drinking the water…We pretend to be giraffes and reach our arms really high and the adults are the lookout giraffes and then the kids are the baby giraffes and they can go over and...drink their water. There's another diorama behind the watering hole where you can see the lions. So we say, 'Oh my goodness, there's danger nearby. How do we know if we're protected?' They notice the adult giraffes.

Fig. 22.6 Water Hole diorama in Akeley Hall of African Mammals (Photo J. Wallace)

> 'Let's try this, what would it be like if we were at the watering hole?' So we'd just kind of scoot everyone over and make a big circle and then model it for them. 'Ok get your big neck and stretch it up high. And we keep our legs as straight as we can. The adults are going to keep a lookout and they'll make sure [we're safe]. Now let's go down and get a drink of water. Ok come up. Are we ok? Ok good. Ok go down again and get a drink of water. Oh no there's danger, go find your grown up, go find your grown up.'

She reflected, "It's very much very playful, they have a lot of fun, they're running around. The more that we let them drink the water, they almost get a little bit nervous themselves like 'Is there danger? What are we doing?'…I love that [activity] because they get so into it. It's very funny how much they really do feel it—they get the anxiety, and they get excited by it."

22.6.3 Playing Games Imagining and Recreating the Scene at a Diorama to Enact a Science Concept

Teachers provided multiple examples of games that entail acting out a storyline featuring a science concept in a diorama. Games take place at dioramas or in the classroom pre- or post-expedition. Two teachers described The Lioness Hunting Activity (a "typical game format"), grounded in predator-prey interactions, a phenomenon portrayed in many dioramas. Teachers facilitate the game with 3–5 year-olds in the classroom following an expedition to the Hall of African Mammals to see dioramas such as the African Hunting Dogs or Leopard and Bush Pig to examine predator-prey relationships and strategies used to help catch prey and avoid predators. Ellis described the activity in the classroom where children imagine that they are lionesses and adopt the role of predator to capture their prey (represented by images of African grassland herbivores like zebra, elephants, and wildebeest on tongue depressors hidden in the room) and bring food back for their pride. Envisioning themselves as predatory lionesses helps students to play the game through that perspective, that they need prey in order to survive. “We give them 15 seconds to go find [prey]. They’re very, very quick! And then they come back, and they get to count…I imagine they’re using their predator eyes; they’re looking around, they’ve already seen what the food looks like.” Parents role play, becoming part of the pride to whom the lionesses bring food, helping children to count the prey caught. Playing multiple rounds, kids run to hunt and collect prey, while teachers facilitate and re-hide animals. After two rounds, teachers change the environmental conditions, such as adding a drought, so the savannah is dry with less grass and food available, “trying to build on the connections with your environment and survival,” making hunting more challenging. Rory reflected, “[Children] get really into it. They want to be lions—like growling, they’re trying not to run but that happens… Visiting the lion diorama, we start growling and pretending to stalk prey at another diorama” (Fig. 22.7).

Ellis commented that the game “sets up a scenario [where you] have [students] put themselves in the place of these different animals and play like that. That’s always fun…They really like it…[we] always end on a happy note when they were very successful hunters.” Recalling how one child became upset during the game this year when he was not as successful on one of his hunts, “I think that also shows that he was really invested in it. I think they tend to be very vested in this activity and take it seriously…this play aspect they definitely get excited about.”

Fig. 22.7 African Lions diorama (Photo J. Wallace)

22.6.4 Building on Pretend Play Inspired by Dioramas to Create a Science-Related Art Project

In this category, children engage in pretend play as part of crafting and creating an art project that integrates or draws on a particular diorama. Ellis recounts an activity called the Spider Hunting Craft in an arachnid lesson for 4–5 year-olds where children "pretend that they are all spiders" and adopt a spider's perspective throughout the lesson. Children make a spider and design a spider web. To create their web that they weave with yarn, the spiders need to go out and catch their prey. The class goes on an expedition "looking through the dioramas trying to find…a prey item, probably a butterfly or an insect…that they can catch in the web and then they can draw that." Ellis notes, "It's trying to connect the science learning but also in a playful way and pretend in a kind of imaginative way." The objective is for the dramatic play to represent students' ideas about how organisms interact with each other, and their environment and the craft provides a tool to share their thinking and creativity. Several teachers expressed their hope that art projects stimulate further conversation and play at home with friends and family, reinforcing what they learned at the Museum.

