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Early Childhood STEM Education for Sustainable Development

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Abstract: Early childhood education is crucial for the development of young children's understanding of the natural world. Children have a role in sustaining a viable environmental and social future. This research interrogated key ideas concerning STEM education for sustainable development, drawing on seminal research and a range of government policy documents to formulate a futures-oriented approach to supporting children to build understandings in early childhood sustainability. Through the use of ethnography, a research methodology that uses both participation and observation of research participants, it became apparent that young children's play-based learning enabled agentic responses in aligning with early understanding of STEM and sustainability. Using accepted descriptors of international Sustainable Development Goals within an early childhood research study, the research highlights how the development of interactive, learner-centred STEM teaching not only enables investigative, action-adapted learning, but also fosters independent learners who are responsive to their natural environment. The implication of this research is that further development of children's environmental agency is suggested by the authors. The introduction of a whole-of-kindergarten approach that focuses on the systemic development of quality STEM education is posited as an avenue for educators to build young children's understandings of sustainable development.

Keywords: girls in STEM; industry partnerships; engagement; career aspirations

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1. Introduction

Over thirty-five years ago, the World Commission on Environment and Development's [1] Bruntland Report defined sustainable development as that which 'meets the needs of the present without compromising the ability of future generations to meet their own needs (p. 15). The international focus on sustainable development has developed significantly over the last decade with many countries and leaders recognising that governmental, industrial and personal behaviour patterns have triggered climate change and endangered future development [2], increasing the urgency to implement change [3]. Across 2005–2014, the United Nations Decade of Education for Sustainable Development, (ESD) developed further and the United Nations Educational, Scientific and Cultural Organization (UNESCO) Global Action Programme (GAP) on Education for Sustainable Development (ESD) was devised [4]. Raising awareness, building capacity, experimentation and implementation of good practice were measures undertaken from this time [5].

In addition to developments around sustainability, the United Nations Convention of the Rights of the Child [6], adopted in 1989 and ratified in 2020, indicates that children 'must be allowed to grow, learn, play, develop and flourish with dignity'.

The early years (birth to eight years of age) is a significant period where learning is encapsulated through a child's own exploration of their world, their environment, their relationships with other and their place in society. It is an important time in which young children are first introduced to the complexity of living and the impact this has on their lives. In early childhood, parents, caregivers, and teachers need to be supportive of children so that they can participate in solving problems to become creators of their own knowledge [7].

Participation in the construction of their own knowledge and in decision making enable children to make meaning of things around them.

Education for Sustainability (EfS), a term used in Australian schools from 2014, deals with recognising 'the linkages and interdependence of the social, political, environmental and economic dimension of human capabilities' [8] (p. 2). Education is one part of the solution and requires a focus away from short-term thinking towards implementing longer-term, future-oriented thinking. As the early years are significant in terms of the opportunities available for young children to explore their world, so too are the prospects for them to engage in interactions with society (family/friends/other). Early childhood education for sustainability (ECEfS) is, according to Davis [8] (p. 28), 'the enactment of transformative, empowering and participative education around sustainability issues, topics and experiences within an early childhood setting'.

STEM (science, technology, engineering, and mathematics) education in early childhood embraces the idea that STEM learning could include all or some of these disciplines. However, it is not as simple as that, as STEM learning also embraces the development of inquiry skills and thinking capabilities. Young children during play and learn in an integrated manner where they apply knowledge or understanding from their experiences to new situations. As young children start exploring their world from birth, they have already been exposed to some of the ideas, understanding, knowledge, and skills of STEM. In the next 10–15 years (when current four-year old children are making career choices at secondary school) many of the fastest growing occupations will require STEM related skills and experience [9]. While previous research indicates students' declining interest in STEM in secondary schools [10,11], the increasing need for knowledge and understanding in STEM-related areas justifies the need for all educational systems to re-visit their actions around STEM learning and engagement. It is essential that educators seek ways to engage children in STEM from the earliest years and research asserts that STEM learning should start in preschool [12,13]. Brenneman et al. [14] states that 'High quality early childhood education and science, technology, engineering and mathematics (STEM) learning have gained recognition as key levers in the progress toward high quality learning for all students'. With the increasing focus on the positive benefits of high-quality early childhood education [15], STEM had been identified as contributing significantly to children's later achievement in STEM knowledge and skills [16]. With international interest in STEM increasing significantly in recent years, groups such as UNESCO and IDOS endorse the critical role of STEM education in the development of a sustainable future of all nations. In general terms, the goals of STEM education are to increase student STEM ability, engagement, participation, and aspiration; to increase teacher capacity and STEM teaching quality; to support STEM education opportunities within school systems; to facilitate effective partnerships with tertiary education providers, business, and industry; and to build a strong evidence base [17].

