Sociocultural Explorations of Science Education 25

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Children's Creative Inquiry in STEM

Springer

Sociocultural Explorations of Science Education

Volume 25

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Preface

Throughout this book, we present rich descriptions of applied research drawn from diverse learning contexts from across the world. As editors bringing the book together, we took the position that creativity is relevant in all aspects of life and is essential for adaptable and innovative thinking. We believe the importance of creativity in children's learning and development should be recognised, valued and nurtured. A common theme shared by all chapter authors was their unique way of seeing the creativity in children's play and inquiry learning in STEM. Each of these authors reflect on their research and share their observations of children exploring everyday problems, seeking solutions and playfully imagining possibilities. Children were observed applying concepts from multiple STEM fields as they were thinking creatively, generating ideas, solving problems, finding alternative solutions or constructing a new and different insight. The pedagogical principles, applied practices and elements of quality learning environments provoking and supporting children's creativity and STEM inquiry, surfaced in the chapters through the analysis and reporting of empirical research.

We have positioned and developed our book through a socio-cultural constructivist lens which framed the meta-analysis and enabled a responsiveness to the broader international settings shared in each chapter. Authors used a range of culturally influenced definitions, habits and frameworks of creativity for shaping their research designs and interpretations of children's creative thinking and STEM inquiry. Through a socio-cultural constructivist philosophical lens, authors collectively critiqued literature and considered the questions "what is creativity?" and "how is creativity expressed and developed by young children?" The importance of creative learning and teaching was recognised as important for engaging children with quality learning opportunities. Yet this book goes further, promoting critical reflection and questioning about creative practices. In critiquing the research and editing the book, we questioned "who was doing the original thinking?" and "was the creative vision and voice of the child heard and given agency?"

The thought leaders contributing to this book highlight both challenges and opportunities for developing children's creativity. The book addresses these challenges by placing children's creative inquiry centre stage within STEM learning contexts. Together, the chapters provide a set of rich and diverse exemplars that capture the essence, characteristics and nuances of children's creativity across multifarious international learning settings. This book redresses the traditional imbalance of undervaluing children's creativity in STEM learning by recognising that teachers' values, design of STEM learning environments and pedagogical practices impact on children's opportunities for creative thinking and doing. It is evident that children's agency impacts on their ability to think creatively, and is in contrast with controlled learning experiences where children followed, replicated or were producing creative outcomes according to instructions. The authors contributing to the book highlight research into pedagogical practices in which creativity is positioned as a social, interactional and meaningful process.

In conclusion, this book reinforces that the STEM disciplines are highly creative in nature and that children's engagement is enhanced by embedding creative teaching into learning environments. The field of creativity has been advanced by filtering the contributions of STEM researchers through a range of creative practice frameworks and lenses. Ultimately, this work is a celebration of children's creativity and educator ingenuity to nurture children's creativity in widely diverse settings. In this fast-changing world, learning to think and act creatively, learning to generate novel solutions that have value to society, and learning to solve problems that haven't yet been invented have become a basic human right that all children deserve. This book celebrates educators who are ready to deliver quality practices that meet this challenge.

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June 2021

Acknowledgements

This book arose out of the European Science Education Research Association (ESERA) Conference (2019) where the Special Interest Group (SIG) in Early Childhood Science discussed the possibility of harnessing research on creativity in STEM. Many of the authors whose chapters form part of this book presented at this conference, and the invitation to contribute was sent to all ESERA SIG members. We acknowledge the role that this important SIG has played in the creation of the book – firstly by supporting the initial idea but also for offering SIG members an opportunity to contribute.

This book includes chapters from others as well, as those ESERA contributors reached out to colleagues and research collaborators to recount their explorations of children's creative STEM experiences. The conference, research networks and academic partnerships brought together 38 collaborating authors from across the world. The authors include high-achieving academic researchers who have worked with their PhD students, teachers and other researchers. This dynamic mix of perspectives from universities, educational institutes and industries provides a wealth of research expertise and diverse experience that underpins each chapter.

The editorial team commends the chapter authors who have been working and finalising their chapters throughout the COVID-19 pandemic. We especially appreciate the resilience and persistence of our chapter authors, who despite experiencing lockdown restrictions, working from home (often combined with childcare and home-schooling) as well as looking after vulnerable loved ones have continued to edit and format their chapters and meet deadlines. We acknowledge and thank all authors.