22.6.5 Play During Free Exploration

Built into each lesson, free exploration is an opportunity for children to discover and play in the classroom before or after visiting dioramas. Stations are designed around the day's topic, each with objects, games, puzzles, books, costumes, and manipulatives appropriate to a given environment. Children and parents move freely during this time. In the emperor penguin vignette, we shared how the environment set up by the teachers encouraged children's play and connection-making. Considering the nature of free exploration time, teachers shared that in their classes, it is "very much set up for opportunities for them to play and play very much on their own terms, whatever they want to do." Another teacher explained, "The objective is for them to select what kind of activity they would like to enjoy with their adult learning partner… It allows the students to create, to use their imaginations…These materials…help them to engage in play in a way that can support their science learning later on." Teachers used terms like "dramatic" and "imaginative" play to convey their observations of children using objects symbolically to enact scenarios and create stories. Dorian shared, "We have times when we go to the hall to look at a diorama and then come back to the room for free exploration and the children are acting out what they've seen in the hall…I've seen kids do that with the Water Hole diorama where they come back and they wind up with all the animals around a blue piece of paper and act out what they're all doing." Drawing on how younger grades particularly enjoy free exploration, Dorian explained that when this time is cut short, children notice and ask, "why didn't we get to play today?".

Free exploration can look different by class; some classes describe this as ‘free exploration’ where play is self-guided, while others regard it as ‘free and guided exploration’ where play appears more directed in that “there are specific ways that teachers hope children and parents will use the materials to access the content that we’re going to teach that day.” An individualized practice, teachers shape free exploration differently in their classes, which can lead to a variety of ways in which teachers and parents interact with children during this time.

22.6.6 Imaginative Play in Constructing and Recreating Dioramas

In this category, play is initiated by children when building or recreating a diorama and incorporating objects. Three teachers focused on a kindergarten project where children create their own “woods in winter” diorama. Throughout the unit, lessons include expeditions to the Hall of North American Mammals, using the dioramas as inspiration for children to design their own scene or tell a story with their own diorama, which can be a recreation or their own creative design (Fig. 22.8).

At the dioramas, children learn how animals adapt and survive in winter. While teachers design the experience in this example, children initiate the play. Amari recalls,

> I have definitely seen them play with their little figurines and start to act out scenarios and start telling stories, even if they are impossible and improbable and scientifically inaccurate. If you’re getting excited about it and sort of imagining yourself in the shoes of your hare or

Fig. 22.8 Dioramas in Bernard Family Hall of North American Mammals (Photo J. Wallace)

> bison or whatever you've [used in the diorama], I think that counts even if it's not true or correct. Nothing wrong with that.

Referred to as "such an explicit play activity," Dorian shares, "I think the act of playing around with their own materials, whether it is building their own diorama or just playing with little plastic toys we have on the table to recreate those scenes, helps them to have a better understanding of…[things] in the diorama… that the diorama tells a story…and pieces in the diorama have a relationship to one another." Other teachers reference how this diorama project has a long-lasting impact on learners. Asking older students to reflect on their years at AMNH, Ellis found many talked about the kindergarten diorama project, "It blows my mind that it's so memorable… Even then as a fifth grader so many years later to think about [this project], that is pretty cool."