This paper will discuss how the development of interactive, learner-centred STEM teaching environments and opportunities not only enables investigative, action-adapted learning, but also fosters independent learners who are responsive to their natural environment. It will draw on research literature and projects to highlight how early childhood STEM and sustainability can work together.

2. Theoretical Perspectives

2.1. Environmental Education for Sustainability

Early childhood education and care reflects the wholeness of the child, recognising many influences that impact upon the child. Bronfenbrenner's [18] bioecological model of development centres the child in an environment that is a 'dynamic entity which is constantly changing' [19]. Another interpretation of the impacts on a child considers the spheres of influence that overlap with a revision of Bronfenbrenner's Bioecological Theory [20]. These spheres include different layers of family and community, but are also intricately enmeshed with cultural, political, and physical aspects that impact upon the

child's learning and development. Halpenney and Pettersen [21] comment that children 'construct' themselves through their engagement with their world and natural setting. Within nature, children undertake a pedagogy where action and self-directed problem-solving are viewed as being central to learning and development.

While environmental education has been incorporated in education internationally for multiple decades, in more recent times there has been shift to understanding and developing sustainable patterns of existence [17]. Sustainability education is informed by organizing principles of systems, (e.g., ecological), world views (societal values and experiences), and future living (actions in the future).

2.2. Young Children as Agents of Change

Research has confirmed that children have an inherent inclination towards natural environments, where they can develop connection with their local place, a sense of belonging, and form lasting sensory memories of play [22,23]. Caiman and Lundegarde [24] state that there has been increased interest in children's learning in education for sustainability and in their meaning–making through their experiences. This is an important aspect of early sustainability education—children start to understand the environment around them and their place within it.

In seeking to clarify the early childhood environmental situation, Davis [8] indicated that environmental education was not adequate for raising awareness of all sustainability issues. Davis commented that early childhood education for sustainability (ECEfS) went beyond nature play and learning, by emphasising the agentic capacities of children to influence the world in which they live, in ways that are healthy, just, and sustainable to 'honour the rights of other generations, the cultures of the communities and the rights of the ecosystem' [8] (p. 23). Boyd also considers early childhood as a 'transformative time, empowering children to act as critical agents of change' [25] (p. 2). The term 'agents for change' is used to describe children's active participation in their daily experiences and practices where they grow confidence and a sense of themselves (who they are) in that environment. Mackey [26] helped to explain this further when she indicated that children's agency was strengthened when they were provided with opportunities to 'plan changes, move materials and adapt their environment on a regular basis to fit the context of their play at a particular time (p. 150).

Davis [27] (p. 61) also acknowledges that there are challenges in 'teaching our children and young people how to create healthy, peaceful and sustainable future, and preparing them to be thinkers and actors'. Children should be provided with experiences that develop their knowledge about the Earth upon which they live, within a range of environments including natural environments, and which help develop a sense of power to make changes within their world. Importantly, ESD should aim to provide children with a sense of wonder about their natural world and a sense of joy about being a part of that world.