A book of this nature requires commitment and many hours of dedication from the editors, who have collaborated across institutions and the states of Western Australia and Victoria. The editors gratefully acknowledge the vital assistance of our editors' assistant and copy-editor, Linda Jaunzems. Her attention to detail, organisational skills and deep experience of the editing process was instrumental to bringing this book to completion. We are also indebted to Springer for its editorial support and valuable advice and insight throughout the publishing process.

Finally, we would like to acknowledge and thank the anonymous peer referees who provided our chapter authors with valuable feedback. Their thoughtful comments and suggestions were much appreciated and contributed to ensuring a high-quality publication, underpinned by academic rigour.

This book exists in the current form due to the dedicated efforts of the contributing authors. We are grateful to you all.

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Endorsements

Professor Susan Danby
Centre Director
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QUT, Brisbane, Australia

Play, creativity, digital experiences, science, engineering and the outdoors – what do these all have in common? At the heart of early childhood education is the core understanding that children learn in a myriad of ways that cannot be arbitrarily separated. This outstanding collection of investigations advances innovative pedagogy and curriculum for young children's inquiry and learning in STEM. A highly readable book that is a must read for scholars, educators, and policy makers.

Professor Susan Edwards
Director Early Childhood Futures
Australian Catholic University, Melbourne, Australia

A robust collection of enjoyable and rigorous research conducted by academics in genuine collaboration with children and educators. Provides rich new insights into the process of creativity and how this interfaces with STEM learning. An important book for researchers, graduate students and teachers alike.

Russell Tytler
Alfred Deakin Professor and Chair in Science Education
Deakin University, Geelong, Australia

This book represents a significant contribution to understanding children's creativity; how we frame it and how we can develop it. Full of fascinating case studies across diverse STEM settings globally, it will be a valuable resource for researchers, teachers, policy makers and parents.

Pamela Burnard
Professor of Arts, Creativities and Educations
University of Cambridge, Cambridge, UK

This is an extraordinarily important and inspiring book which advances our understanding and practice of creativities. The time is ripe for this kind of innovative collection of leading edge ideas for moving forward in STEM education. A bracing tonic to read and must-read for anyone interested in mutually (re-)shaping children's education.

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Chapter 1
Introduction

Karen Murcia, Mathilda Marie Joubert, Coral Campbell, and Sinead Wilson

Around the world we see children thinking creatively, inquiring and discovering STEM (Science, Technology, Engineering and Mathematics) understandings and capabilities in their everyday learning and through their play. As children inquire, they can pose their own questions, make predictions, try out new construction ideas and playfully use and create with technologies. They use their senses to answer questions, talk about their ideas and represent their understandings in a number of different ways. Children's creativity, as they inquire about their worlds, is the theme that brought together international researchers from diverse cultural settings. In the book's chapters, these researchers present their investigations, evidence and key findings as to how children think creatively and learn through cross-disciplinary STEM inquiry approaches. Creativity is viewed as a socio-cultural, everyday process displayed in inquiry learning that can be experienced by children through free play or play-based learning, guided or led by early years educators, teachers and families.

According to socio-cultural theory "any human act that gives rise to something new is referred to as a creative act, regardless of whether what is created is a physical object or some mental or emotional construct that lives within the person who created it and is known only to him" (Vygotsky, 2004, p. 7). Through this lens,

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educators were observed playing a critical role in encouraging children's creativity by modelling behaviours and habits of mind, providing creative projects for children and, importantly, establishing a rich, culturally-connected environment where children had the resources, conditions and opportunities for acting and thinking creatively. Children's STEM inquiry can generate learning and teaching opportunities where the integrated nature of the content from the STEM domains, can be socially constructed within authentic everyday contexts that are meaningful and enhance learning outcomes.