22.6.7 Physical Play Through Games to Understand Dioramas

Unlike the earlier category on playing games to recreate a scene in a diorama through play, these games are a kinesthetic way in which teachers introduce science vocabulary vital for understanding concepts at dioramas during expeditions. These games are typically played in the classroom before seeing dioramas. Several teachers mentioned this type of movement as a way to "get the wiggles out." During a lesson on the rainforest, 4–5-year-olds play a game with "lots of movement" similar to Simon Says to learn the layers of the rainforest, with terminology such as forest floor, understory, emergent layer, and canopy. These terms are essential for children's learning and participation in the next activity at the diorama. On an expedition to the Dzanga-Sangha walkthrough diorama, children in partnership with their adult, play an identification game to find specific animals hidden in the layers of the rainforest. Back in the classroom, they use manipulatives and figurines to create a collective rainforest diorama with the animals they identified hidden in the layers they are now familiar with after the movement game and diorama. Thus, it is helpful for children to know the layers of the rainforest before those activities take place. "It's a nice, nice way to do something fun that's tied into the science learning," Ellis reflects.

22.6.8 Free Play

In this category, play is child-initiated, child-driven and can take place anytime, anywhere. Dioramas are also incorporated into classes in ways that are not play-based but can become so through children's spontaneous free play. Examples include unexpectedly seeing kids enacting animal behavior like leapfrogging through a gallery when seeing a diorama. Teachers shared how during free exploration or walking past particular dioramas, they've heard children roar or growl and make physical movements to enact a specific animal's behavior in their natural environment. Overall, teachers provided fewer in-depth examples of play in this category and descriptions were fairly brief as these experiences were not curated or facilitated (Table 22.2).

The categories above offer an organization to explore examples of play and learning at dioramas. Only a handful of examples are incorporated, primarily ones that multiple teachers cited as good exemplars, due to space limitations. Overlaps across the categories are evident, even within the same lesson, and demonstrate assorted ways in which play is enacted. Common typologies such as free, mediated, and guided play are evident throughout the categories. While following a similar lesson structure, play-based diorama-based experiences look different across classes. Teaching approaches and strategies also vary. Educators curate activities, and have flexibility to personalize and express creativity in their facilitation across the spectrum of playfulness or direction and guidance. Some teachers share instances of pretend play based in exploration, integrating objects, whereas, in other cases, game play with movement is more apparent. Accompanying adults are perceived as learning partners and take on responsibilities to scaffold experiences for children, through engaging in play or supporting the learning; however, their role also differs across classes and activities.

22.7 The Intertwining Nature of Teachers' Perceptions of Affordances of Dioramas for Play and Learning and the Various Pedagogical Approaches They Use to Tap into Them

Teachers identified dozens of affordances of dioramas for early learners. One major finding is that teachers intertwined their perceptions of the affordances and opportunities that dioramas provide for play and early learning with the pedagogical approaches and strategies they use. Frequently, teachers also connected affordances to diorama characteristics or features and how they can be leveraged to inspire and motivate play and learning. Below, we outline teachers' perceptions about the types of affordances that dioramas provide for play and learning.

22.7.1 Tell a Story

All 10 teachers described how dioramas offer the chance to engage in storytelling, creating, imagining, or pretending. Storytelling can happen at the individual or social, collective level; and is often easily accessible for children. Teachers indicate various ways in which they shape and mold the narrative of dioramas into their practice. Several drew immediate connections between storytelling and scientific phenomena

Table 22.2 Categories of play-based, diorama-based learning activities

Category	Description	Example
1) Role play during the expedition	Pretend or imaginative play enacting a role at dioramas (e.g., personifying animals); the expedition itself is part of the role play; can include tools and objects	**Scientific expedition to the Dzanga-Sanga Rain Forest to discover evidence and observe butterflies (3–4-year-olds):** "*'We're going to go to see a beautiful rainforest in [Central] Africa and we think it's sort of special and it's really dark…You definitely need your flashlights in the Dzanga-Sangha… There are lots of animals living in here and it's your job to try to find some of them.' … looking for butterflies, we would bring them to … the elephant poop and the footprints… 'And what are the butterflies doing? What are other insects doing to the dung?'*"
2) Role play and acting out the story	Acting out a narrative related to or portrayed in a diorama; occurs at dioramas or classroom; can include gestures, movements, mimicking, embodiment	**Predator–prey game at the Water Hole Diorama (2–5-year-olds):** At the diorama, "*We pretend to be giraffes and reach our arms really high and the adults are the lookout giraffes and then the kids are the baby giraffes and they can go over and they can drink their water…[We] make a big circle and then model it… 'Ok get your big neck and stretch it up high. And we keep our legs as straight as we can. The [parents and teachers] are going to keep a lookout and they'll make sure [we're safe]. Now let's go down and get a drink of water. Ok come up. Are we ok? Ok good. Ok go down again and get a drink of water. Oh no there's danger, go find your grown up, go find your grown up.'*"

