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STEM begins in infancy: Conceptual PlayWorlds to support new practices for professionals and families

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Many societies are increasingly worried about a lack of interest and expertise in STEM in our communities. At the same time families and educators are wanting guidance on how to engage their children in STEM. Yet little research is available about this young age group. This review examines the evidence and the practices for supporting STEM thinking, learning and development for infants and toddlers. It illustrates through examples of STEM concepts, how infants and toddlers become engaged in STEM, and concludes with an evidence-based model suitable for educators and families to increase wonder and imagination, and create a collective sense of being a STEM thinker in everyday life.

Keywords

Play, infants, toddlers, STEM, concepts, children's books,

STEM starts early

Making a case that scientific understanding starts early in children Keil (2011) argues that infants are not mere "bumbling babies rather they are deeply interested and can learn surprisingly fast about the patterns of nature." (p. 1023). Thus, for the first 1000 days of their early life children are not mere passive recipients of information from their environment. Baillargeon and De Jong (2017) have claimed that infants as early as 2.5-4 months of age expect an object to fall when it is released in mid-air. Wynn (1992) has shown that "human infants can discriminate between different small numbers of items" (p. 749). There is overwhelming evidence as Woodward (2008) also claims that Piagetian hypothesis of seeing children as mere sensorimotor beings does not hold true. Children even as early as infancy are capable of conceptual knowledge (Woodward 2008). The pedagogic challenge though would be to understand the

nature of this conceptual knowledge in infancy. One possible path as suggested by Sikder and Fleer (2015) could be to consider these early concepts as “small science concepts” drawing on from children’s everyday experiences. This paper shows that children are capable of making purposeful and intentional action from the very early age in Conceptual PlayWorld. Following the line of analytic philosophy after Robert Brandom (1994, 2009); Derry (2013) and Rai (2017) have argued that this capability to engage with the inferential commitments of their own and others action is very central and unique to human learning/mental functioning and especially in STEM concept formation. An infant’s capacity to see the distinction between rolling, sliding, pushing and pulling shows a clear indication that they understand the inferences of these different acts. A connected and intriguing question would be to explore how we can support these early experiences to develop STEM concepts in early years.

Play as a leading motive in early years

Insurmountable evidence across theoretical paradigms suggest young children especially till the age of 5 have a natural inclination to play (Singer et al. 2013). One of the great Vygotskian insights which later laid foundation to works of Elkonin (2005), Fleer (2013) and Hakkarainen (2005) is that “play is not just a predominant moment in child’s development but a leading factor” (Vygotsky, 1966, p. 63). Apart from the everyday understanding that play generates great joy and fun in children, the Vygotskian position emphasises on play as an activity in which children are challenged and more aware of their cognitive functions than otherwise. Underlining the importance of play in early years Vygotsky argued that “in play a child is always above his [sic] average age, above his daily behaviour; in play it is as though he were a head taller than himself. As in the focus of a magnifying glass, play contains all developmental tendencies in a condensed form; in play it is as though the child were trying to jump above the level of his normal behaviour” (Vygotsky, 1967, p. 16). Singer (2013) reports the work in affective neuroscience done by Jaak Panksepp that argues that the “play system is a primary process that arises from ancient regions of the brain that are related to survival, just as, for instance, the panic system, the care system or the lust system” (Singer, 2013, p. 179). Thus, play is not a pleasure activity but a distinctive activity that makes us fully human.

Conceptual PlayWorld as an activity setting for STEM learning

From a cultural-historical perspective play emerges as a result of the dialectics between children's psychological functioning and the social and material conditions afforded in their environment. The research at Conceptual PlayLab (<https://www.monash.edu/conceptual-playworld>) makes best use of these insights in developing an engaging, socio-dramatic and challenging pedagogic model to support children's STEM learning in early years. Conceptual PlayWorld (Fleer 2019; illustrated in practice further below) builds on this understanding that play is children's creative engagement with their world. Children's play motives are thus employed in making children from very early years more aware of their STEM learnings. Conceptual PlayWorld as an activity setting is not an expression of a single child's mind or single will or teacher guided pedagogy but a socially-articulated space for collective imagination. As we have shown in Fragkiadaki, Fleer and Rai (2020) children develop collectiveness in these first years of their lives. Instead of highlighting the cognitive processes or over intellectualising the symbolic characters in children's play Conceptual PlayWorld follows the essence of a Vygotskian argument in understanding "what might develop in the child with the help of the imaginary situation" (Vygotsky, 1967, p. 9).