Implementing STEM education raises many questions and there continues to be a range of diverse perspectives on what constitutes STEM and effective early years practice in both the literature generally and also within the chapters of this book (Bybee, 2013; English, 2016). Young children's engagement with STEM learning can be provoked and guided in many different ways while building on the epistemological connections between the four disciplines. Children's STEM learning experiences arguably build on the intersection evident across the disciplines, as ways of understanding and constructing knowledge emerge. The early chapters of the book elaborate ways a single disciplinary approach can underpin and drive the learning design. In these chapters, science concepts are central to the children's experience, yet there are also mathematical learning opportunities evident in the descriptions of investigations and experiments with light, water, properties of materials and growing plants. Other researchers present STEM learning projects where there is a theme or problem to be solved which, intentionally encourages an interdisciplinary approach and learning from two or more disciplines. Rich interdisciplinary STEM examples are provided by chapter authors who illustrate how children's construction tasks can be facilitated by an engineering design approach, while drawing on mathematical and scientific concepts and skills. With the aim of deepening knowledge and skills or in a transdisciplinary manner, knowledge and skills from across and within the STEM disciplines are also applied in other chapters, to more 'real-world' problems and projects emerging out of children's play and curiosity. In the fourth and final section of the book, authors explore STEM with digital technologies and their cross over into mathematics; specifically computational thinking as children are learning to code.

Creativity is often described as a complex, elusive and multifaceted concept that poses many challenges to educators and is often given low priority in classroom pedagogy. Importantly, research presented in this book is built on an expansive history of research scholarship on creativity inside and outside education. At least 20 different definitions of creativity are cited across the chapters. Whilst there are unique points articulated in each chapter, there is general consensus that children's creativity involves the generation of new or novel ideas that have value or purpose. From the collection of chapters, common ideas emerge that characterise children's creative inquiry in STEM learning. Firstly, children's creativity is playful: it draws on curiosity, involves imaginative possibility thinking and is integrated into their everyday living and learning. Secondly, children's creativity is socially constructed, as it involves dialogic conversations, questioning, and making connections whilst acting and interacting with personal agency. Thirdly, children's creativity involves problem solving, where the focus is on children experimenting, thinking divergently, reasoning and expressing meaning in their pursuit of solutions and new knowledge.

Therefore, no single theory or framework of creativity is offered across the book as the various chapters explore different facets and perspectives of children's creativity in STEM inquiry. However, a number of influential theories or frameworks of creativity were used to frame individual chapters, including the *PISA Framework of Creative Thinking* (OECD, 2019), Craft's *Possibility Thinking Theory* (Craft et al., 2012), the Rhodes (1961) *Four Ps of Creativity Framework*, the *European Creative Little Scientists Conceptual Framework* (CLS, 2012), and the four components of the *Torrance Test for Creativity* (Torrance, 1966), among others. The Murcia et al. (2020) *The A to E of Creativity: A Framework for Young Children's Creativity* is also used by authors in different sections of the book, as a unifying framework to characterise children's creativity across the dimensions of the creative product, person, place and process.

Expressions of children's creativity in different STEM learning contexts are captured by researchers and presented in each chapter, providing a rich resource of the similarities and differences of what children's creativity looks like in Science, Technology, Engineering and Mathematics domains. Collectively, authors explore a range of signature pedagogies that impacted children's creativity, including project-based, arts integration, play-based, engineering design, and nature-based learning. Importantly, the dynamic interplay between teaching creatively and teaching for creativity is explored in depth with a focus on strategies to facilitate shifts in pedagogical practices to include and embed teaching for creativity. The nature of learning environments conducive to enhancing children's creativity is also investigated from different perspectives; including physical, digital, emotional, social, intellectual, and cultural environments. Generally, there is evidence of overcoming barriers to creativity in STEM, as authors demonstrate through rigorous empirical research how the challenges of curriculum, assessment, procedural knowledge limitations, resourcing, teacher training and conceptual understanding of creativity can be addressed.

The book's chapters are grouped into four parts which focus on connecting themes. These are, Part I Creative Dispositions and Processes, Part II Characteristics of Creative STEM Learning Environments, Part III Creative Approaches to Teaching STEM and Part IV Digital Creativity in Children's STEM Learning.

To begin, Part I explores the dispositions and processes involved in the multifaceted concept of creativity from a variety of different perspectives. Collectively the six chapters in this section offer fresh insights into conceptions of children's creativity, what it looks like, how it is enacted in STEM learning, and what the synergies are between creativity and inquiry learning. Some of the key processes of children's creative inquiry are interrogated, including curiosity, questioning, agency, dialogue and divergent thinking.