(continued)

Table 22.2 (continued)

Category	Description	Example
3) Playing games imagining and recreating the scene at a diorama to enact a science concept	Playing a game that imagines and recreates the scene from a particular diorama to kinesthetically explore a science concept; frequently occurs in classroom after expedition	**Lioness Hunting Activity on predator–prey relationships (3–5-year-olds):** After visiting dioramas portraying predator–prey interactions, children become lionesses, running to hunt and collect prey to bring food back to their pride (adults). "*We're all going to take an imaginary journey to the African savannah and… pretend that we are lionesses, because lions live in big prides and it's actually the females that go out and do a lot of the hunting. Spread throughout this classroom there are lots and lots of prey animals. It's your job… to hunt these prey animals and try to catch food for you and your family.*"
4) Building on pretend play inspired by dioramas to create a science-related art project	Acting out or role play in connection to dioramas as part of a science-related art project; can include gestures, movements; takes place pre/post-expedition to dioramas	**Spider Hunting Craft (4–5-year-olds):** Creating their own spider and threading a web with yarn, children pretend they are spiders and have to find prey to catch in their webs. At dioramas in the Hall of North American Forests and the Dzanga-Sangha rainforest, they "look through the dioramas trying to find… a prey item, probably a butterfly or an insect…that they can catch in the web and then they can draw that."

(continued)

Table 22.2 (continued)

Category	Description	Example
5) Play during free exploration	Stations designed to focus on a science topic in the classroom pre/post expedition; children move freely and initiate play; incorporates objects, manipulatives	**Free exploration during an elephant lesson (2–4-year-olds):** One table featured buckets of water and baby elephant figurines, and some kids gave the baby elephants a bath. At another table, children created elephant ears on headbands that they can wear throughout the lesson if they chose. Children often wear their elephant ears on their expedition to the elephants in the Hall of African Mammals or Hall of Asian Mammals, where teachers facilitate conversations examining and comparing physical characteristics including the size and shape of elephants' ears and modes of communication
6) Imaginative play in constructing and recreating dioramas	Play in the context of making a diorama; involves the use of objects; frequently child-driven	**"Woods in winter" diorama project (5–6-year-olds):** Referred to as "an explicit play activity," children create their own diorama, informed and inspired by expeditions to dioramas in Hall of North American Mammals to build their own scene or story. At the dioramas, the class learns how animals adapt and survive in winter. Teachers share how children play with animal figurines to tell stories and enact scenes
7) Physical play through games to understand dioramas	Playing a game to learn about something they will see in the dioramas; involves movement; typically occurs in classroom prior to expedition	**Layers of the rainforest game (4–5-year-olds):** A kinesthetic way in which teachers introduce vocabulary on the layers of the rainforest (forest floor, understory, emergent layer, canopy) in an interactive game based on Simon Says. These terms are essential for children's learning and participation in the next activity (an identification game with visuals to find specific animals hidden in the multiple layers) at the Dzanga-Sangha

(continued)

Table 22.2 (continued)