2.3. STEM and ESD

One of the main ways of addressing sustainability is through placing emphasis on STEM education and the 'scientific and technological solutions to sustainability issues', which has 'led to an emphasis on STEM education as education's main way of addressing sustainability' [8] (p. 1). Focusing on combining the STEM and sustainability education may produce a 'citizenry that will be able to solve problems for a sustainable society so that STEM and EfS can finding common ground for a flourishing future' [28] (p. 9). When considering EfS, Bascope et al. [29] contended that research in EfS in early childhood education was still scarce and that adding the component of STEM reduces the field further. The obvious links for EfS with the key disciplines that underpin our understanding of the world (science, technology, engineering, and mathematics) allow students and young children to draw on their understandings in STEM as a basis for acting for sustainability. With STEM knowledge, skills, and understanding, children can better understand sustainability issues and problems. Armed with this understanding, they can develop their own individual

actions that confront these issues in a meaningful way. Even young children can act locally and responsibly in way to change their immediate environment. Pahnke et al. [30] outlined aspects of how STEM education could be used to aid young children's understanding of sustainable development. In coining the phrase 'STEM Education for Sustainable Development (STEM4SD)', they highlighted how children could 'draw on their STEM competence and the process of science as a key basis for reasonable action in our world' [30] (p. 1). They suggested a number of guidelines that will be used to discuss how ECE can guide young children's developing awareness and agency in ESD. These are listed as:

- Promote inquiry-based learning and scientific thinking and practice.
- Encourage interactive, learner-centred teaching that enables exploratory, action-oriented, reflective, and transformative learning.
- Reinforce a whole institution approach that focuses on the systemic development of the educational facility towards quality education and sustainability and considers the role of management at the school, state, or government level.
- Foster independent thinking and responsible action that takes place in the learner context and involves the institution's social and natural environment, providing the opportunity to implement and experience real changes in the learners' own community, which then strengthens their capacity for agency.
- Be compatible with the goals of sustainable development.
- Strengthen evidence-based and reasoned argumentation, recognize complexity, promote diversity of opinion and change of perspectives, and encourage the critical reflection of values.
- Empower present and future generations to use science, technology, engineering, and mathematics (STEM) skills and reflective reasoning to solve complex sustainability problems.

Obviously, not all guidelines could be implemented at once, and not all aspects of the guidelines are directly applicable in early childhood, but they do provide teachers with some considerations when planning or working with young children in guiding ECE-STEM4SD.

3. Research Methodology

The paper draws from a research project that investigate ECE–STEM4SD undertaken in natural environments in Australian pre-school settings: bush and beach kindergarten settings. Kindergarten is considered to be the year before primary school and typically involves children in the age group 4–5. The research considered aspects of science and STEM learning. While the initial project did not initially set out to consider STEM for SD, it became apparent as the data were gathered that there were many instances of children's learning that highlighted a need to consider this as another outcome.

In bush kinder settings, an ethnographic study was undertaken. Ethnography is a research methodology that uses a range of methods [31]. The methods include observations, interviews, and reflexive note taking [31], plus participation and listening [32]. Last [33] states that ethnography is well suited to longitudinal research as abundant opportunities exist to understand and observe the learning environment and its participants. Bush kinders present the researcher with a challenge—"How can data be gathered from three educators and twenty-five children playing and interacting in a wide-open space simultaneously?" Ethnography has been demonstrated to be an appropriate methodologically for research in the outdoors where children learn through play [34]. Ethnographic methods provide researchers with a range of data gathering methods critical to building understandings of educator and children's activity [34]. As close interactions occurred over a prolonged period, educators and children can build trust with the researcher leading to closer relationships. Ethnography was determined an appropriate methodology due to the emergent nature of the research that was undertaken. When commencing our research, bush kinders were themselves in an emergent phase, having only been introduced to Australian ECEC in the early 2010s. Our research, which occurred in 2015, 2017 and 2020, involved us both spending

considerable time in the field over an extended period [33]. We found ourselves collecting research data through listening to interactions, participating in activities, observing the children and teachers and reflecting through journal notes on what we have been involved in [34]. Although limited data exist, ethnography has been found to be beneficial in understanding the contexts, relationships, and behaviours that exist in ECEC settings [35]. Typically, an ethnographer observes, listens, interacts, questions, and supports informants, which makes ethnographic methods suitable for bush kinder research, particularly as children can be challenging informants, and are often mobile, particularly when outdoors.