In Chap. 2: *A systematic literature review of children's creative inquiry,* author Mathilda Marie Joubert presents a review of research literature and provides a comprehensive analysis and summary of how children's creative inquiry is conceptualised in the scholarly literature. This chapter offers a departure point for other chapters in the book, while also offering a definition of children's creative inquiry that was used to frame the literature review: creative inquiry is the ability to generate new and alternative ways of addressing problems, answering questions or expressing meaning in the pursuit of learning. Through analysis of the literature, trends are identified in the representation of creativity and it also highlights a scantness of studies directly representing children's perspectives on creativity. Thematic analysis of the literature leads to a summary of the key elements framing research of children's creativity, which includes the criteria for creative outcomes (creative product), perspectives on who does the original thinking (creative person), elements of an enabling environment (creative place) and characteristics of children's creative thinking (creative process). As an outcome, creative tensions are identified that need to be carefully and contextually balanced by educators to enable children's creativity to flourish in learning contexts.

Authors Esmé Glauert and Fani Stylianidou, in Chap. 3: *Teachers' reflections on their changing roles and young children's learning in developing creative, inquiry-based approaches in science education*, offer a unique insight into early childhood teachers' reflections on their changing roles as they introduce creative, inquiry-based learning approaches in science education. The chapter is based on work conducted during the *European Erasmus + KA2* project *Creativity in Early Years Science Education* (CEYS) (2014–2017). The CEYS project drew on the Conceptual Framework developed for the European *Creative Little Scientists* project (CLS, 2012). This chapter reports early childhood teachers' reflections on the changing nature of their roles as science educators during the reported action research project and transition to creative pedagogical practice. Teachers reflected on the challenges they faced in this process, which included limitations to their own science knowledge, experience or confidence, and the challenge of letting go to allow student decision making and agency. Yet ultimately the teachers learnt, both from and through research, how to overcome challenges and successfully make children's creative inquiry visible within science learning and teaching.

In Chap. 4: *Developing children's questioning skills for inquiry in STEM*, Marta Carli, Anna Fiorese and Ornella Pantano report the results of a study that investigate how children's questioning can be developed as a creative activity in school science lessons. Whilst asking well-formulated, empirically answerable questions can be considered the driving feature of inquiry, teachers mostly provide children with the questions to be answered, rather than inviting them to creatively generate their own questions. In this study the authors introduce a variety of strategies to encourage a creative process of questioning amongst children, in terms of fluency, variability and originality of the questions. Analysis of the questions generated by the children during different inquiry cycles, suggests that creative questions hardly emerge spontaneously in prescriptive, transmission-based pedagogical environments, but that inquiry contexts that model and teach question generation can foster not only the children's general curiosity, but also their ability to formulate empirically answerable questions that can effectively drive science inquiry.

Author Nina Skorsetz considers how cognitive style could influence children's creative motivations and actions in STEM learning. In Chap. 5: *Creativity and motivation in early years science as it relates to cognitive styles*, she explores to what extent preschool children's creative actions and statements are related to their cognitive style in different pedagogical science learning environments. In the reported study, children's creativity in science learning settings is deductively coded, revealing that the pedagogical structure of a learning setting influences the kind of creative actions displayed by learners. In more play-based learning environments, actions are more creative, spontaneous and emotional, whereas children use more technical terms in instructive and structured settings. The results show no correlation between the amount of creative activity and children's cognitive style, however, there are indications that children find ways to be creative that matches their cognitive style. Characteristics of motivating, creativity-promoting scientific settings identified in this study are the inclusion of real problems with inquiry possibilities, resources that allow for organised and structured interpretation of investigations, and opportunities for collaboration between children and teacher.

In Chap. 6: *Child-focused primary science inquiry: Can the right balance be found between creativity, curriculum objectives and assessment requirements?*, authors Lynne Bianchi and Sarah Earle report findings from two UK curriculum projects: the *Great Science Share for Schools* and *Teacher Assessment in Primary Science*. Both programs place children's agency at the centre of guided inquiry-based science learning and aim to provoke a shift in focus from creative teaching to creative learning. The authors explored how a guided inquiry approach empowered learners to ask and investigate questions based on their own interest. Evidence is provided in the chapter, of how teachers were supported by the programs to embed inquiry-based teaching and to develop more complex science assessments. This shift in practice lead to more diverse outcomes that challenged the way science attainment could be measured and reported in schools. Whilst the dynamic tension between creative inquiry and curriculum assessment requirements remains a reality, this chapter offers research-informed and practical suggestions for how a healthy balance can be found between these competing forces at a classroom level.