STEM concepts and practices for infants and toddlers

As a result of the limited research into STEM learning of infants and toddlers discussed above, we introduce in this section a brief overview of research that exemplifies and expands on, what is known about how to create the conditions for infant and toddler learning in STEM.

In the following examples taken from an educational experiment (Hedegaard 2008) designed to support infant and toddler learning in STEM (Fragkiadaki, Fleer & Rai, 2020), we illustrate everyday practice moments experienced in the educational reality of an infants' class of a playworld (Lindqvist, 1995). The class was positioned in a suburban location at the southern part of the state of Victoria, Australia. The teachers of the early childhood centre created a *Conceptual PlayWorld* based on the children's book '*Possum in the House*' written by Kiersten Jensen and illustrated by Tony Oliver.

The plot of the story is about a possum, an indigenous Australian mammal. The story introduces a problem situation; how to get a naughty possum out of the house? Infants and the teachers were engaged with this *Conceptual PlayWorld* (Fleer 2019) over three weeks and worked closely with the researchers to design and re-develop the model in ways that were suitable for infants and toddlers. As will be illustrated through the data showcased here, and discussed in more detail later in the paper (see table 2), the *Conceptual PlayWorld* gave the opportunity for the emergence of multiple good practises and the engagement with a wide range of STEM concepts for infants and toddlers.

a. Good Practices

Adults as play-partners. In the following vignette (Vignette 1), Mei, the teacher, and Anna are in the *Conceptual PlayWorld* of “*Possum in the House*”. Mei had set up the *Conceptual PlayWorld* space while the infants were having their afternoon nap. The room is set up with a tent, possum puppets and paper possum footprints to follow around the room leading to the possum puppets. Anna is the first infant to wake from her nap. She is quick to spot the possum prints and follows them to the tent trying to find the possum puppets (i.e. Mummy Possum, Aunty Possum and Baby Possum.) Anna goes into the tent but does not find the possums. Mei joins Anna in play. Being in the role of Mummy Possum, Mei holds the Mummy possum puppet and compares the foot of the possum to the footprints on the ground. Mei makes possum noises “*Screech, screech!*” pretending to be the possum. She stands and moves on her knees like being a possum. Mei orients Anna to observe the shape of the footprints. Together they take various animal toys from a basket next to them and compare the animal’s feet with the possum’s feet. Anna correlates the animals’ feet with the possum’s footprints. Anna puts a horse on the paper footprints. Mei explains that horses’ feet do not align with the footprints. Mei and Anna are in the role of possums together. Together they keep following the possums’ footprints pathway in order to find the other possums (see Figure 1).



Figure 1. Adults being in role in infants' play as play- partners

Typical practice tradition positions adults (i.e. teachers, parents, caregivers) as facilitators of young children's play. This conceptualization keeps adults at a peripheral sphere of children's play leading to limited opportunities of merging the learning process with playing process. However, acting as play- partners during play, adults can transform children's play to a dynamic and still enjoyable learning experience in STEM. Adults can position themselves as play-partners by being in role in the imaginary situation that children experience in a *Conceptual PlayWorld*. The tone of their voice, gestures, body language and body positioning are indicators that an adult is dynamically participating in play instead of being an observer or a supporter of play.

Adults using props. In the following vignette (Vignette 2), Mei uses an iPad to let the infants listen to the possums' sounds. She stimulates the infants by saying "*Someone here is making a really anxious noise!*". The sounds coming from the iPad get infants attention. At the same time, Mei picks up the Mummy possum puppet. Being in the role of Mummy possum, Mei calls the infants to think where to search for the baby possum (e.g. "*Can you help to find my baby?*", "*Where is it?*"). Using the puppet, Mei leads the children around the classroom. Together they see some possum footprints made by paper. Mei encourages infants to count together the footprints (i.e. "*One, two, I think we are very close.*") She keeps infants engaged in the imaginary situation of

the *Conceptual PlayWorld* by using the puppet and talking through the puppet changing her voice (i.e. “*Can you please help me find more footprints of my baby? Where are they?*”). Infants keep following the puppet searching together for the Baby possum. They finally settle next to a basket where the possums are set to be having a sleep.