Category	Description	Example
8) Free play	Spontaneous, child-driven play; can happen anytime, anywhere	**Leapfrogging around Hall of Reptiles and Amphibians (2–7-year-olds):** Following a read aloud of a story on frogs, “*We had a bunch of kids leapfrogging through Reptiles and Amphibians… I just remember turning around and being like ‘oh great, please don’t hit into the visitors who are trying to get to T-rex!’ because the aisle is not that wide!*”

such as camouflage or survival, noting how animals depicted in the foreground and background of dioramas feature into storylines. While some focused predominantly on science content, others used storytelling to enhance science skills like observation and questioning. Using questioning as a strategy to develop and expand the narrative of a diorama was strongly emphasized, providing chances to deepen content understanding, enhance experience, and bring students into the storytelling. Providing students with opportunities to create or tell the stories they imagined at dioramas was important to the teachers. They also described how stories can be extended. One teacher shared strategies like integrating objects and tools or playing games in front of the dioramas to extend the story, to make it "more interactive and to make it interesting… to include kids as part of the diorama." Another reflected, "the act of playing really helps the story in the dioramas come to life."

22.7.2 Spark Students' Imaginations

Many of the teachers perceived that an affordance of dioramas is that they spark children's imaginations. "I just think that provides a really great spark for their imaginations…It really is a launching point for kids to play and explore creatively," Dorian shared. Similarly, another teacher relates, "[Dioramas] are perfect for early childhood who are just so inherently imaginative." Multiple teachers shared the approach of having students imagine themselves in a particular scene or situation depicted in a diorama. For instance, Blaire described, "You are inviting [children] to imagine what it would be like to be in a diorama or imagine what it would be like to look closely and learn more about that specific animal or habitat." In another example in front of a diorama in the Hall of North American Mammals, two moose are aggressively in combat (see Fig. 22.9). A teacher shared, "Using that element of narrative and saying 'Ok, we're standing here…these two moose are going at it and there's something happening here.

But who is going to win and what's going to happen next?" Amari notes that tapping into their imagination allows students "to get a better sense of the ecology but also a deeper understanding of what's happening." Kai relates how she uses a multisensory approach at dioramas to help activate imaginations, "I often ask the kids to pretend that they can use all their senses outside of what they see." For instance, asking "What are you hearing? What sounds might you hear if you're at the watering hole? What smells are you experiencing?…If you could taste the rain in this one, what do you think it would taste like?…And the kids really get funny faces trying to imagine it." Several teachers noted that dioramas offer a chance "to see things that they can then play around with and explore once they're gone." Addressing potential outcomes of tapping into children's imagination, teachers noted that it: enhances creativity and artistic abilities, deepens science skills, and motivates for continued learning. Teachers also shared how dioramas make you feel "*transported to a totally different place*." By providing a realistic, life-size scene of another place, there's

Fig. 22.9 Alaskan Moose diorama in Bernard Family Hall of North American Mammals (Photo J. Wallace)

frequently the chance to feel as though you have magically travelled somewhere else.

22.7.3 Harness Awe, Wonder, and Curiosity

Teachers mentioned that dedicating ample time at a diorama is important to provide the space for children to look closely, observe, and 'puzzle out' or 'piece together' what's happening in the detail, painted in the background, and in the different layers and features. "There's an element of magic and wonder to walking up to those big dioramas for a very small person," Amari commented. Representing existing places and constructed with real specimens and artifacts, one of the most common questions that teachers encountered at dioramas is "Are these real?" Incorporating this notion of authenticity, teachers support students in seeing the realness through specimens and objects that they can see and touch. Describing an elephant lesson, Marlo explored this pedagogical approach, "We also make it real… We bring it down to them. By having specimens… they can see it's real—this is a real elephant tooth…We have them see it and feel it."

22.7.4 Observing Animals in Their Natural Habitats

This depicts relationships and interactions between animals and with their environment. More than half of the teachers referenced this, drawing on background paintings, plants on the ground, and animal behaviors. For instance, by looking at the background you can learn about where the animal lives and examine geography, time of day, and weather. Another teacher focused on how dioramas frequently portray animal behavior, using that as an entry point to elicit prior knowledge by posing questions, providing space for children to share what they already know about the animal. "I think there's always the opportunity to act out what they're seeing… pretending that they're in the diorama, they're alongside this animal and how they might behave." With more than one hundred displays that portray landscapes and regions throughout the globe across the Museum, dioramas provide *exposure* to the vast diversity of living things.