Continuing this program implementation and assessment focus, in Chap. 7: *Working with inquiry activities to encourage creative thinking,* authors Christine Harrison and Sally Howard explore activities that aim to encourage children's divergent thinking in STEM inquiry experiences. They share episodes from two different projects: the European *Strategies for Assessment of Inquiry Learning in Science* (SAILS) (SAILS, 2012–2016) project and the UK *Ninja Science* project. The starting point for these projects was that, despite their best intentions, many teachers lack the pedagogical knowledge to effectively embed inquiry learning strategies and routines in their science lessons. As participants in these projects, teachers collaborated in the development of inquiry units and assessment practices that supported the embedding of practical inquiry-based science methods into the learning environment. This chapter shares vignettes from these projects, identifying how science inquiry created opportunities for learner creativity. Reported observations suggest children were given agency to make decisions and anticipate outcomes based on the evidence they collected. They demonstrated possibility thinking through inquiry activities that encouraged discursive, negotiated classrooms, resulting in learners being better able to govern their own thinking. The authors propose that this creative, dialogic approach to teaching through challenging inquiry activities, supported learner divergent thinking, and led to an increased range of pathways for children's achievement of science learning outcomes.

The chapters in Part I capture the richness of the creative dispositions and processes involved in children's creative inquiry. They offer new perspectives to overcoming the identified barriers to creativity in education; including curriculum constraints, assessment pressures and limitations in teachers' understanding of creative inquiry learning processes. In response, research-informed, practical strategies for maximising enablers of creativity are proposed by the authors. They provide concrete suggestions and practical examples in relation to improving motivation to engage with STEM, creating flexible environments, implementing intentional teaching of creative thinking strategies, and exploring teachers' professional development through project-based learning and action research.

Part II illustrates the richness of multiple learning environments for children's creative STEM engagement and developing understandings. Embedded in this series of chapters is the underlying premise that creativity is exhibited in children's every-day, socio-cultural play experiences and can be enhanced through the affordances of the environment, teachers' guidance and other children's involvement.

Consideration is given to the Reggio Emilia approach which indicates that children's creativity is enhanced through the provision of a safe, welcoming and cheerful setting that stimulates children's interests while providing an environment that enables exploration and experimentation. Many of the chapters in this book highlight this in the way they discuss the learning environment in which the children's creativity is displayed. In addition, Australian bush kinders are mentioned and highlight potential differences in the learning environment when compared with Forest schools in Europe. Internationally, nature or outdoor learning in many countries has a requriement to adhere to specific curriculum that governs the structure of the learning. In Australia, with no prescribed curriculum, children's play and learning is unscructured and derived using only the materials available in the natural environment. The following chapters consider how the environment contributes to creative learning and how the teachers interact with the children and the setting to enhance and enable creativity.

In Chap. 8: *Young children's creativity in the context of STEM learning experiences,* authors Christine Tippett and Roxana Yanez Gonzalez highlight how the provision of meaningful STEM experiences in a supportive and constructivist learning environment impacted on young children's engagement with creative STEM learning. In this chapter, the authors discuss aspects of creativity that were observed during a collaborative project in which researchers and early childhood educators in a Canadian childcare centre, worked side-by-side to identify, document, and expand on child-initiated STEM investigations. Over 27 weekly visits, early childhood educators were observed as they supported the STEM experiences of toddlers (18–30 months) and preschoolers (2 ½ to 5 years). The data collected, including fieldnotes, photos and anecdotal descriptions, was synthesised to produce 143 documented episodes of STEM-related learning. Detailed re-analysis of 52 of these episodes was then conducted to explore the aspects of creativity as manifested in the context of early years STEM. The authors describe several examples of creativity in STEM and discuss the aspects of product, person, place, and process as observed in the play-based and constructivist oriented childcare centre.