Figure 2. Adults using props during play with infants

Props are widely used in everyday educational reality in order to enrich, extend and expand young children’s play. The above vignette (Vignette 2) is suggestive of the way props act as a linkage between adults, infants’ play and STEM learning. The teacher creatively used the props to a) initiate infants’ imaginary play, b) get access inside their play as a play-partner, c) keep infants consistently engaged in the collective experience and d) deepen their learning experience about possums and footprints pathways made by possum’s feet.

The above evidence is suggestive of a new kind of pedagogical positioning in STEM learning and development in early years based on the reciprocal participation of infants and adults in play and imagination. This new practise tradition gave the infants access to various STEM concepts. These set concepts are presented below.

b. Accessible Concepts

Inspired by a story. A wide range of STEM concepts can be introduced through a single story. The concepts can be either directly or indirectly inspired by the story. In the “*Possum in a House*” story, the educators were initially inspired directly by the story in order to unpack a set of concepts to initiate infants’ learning in STEM. These concepts were Science concepts related with the biological nature of the possums. As the *Conceptual PlayWorld* was elaborated during a couple of days, teachers started also exploring new and more advanced concepts. The concept of sound was an abstract concept also inspired by the story. The references in the text about the possums’ sounds such ‘*Crunch, crunch!*’ generated the engagement with this particular concept. At a first level, the teacher introduced some cornflakes in a packet to produce sound and let the infants explore the production of sound as well as the diverse sounds that come from different objects such as a metal saucepan or a plastic bowl. Using concrete objects and creating a narrative around sound, the teacher made the concept of sound concrete and personal meaningful for the infants. At a second level, the teacher introduced a drum to produce vibration through the sound waves and let the infants explore the vibration created through sound (Figure 3).



Figure 3. Exploring the concept of sound: vibration by the sound waves

The following table (Table 1) illustrates the diversity and richness of concepts that emerged through the story.

Table 1. STEM concepts inspired by the “*Possum in the House*” story

Type	STEM concepts
Related with everyday life and experience	external biological characteristics (i.e. fur, tail, nose, feet, pouch)
	heredity (i.e. family of possums with the same external characteristics),
	basic biological needs (i.e. sleep, nutrition, self- protection),
	conditions of living (i.e. habitat, nocturnal living)
Related with scientific knowledge and understanding	concept of sound (i.e. vibration by the sound waves, diversity of sound)

As infants interacted, explored and played with their surroundings as a collective in the *Conceptual PlayWorld*, they became engaged in STEM through exploring the above concepts. The above concepts are exemplary of the infants’ engagement with STEM through the “*Possum in the House*” story over the period of three weeks. STEM challenges and opportunities can include but not limited in the above set of concepts. Infants’ interests, curiosity and wonder can lead their engagement with STEM concepts deepening their learning experience and at the same time customizing it in their unique needs.

Relevance for practice - STEM PlayWorlds for infants and toddlers

What we have learned from our educational experiment is that under the conditions of a *Conceptual PlayWorld* model, the practices of the adults’ matter. The educators in

our study acted as play partners with the children, the adults used props to signal to the infants and toddlers what the collective focus was for the group (as placeholders of the story, Vygotsky 1966), and the adults considered what STEM concepts would be personally meaning for infants and toddlers and used the story to make them accessible in role-play and exploration. A core feature is the role-playing of a story to frame and expand STEM learning.

When the literature into the learning of STEM concepts for infants and toddlers is considered, in the context of the educational experiment reported above, we can identify that

- infants and toddlers can and do engage with abstract STEM concepts
- that the narrative of a story creates an intellectual and emotionally charged context which unites the infants and toddlers as though one (Fragkiadaki, Fleer & Rai 2020)
- educator actions are both intentional and responsive to the infants' initiatives,
- a form of conceptual reciprocity between the adults and infants and toddlers emerges during the story and STEM adventures
- the Conceptual PlayWorld developed from research into play-based settings, appears to be a productive model of practice to support adults creating STEM learning conditions for infants and toddlers.

Table 2 brings together the unique conditions of a STEM PlayWorld for infants and toddlers that were co-developed by the adults and the researchers and supported by the literature.

In the development of parenting programs for families with infants and toddlers, Table 2 gives a stepped approach to planning and then setting up a Conceptual PlayWorld for infants and toddlers. Table 1 gives the STEM concept details that together with Table 2, show how an adult can read a story, use props to retell or amplify the images in the book, and then set up problems that need STEM solutions to enrich the play. Going on a possum hunt, learning about the life conditions of possums, which mirror the life conditions for infants, expand the play and enrich the learning of infants and toddlers. Imagination in play and imagination in STEM are united through the Conceptual PlayWorld.