22.7.5 Create Social and Emotional Connections, Develop Empathy, and Make Memories

Teachers described techniques that they use to make connections between what children see and themselves and bring in an empathetic component. Amari described an approach she uses at the Water Hole diorama depicting family groups and charismatic species. "Have them looking for those family groups and see a parent taking care of a baby, and what's happening here?…Does your mother or your father or your grandmother look out for you in that way?…Getting them to connect with these animals on an empathetic level and realize that they also have family relationships is a really powerful avenue." As one teacher emphasized, drawing empathetic connections to animals in the dioramas are important because it helps students to foster an attitude of care and respect for wildlife.

Teachers intentionally facilitate social interactions at dioramas, having children and adults share their noticings in a 'turn and talk' or work together to complete a task, or the collective nature of playing games and role playing as a group. Emphasizing the importance of generating memories, Reza explained that play helps to "build comfort so [children] can start using those first science inquiry skills" and "absorb science content in a way that they don't even realize and help them remember in the future. 'I remember when we studied the Water Hole because we played that game and I remember that it was predator-prey.'" Dioramas also provide the opportunity to relive or share experiences, eliciting emotions and evoking memories. Kendall related moments when parents shared memories of their own experiences at dioramas from when they were young with their children.

22.7.6 Develop a Sense of Place Within the Museum

Four teachers explored how the permanency of dioramas allows for revisiting the same place over and over, from different perspectives or angles. In this way, students have more chances to make their own connections to the dioramas and enhance those memories, as well as notice the stability and sturdiness that dioramas will still be there when they return. Teachers noted how having familiarity and experiences at dioramas help children feel connected, develop confidence in knowing and navigating the physicality of the museum, contributing to "feeling safe and secure to play in a museum." Reza shared her perception that children take away from play experiences at dioramas, "Comfort and confidence… Finding spaces in that huge museum that can help them feel like home because that's their diorama and they know what's happening there."

22.7.7 Flexibility as an Educational Tool

Several teachers noted the flexibility that dioramas offer for teaching in that they can be used with multiple approaches for different purposes. For instance, it is possible to return again to the same diorama each week and focus on a different organism or one particular feature like the painted background and then return again to examine another feature. "We can go back to the African savannah all eight years and look for something different and engage with it in different ways." Multiple teachers shared approaches to incorporating play at or with the Dzanga-Sangha walk-through diorama exploring different topics like layers of the rainforest, butterflies, and scientific discovery. While one teacher commented that how they use the diorama depends on the topic, another explained that it is contingent upon the teacher's facilitation, remarking "it really depends on how the instructor utilizes it."

22.8 Conclusion

In this chapter, we opened the door to examine teachers' perceptions of play and learning at dioramas with young children and explored what this can look like through their examples. We learn how dioramas are incorporated into activities with a variety of approaches and purposes, and how play happens in intentional and unintentional ways. We believe that dioramas can play a unique and vital role in children's play and learning that stimulates imagination and creativity, helps make science learning come alive, enhances wonder and curiosity, creates memories, and potentially has a long-lasting effect. Integrated into the fiber of informal learning environments like natural history museums, we advocate that dioramas are untapped resources to spark and inspire play for early learners and one way in which to leverage resources and assets of informal settings (Adams & Kanter, 2011; Ingber et al., 2020).

Building on recent research on Scientific Playworlds (Fleer, 2019) and studies on teaching and learning with dioramas (Tunnicliffe & Scheersoi, 2015; Scheersoi & Tunnicliffe, 2019a, b; Washinawatok et al., 2017), we learn about the ways that dioramas can provide opportunities for both individual and collective, shared play experiences for students, parents, and teachers, and unlimited potential for multiple types of play. With key affordances such as inspiring storytelling and forming memories connected to scientific phenomena, dioramas offer a unique portal that can transport children to another place or time and can be leveraged as a flexible pedagogical tool for experiential play-based learning of the natural world. Dioramas can also offer an entry point to foster and develop empathetic connections to animals and other living beings, potentially inspiring a disposition for environmental respect, care, and conservation (Young et al., 2018). Each of these affordances contribute to children developing a sense of place within the Museum.