In Chap. 9: *Creatively using pre-school children's natural creativity as a lever in STEM learning through playfulness*, authors Chrystalla Papademetri-Kachrimani and Loucas Louca narrate two stories of a group of young children, playing and learning in the context of a STEM afternoon club which, aimed to support mathematics and science learning through the dynamic interaction between ideas, objects, peers and adults. In this chapter, authors firstly describe an open investigation that involved children 'playing' with calculators, and the teacher purposefully listening and responding to their emerging ideas related to numbers and button functions. Children investigated the 'mystery' button—the square function and while exploring with their own calculators, they confidently discovered what the mystery button could do and they were observed building number understandings. The second case presented in this chapter, describes how the children's curiosity drove their investigation of dissolving and construction of important early chemistry understandings. With teacher scaffolding, children presented interesting and unique interpretations and representations of their observations. Both cases highlighted the role of the educators in supporting the children's own investigations. The authors reflected on the STEM learning situations that afforded creativity, the children's thinking and working in creative ways and the activities that stimulate children's creative thinking. As an outcome, the researchers propose that creativity is built on a level of uncertainty and willingness to experiment, where mistakes are part of the process. These qualities were identified in both the adults and the children engaged in the learning 'space' created by the STEM club.

Authors Kenji Matsubara, Masato Kosaka and Yoshimi Kobayashi bring into play the characteristics of learning environments in Japan. In Chap. 10: *Characteristics of learning environments and teachers' support for children's creative STEM inquiry in Japan,* the authors interrogate the national curriculum for kindergarten, paying particular attention to STEM inquiry and focusing on how teachers support children. Through this analysis, competencies related to creativity in STEM are identified. Existing research studies are reviewed, and a collection of both common and unique STEM inquiry teaching practices in Japan are identified. The discussion of teaching practices is focused on two aspects; the learning environments provided by the teachers and the intentional teaching that assists children's creative thinking and acting. The discussion concludes with the identification of both opportunities and challenges present in Japan for teachers to develop quality STEM learning environments that encourage children's inquiry and creativity.

Creative learning in STEM is explored through kindergarten programs conducted in Australian outdoor learning environments. Australian bush kindergartens is the focus of Chap. 11: *Bush kinders in Australia: A creative place for outdoor STEM learning*. Authors Coral Campbell and Chris Speldewinde propose that while similar to European Forest kinders, Australian bush kinders differ in small but significant ways. In particular, children's creative learning is dependent solely on what the environment provides. Situated in several bush kinders, this chapter documents the novel ways children solved their own STEM-related problems. Firstly, it explores how bush kinder environments provide affordances for children to develop their creativity that then enables solving of STEM problems. Secondly, it provides insights into how enhancing the environment enables children's creativity to develop, using current theories related to creative play. Through their own child-instigated play situations, children used judgements and assumptions, generated new ideas, overcame obstacles and took risks in the development of learning. The interactions of the teacher with the children, and the children with the environment, are analysed using theories related to creative play. The chapter concludes with advocating the strong link between creative play and STEM learning in bush kinders.

This part on the *Characteristics of Creative STEM Learning Environments* highlights the multiple ways that both the physical environments and the learning environments play a part in children's creative play. All four chapters provide a different focus on what constitutes the physical environment from standard indoor kinder settings to outdoor bush kinders. The four different sites of learning were instrumental in engaging children, whether it was through the availability of appropriate resources (e.g. calculators) or through the lack of specific resources which stimulated problem-solving (bush kinder). The single constant factor across the cases was the role of the teacher or educator, who, through their intentional interaction, guided, promoted and enabled children's creative STEM learning in resource-rich and provocative learning environments.

Part III explores the pedagogical approaches taken by educators as they aimed to support children's creativity in STEM inquiry projects. The applied research described in each chapter, was conducted in formal learning environments, including early years learning centres and school classrooms. Consideration was given to the ways in which teachers' design of learning and classroom pedagogies impacted opportunities for children to think and act creatively.

Firstly, open tasks framed by an engineering design process are proposed by authors Karen Murcia and Chloe Oblak as a learning design approach for encouraging children's creative thinking. In Chap. 12: *Exploring an engineering design process and young children's creativity* they discuss outcomes from practitioner research that investigated how three and four-year-old children attending an Australian Early Years Centre's Kindergarten, responded to the intentional inclusion of an engineering design process into integrated STEM activities. The provocations introduced into the learning environment prompted a focus group of children participating in the study to apply science and mathematics concepts as they engineered solutions to problems. Indicators of creativity were observed in children's discussions, design drawings, and constructions resulting from their inquiry projects. The descriptive learning stories shared in this chapter, illustrate how the intentional introduction of the engineering design process impacted children's creativity;

increasing the amount of time children engaged with tasks and importantly the number of observed indicators of creativity in their activities.