Table 2. Conceptual PlayWorlds as an evidence-based model of practice for supporting infants and toddlers in STEM learning

Characteristics of a Conceptual PlayWorld	New practices to support infant and toddler learning of STEM	Examples of infants and toddlers' actions
<p>Dramatic story is selected (Hakkarainen & Brédikyté 2019)</p>	<p>Selecting a story that is enjoyable to infants and toddlers and the adults</p>	<p>Repetition of the plot on each page</p>
	<p>Building empathy for the characters in the story</p>	<p>Naughty possum is in the wrong place and needs help</p>
	<p>A plot that lends itself to introducing a problem situation to the children</p>	<p>Naughty possum runs all of the house making a mess</p>
	<p>A dramatic problem with different possible solutions</p> <p>Learning about possums to solve the problem</p>	<p>How to catch the naughty possum?</p> <p>What are the conditions for living? i.e. habitat, nocturnal living</p>
<p>Designing a Conceptual PlayWorld space (Lindqvist 1995)</p>	<p>Creating different spaces that give opportunities for exploring both concepts (STEM - life and living) and social and emotional development (empathy for the possum who doesn't understand that it is in the wrong place) through creating a PlayWorlds space of the story</p>	<p>The area where the story of Possum in the House is read, becomes the Conceptual PlayWorld space. This space has the props and the storybook to signal it is the PlayWorld of Possum in the House. A tent is used to support the illusion of a specific PlayWorld space.</p>

Entering and exiting the collective imaginary space	Whole group enters the <i>Conceptual Playworld</i> through the reading of the story and through using the soft toys and objects in the story	Displaying possum soft toy, pots and pans, blankets, cots, etc.
	All the infant and toddlers enter and exit the same imaginary situation	When the props are put away this signals they have left the PlayWorld of Possum in the House
	Being together in the story, enacting the story together with the adult leading	Using the book to role-play being possums
	The adult is always a character in the story or acting as a human prop	Such as the adult being the possum or being a possum hunter
Problems arise that need to be solved (Fleer 2019)	<p>Adults set up problems in play that need to be solved</p> <p>Adults introduce content knowledge to enrich the play of the infants and toddlers</p>	<p>Looking for the Mummy possum</p> <p>Learning about external biological characteristics of the possum (i.e. fur, tail, nose, feet, pouch)</p> <p>Learning about nocturnal animals - possums are awake at night and sleep during the day. Can we find them asleep outside?</p>

Table 2. (Cont.)

Characteristics of a Conceptual PlayWorld	New practices	
<p>Adults are inside the imaginary situation with the children – subject positioning (Kravtsova 2010)</p>	<p>Leading the infants and toddlers (above position)</p>	<p>Inviting the children to go on a possum hunt</p>
	<p>Acting with the infants and toddlers (equal position)</p>	<p>Being possums with the children</p>
	<p>Following the infants and toddlers' lead (below position)</p>	<p>When the infants put the possum to sleep, the adults do this too, adding to their narrative by singing or stroking the possum</p>
	<p>Infants and toddlers acting independently of the adults, but social reference back to them (independent position)</p>	<p>Infants follow the paw prints of the possum around the room, whilst the adults follow what they do, being available to them if needed</p>
	<p>Adults with the infants and toddlers are acting together as if one person (primordial we position) e.g. Adults hold the infant's hand as they walk together to look for possums</p>	

Conclusion

There has been limited exploration of STEM learning or conceptual development during infancy. Two prime imageries that guide this limitation are that the infants are often seen as having only physical and largely personal/individual needs. Borrowing the phrase from Ferenczi, Vygotsky argued that infancy is seen as movement of children from an endoparasite to exoparasite (Vygotsky, 1987, p. 207). This has largely led to early years pedagogy to be individualistic care giving instead of collectivistic and exploratory. The evidence from the Conceptual PlayWorld presented above further amplifies the claim that children are capable of collective communicative potential (Fragkiadaki, Fleer & Rai 2020) before the development of language. It also challenges the biologically deterministic and maturational models of learning that waits for a particular developmental level to teach children STEM concepts. Conceptual PlayWorld sees learning as pulling up the development. The insight then is to support children's intellectual functioning that can support their STEM learning. A challenging, collectivistic and exploratory play setting offers the social situation that can facilitate children's STEM learning.

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