Pedagogical approaches help bring dioramas and the science concepts represented to life, "extending the learning" through role play, storytelling, and interactive games. It is evident that teachers perceive that dioramas provide extensive benefits for play and early learning. Yet, it is apparent that not all play physically takes place at dioramas and that some activities are designed for the classroom. Space and visitors were cited as challenges that arise when designing playful experiences at dioramas in museums, signaling why many activities and games happen in the classroom. Yet, one teacher shared the possibility of playing in front of any diorama noting, "We have learned to speak and move in a way that students know and are able to hear us" when visitors are present; perhaps suggesting differences in facilitation styles and approaches.

Teachers' examples highlight the multidimensionality of dioramas and how they can be layered into activities and lessons. They can be forefronted as both the scene of the story and the play space, as we see with role playing predator-prey games at the Water Hole; or slightly more peripheral providing inspiration for the Lioness Hunting Activity in the classroom. Through facilitation approaches and strategies, we also learn how the same diorama can be used in play in different ways. Examples show how play and learning at and inspired by dioramas is contextual, situated, and place-based. We also recognize that these are examples set in a particular context—in classes in a large natural history museum in a complex, urban setting—which has its own affordances and limitations.

Given the experience and expertise of early childhood teachers at the Museum and what we are learning through this study, we provide a set of recommendations of strategies and approaches to use with children at dioramas. These suggestions can be used to deepen the experience of play and learning at and around dioramas, regardless of whether you are a parent, caregiver, or educator:

- Let children tell the story: What do *they* notice?
- Draw on *observation skills* and utilize characteristics of the diorama to let the story unfold

- Consider *whose perspective* you are taking when you explore the story
- Integrate movement, gestures, games for children to *enact* the story
- Make the experience fun and interactive by *extending* the diorama to include children in the story
- Consider connecting the diorama with a *read aloud* (before, during, or after)
- Draw *familial connections* between the diorama and the children
- Invent games to *act out* the story
- Consider ways for children to *continue the experience* later through games, art, design
- Use the story of the diorama to pair the experience with relevant *objects, toys, and manipulatives*
- Let their *imaginations* run wild and free (Fig. 22.10).

While drawn from our data, these suggestions also highlight specific examples of ways in which research on play and learning can be applied to teaching and learning with dioramas. For instance, teachers infuse ways for students to incorporate perspectives of daddy penguins during role play in the emperor penguin vignette, which is supported with findings that role play is an effective strategy for developing perspective taking in science education (Howes & Cruz, 2009) and how some children engage in perspective taking of animals in their play and talk with dioramas (Washinawatok et al., 2017); bringing us to the recommendation to think critically and consider perspectives of others at dioramas.

Fig. 22.10 Suggested strategies and approaches to use with children at dioramas

Learning about teachers' perspectives and experiences with play and learning at and with dioramas provides insight into a hidden world of curiosity, excitement, and wonder; helping us to imagine a vision of the possible. It has also raised more questions for us. For instance, what are children's experiences and in what ways do children's play at dioramas make visible their sensemaking and understanding about the natural world? A study of children's learning through play at dioramas could offer immeasurable insights into their understanding about nature, the environment, and the role of play in that learning. Given the unique model of the early childhood programs and the role of the accompanying parent or caregiver in classes, we also wonder about their experiences interacting with their children at dioramas and their perceptions of how play and learning factor into children's sense-making. These are all angles we hope to pursue. Working at and amongst the dioramas offer insight and possibilities to build on this research.

Advocating for the importance of play-based experiences in early science learning, this study reveals how teachers can facilitate play in places most often designed for adults. We learn how teachers integrate dioramas into play-based learning experiences and approaches or strategies they use. We hear about teachers' perceptions of what students take away from these experiences. Throughout this study, we see how dioramas are incredibly dynamic, approachable, and rich learning contexts for children. Our research highlights how dioramas can be an integral part of early childhood science learning—making museums that are not traditionally designed for children into places for play.

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