4. Research Design

Early childhood settings in Australia are somewhat similar to those of other parts of the world, although with some differences as well. Firstly, there are government settings which provide fifteen hours of free pre-school (kindergarten) early childhood education and care (ECEC) for children in the year prior to school (4–5 year olds). In addition, twelve hours of ECEC is provided by the government for 3 year old kindergarten children. There are multiple private providers who provide early childhood care for children (birth—5) from early in the day until quite late and are mandated to provide kindergarten for pre-school age children—up to 15 h/week. All early childhood settings have both an indoor environment as well as an outdoor setting. Many kindergartens also offer bush or beach kinder. In these settings, children learn through play and through teacher-instigated and child-instigated practices.

Across the duration of the research, we returned on three separate years. We were involved in research at four different pre-school bush kinder settings. We attended the weekly bush kinder session for 2–3 h each week for ten-week periods over the three years. In this time, we engaged with 12 teachers/educators, and upwards of 240 children. Please see Table 1 which indicates further details of the research project.

Table 1. Features of the research project.

Features	Bush Kinder Settings
Date of research	2015–2020 (intermittent—3 years total)
Methodology	Ethnography
Number of pre-schools	4
Number of teachers	Each kinder had a lead teacher and two educators. Total of 12.
Number of children	20–25 four-year-old children in each bush kinder class. 4 kinders × 3 years × 20–25 children = 240–300 children over 100 visits.

Data consisted of interviews with teachers at the commencement of each program and discussions at the end of the sessions. Signed consent forms were gained for all participants, with parents approving children's involvement.

In the bush kinder settings where we investigated STEM and environmental learning as part of child-instigated play, we used data (interviews, observations) to describe the programs, the experiences of the children and to illuminate learning through play [34]. Educator perspectives were sought to clarify the observations, along with researcher notes and video capture on site. The video was used to extract educator voice and opinions and to enrich researcher's notes. Children's engagement was observed until the children exhausted that line of play. It should be noted that in early childhood, children will frequently return to a previous play experience and extend and expand on it—and this occurred several times during the observations.

5. Results

The children's experiences will be captured through four vignettes following that will be interrogated for the evidence of children's learning in STEM and environmental understanding. The guidelines of STEM for Sustainable Development (STEM4SD) developed by Pahnke et al. [30] will be used to highlight features of children's play-based learning that connected the STEM learning with the sustainability learning. In particular, children's agency will be highlighted to emphasise the development of the agentic capacities of children to influence the world in which they live [8].

Vignette One—Cubby house building.

Two young girls wanted to build a 'cubby house'—A sheltered structure made of natural timbered materials, tree branches covered with foliage and chosen for their shape and functionality. The girls chose a site adjacent to an existing tree so that they were able to lean their branches against the tree. They moved around the bush kinder site selecting branches that were around one to two metres in length and positioned the longer ones against the tree first, arranging the shorter branches on the outside to back-fill the gaps. They left a gap for entry into their 'cubby'. Several times, they stopped and moved under the branches to ensure that they could both fit inside. After about an hour's concentrated work, they completed their 'cubby' and moved inside to play. During the entire time, the girls were discussing their options, making judgements about each part of the process, conferring with each other and being adaptable to each other's suggestions. It was a very cooperative gesture. Within a short time of their completion, another two girls came over to play with them, but the cubby wouldn't hold them all. In a very practical and considerate way, the four girls disassembled the cubby and went looking for longer and larger branches and proceeded to re-build their cubby to accommodate everyone.

In this vignette, children demonstrated several key elements of STEM4SD. They were able to discern a problem and its solution (building a cubby), they negotiated a range of choices in solving the problem turning it into a physical action, and finally were able to improve their solution through more collaborative choices [24]. In addition, they exhibited inquiry-based learning and scientific thinking and practice, interactive, learner-centred explorations that were action-oriented and reflective [30]. Finally, their actions could be considered agentic as they were able to 'plan changes, move materials and adapt their environment' [8,26]. This evidence of children's learning is provided in Table 2 which shows the specific feature of STEM and Sustainable Development learning.

Table 2. Evidence of children's learning in STEM and environmental understanding.

Features of STEM	Features of Sustainable Development
discern a problem	learner-centred explorations
find a solution	fosters independent thinking
negotiated a range of choices	reasoned argumentation
improve their solution	their actions considered agentic
inquiry-based learning	plan changes, move materials and adapt their environment
scientific thinking	empower present and future generations to use STEM skills

Through their actions of picking up the worm and their close observation of it, they were aligning with the STEM4 SD guideline of 'inquiry-based learning and scientific thinking and practice observation'. The girls in this vignette demonstrated an 'ethic of care' in handling the worm. They had clearly developed an empathy for the worm as a living thing as indicated by their careful handling of it, their observation without harm and their subsequent questioning of the teacher. They were participating in the construction of their own knowledge and in decision making, enabling them to make meaning of things around them. The evidence of children's learning for vignette two, is provided in Table 3 which shows the specific features of STEM and Sustainable Development learning.

Vignette Two—finding worms.

Sitting on mat, under some trees, two girls found a worm on the surface of the soil. One girl picked it up and held it on her hand while they both looked at it closely. She remarked to the other that the worm felt cold and slippery. Although initially hesitant, the other girl wanted to hold it, so they very carefully transferred it from one to the other. They both observed closely and made comments relating to the 'rings' they could see around its body. They noticed that one end kept lifting up and determined that the worm was trying to look around, possibly to escape their hand. After a few more minutes of observation, they asked the teacher where they could put the worm and she advised them to return it to where they had found it—or as close as possible. This started a conversation (child-instigated) with the teacher about the worm's 'home', where it lived and why.

Table 3. Evidence of children's learning in STEM and environmental understanding for vignette two.

Features of STEM	Features of Sustainable Development
inquiry-based learning	ethic of care- empathy for the worm
scientific thinking	careful handling
practice observation	observation without harm
construction of their own knowledge	construction of their own knowledge
make-meaning of things around them	decision making

Vignette Three—Weather watching.

The children had been discussing the weather during their first teacher-instigated science session. They provided their own observations of what clouds looked like and indicated their experiences of getting wet when it rained. They had been talking about rain clouds being dark, while most clouds looked white and fluffy. They undertook an art activity whereby they made clouds by sticky white cotton-wool material onto cardboard shapes and pinned these up around the room. After finishing the activity, the teacher took the children into the bush kinder environment and ask them to observe the clouds and again describe what they looked like. Apart from some descriptions that linked with objects of animals ('it looked like a dog!'), children were able to more accurately describe that some could were wispy, while others looked 'full up'. They commented about the different colours that ranged from white to dark grey. On returning to the classroom, they had a further discussion about why the clouds might look so different. Several children raised the idea of wind in the sky pulling the clouds apart.

In this vignette, the teacher introduces a topic of familiarity to the children with an awareness that all children would be able to participate in the discussion. Aligning with STEM4 SD, she was using the children's own observations and discussion to 'Strengthen evidence-based and reasoned argumentation, recognize complexity, promote diversity of opinion and change of perspectives' [30] (p. 1). She engaged the learners in participatory action-learning through their involvement in viewing the clouds outside—but then extended this by inviting them to make reasoned judgements based on their observations. Table 4, below, provides the evidence of children's learning for vignette three, and shows the specific features of STEM and Sustainable Development learning.

Table 4. Evidence of children's learning in STEM and environmental understanding for vignette three.

Features of STEM	Features of Sustainable Development
skill—observation	recognize complexity
skill—discuss observation	participatory action-learning (agency)
evidence-based and reasoned argumentation	promote diversity of opinion and change of perspectives (agency)
reasoned judgements	construction of their own knowledge

Vignette Four—Rockpools at beach kinder.

The children attended their normal beach kinder session, where they would play in and around the tea-tree bushes and on the edge of the sand. But today, there was a surprise. The teacher had arranged for a marine biologist to visit. He sat the children in a circle and asked whether any of them had visited the rock pools. Some had, but couldn't really describe them properly. From buckets, the biologist produced specimens and artefacts common to rock-pools and passed them around amongst the children. He would ask them what they thought and challenged their thinking about the object—where it might it be found, what it might eat, was it even really alive once? The children were enthralled, but sitting for more than 15 min was enough! At that point, he led them a hundred metres away to investigate the rock-pools. He gave them clear instructions that they were not to pick up any sea creatures, but to call out if they found anything so that other could share as well. With 20 children and four adults, a further 30 min was spent at the rock pools investigating the life forms, including the sea plants that lived there.

In this vignette, the introduction of the marine biologist added authenticity to the rock-pooling activity the children were undertaking. The time spent previewing the marine samples gave children agency over the language of science, giving them confidence to use the language with others when rock-pooling. When the parents came to pick up the children at the end of the session, the children had the knowledge and experiences to share and were therefore empowered by the authority these rock-pool experiences had given them. This experience gave the children agency in their broader social world, where the active participation in their daily experiences and practices gave them confidence to contribute at a different level. Evidence of children's learning for vignette four is provided in Table 5 below and demonstrates the specific features of STEM and Sustainable Development learning.

Table 5. Evidence of children's learning in STEM and environmental understanding for vignette four.

Features of STEM	Features of Sustainable Development
agency over the language of science	agency over the language of science
the knowledge and experiences	Empowered through knowledge
	agency in their broader social world
	confidence to contribute at a different level.

6. Discussion

The vignettes above set out to describe children's various STEM experiences in conventional early childhood settings as well as bush kinder settings, to investigate how children interacted responsively to their environment. Through engaging in their natural world, children were not only learning about the environment, but also acting in a way that acknowledged their understanding of it. They were developing agency over themselves and their immediate environment. The vignettes are just a representative sample of many such stories that were observed and could be used to highlight how early childhood education in STEM is advancing children's understandings of sustainability. In many of these examples, children's engagement with their world and natural settings enhanced their construction of themselves as being capable of solving their own problems. When children were placed in an environment that is 'dynamic entity which is constantly changing' such as the bush kinder setting [20], they undertook a pedagogy where action and self-directed problem-solving were central to learning and development [19] (p. 35). They are influenced by family and community and the social and cultural aspects of the settings of their early childhood setting. When teachers provided opportunities for children to take on agency, controlling the inputs and outcomes of their learning, we observed children's developing understanding of some key elements of sustainability where they drew on their STEM competence and the process of science as a key basis for reasonable action in their play environment [30]. The vignettes highlighted how the teachers supported democratic practices, providing opportunities for children's voices and opinions to shape their understanding of the weather and clouds. By seeking children's contributions in a manner that appreciated

everyone's input, children gained an understanding of the respect needed when dealing with others. Children saw how their contribution to the group can make a difference and influence outcomes.

As the vignettes demonstrated, young children were developing their STEM understandings in a number of ways and, in several of the examples, these understandings of biological sciences (as with the worm) enhance children's empathy with other living things or provided them with skills of 'problem-solving'. With enhanced STEM understandings or skills, children can draw on their capabilities when acting to solve sustainability issues. With competence, comes agency and with agency comes the opportunity to act on behalf of oneself or others.

7. Limitations

This paper presents only limited research data, but draws on a longitudinal study that provided a plenitude of examples from which to choose. The data available from the research were extensive. Recent research publications were sought when considering the links between STEM and ECE EfS. It is recognised that there is a dearth of international research evidence on this topic. Early childhood education, its pedagogies and education for sustainability are relatively recent fields of research, when compared with many others, so it is not unusual that depth and breadth may be missing.

8. Conclusions

This paper set out to discuss how the development of interactive, learner-centred STEM teaching enables investigative, action-adapted learning, fostering independent learners who are responsive to their natural environment. It drew on research literature and projects to highlight how early childhood STEM and sustainability can work together. In developing the descriptions within the vignettes above, several aspects were highlighted.

While it was apparent that child-centred play dominated most of the interactions between children and their teachers, the way this was enacted varied across the settings we visited. For children to develop a sense of agency, they need to always feel that their view is important. Perhaps the links between agency and environmental sustainability need to be further elucidated for teachers, so there is a greater understanding of the impact of their interactions with children. Similarly, in each setting, STEM practices varied and in most cases were not inculcated through policy. STEM was usually the province of an enthusiastic teacher whose passion caught the interest of the children.

The research highlighted two key factors:

- The necessity for STEM and sustainability to be at the forefront of early childhood education
- Teachers need more professional learning in both these areas, but particularly at the intersection between STEM for Sustainable Development.

A whole-of-kindergarten approach that focuses on the systemic development of quality STEM education for sustainable development is needed if we want to see a further development of children's environmental agency.

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