In Chap. 13, *From slavery to scientist: Dramatising a historical story to creatively engage learners in resolving STEM problems*, authors Deb McGregor, Sarah Frodsham and Clarysly Deller explore the impact of dramatised inquiry activities on children's creative thinking. They describe how involving children in dramatic inquiry, through activities introducing how scientists and technologists have worked in the past, can 'set-the-scene' to STEM inquiry and problem-solving. In this chapter the authors describe how a sequence of dramatised activities enabled children to think about scientific and technological issues that were pertinent in the life and work of George Washington Carver (GWC), an American born into slavery. They describe how an action research approach was adopted, using mixed methods to collect the impact data. Data included field notes, informal discussions, interviews and questionnaires. Evidence emerged from the data suggesting that using historical and dramatised inquiry activities not only increased pupils' engagement, learning about science and generation of original ideas but also demonstrated how teachers could be creative in STEM teaching.

Next, in Chap. 14: *Leonardo da Vinci's apprentices or tinkering belles and boys at ludic play?,* author Debbie Myers argues that to stimulate children's curiosity and motivation to learn, educators must provide potentiating experiences so they can work creatively and apply their knowledge and skills. Outlined in this chapter is a teaching initiative referred to as 'da Vinci's Apprentices', that describes how an educator role played as da Vinci and guided apprentices (students) through an iterative engineering design process. This initiative was developed to situate the practices of science and engineering across subject boundaries. The approach was based on a conceptualisation of creativity as possibility-thinking and drew from dramatic inquiry pedagogy. An example of a dramatic inquiry focusing on a bridge commission is presented in this chapter to show how creative thinking was integral to children's initial ideation and in their development of engineering solutions to resolve problems.

In Chap. 15, *Working with nature of science in early childhood education: Inspiring children's curiosity, inquiry and play*, authors Lena Hansson, Lotta Leden and Susanne Thulin draw on a research project that explored possibilities for teaching nature of science (NOS) in Early Childhood Education (ECE). NOS deals with issues about what science is, how scientific knowledge is developed, the place of creativity in science and in what ways humans are involved in these processes. The teaching of such issues to older children has been extensively investigated, but research on NOS in ECE is extremely limited. The idea of the project, described in this chapter, was to explore how illustrated science trade books and related book-talks connected to these, could be used to introduce NOS in ECE. The project was conducted in collaboration with five preschool teachers who worked with children aged two to six. In this chapter the authors provide narratives from two events observed in a preschool context that illustrate how the book-talks about NOS teaching stimulated children's curiosity, inquiry and play.

Chapter 16: *Taking STEM to STEAM and enhancing creativity* makes a conceptual step-up and considers opportunities for including the arts in STEM education. Authors Marion Cahill and Jacinta Peterson show, through a school case study, how incorporating the arts into STEM approaches can enrich children's creativity. The authors analyse the benefits and challenges of STEAM and the possible issues with implementing a whole school integrated curriculum plan. Aspects such as pedagogical approaches, teacher development, and the influence of STEAM on creativity are explored using the context of a Western Australian Catholic primary school. The learning design and evidence of impact present by the authors, leads the reader to reflect and consider the importance of the arts across a child's learning journey. The benefits and challenges of STEAM approaches are discussed in the chapter and some of the issues with implementing a whole-school approach to STEAM are examined.

Together, the chapters in this part on *Creative Approaches to Teaching STEM* highlight the influence of intentional learning design and creative teaching on the opportunities children have to think and be creative. The chapters in this part provide examples of how teachers applied principles of dramatic inquiry, possibility thinking, arts integration and the engineering design process to provoke and scaffold children's STEM inquiry and creative thinking.

The fourth and final part of this book focuses on *Digital Creativity in Children's STEM Learning—Looking forward in the digital era*. Authors in this section share the view that a desirable outcome of STEM education is digitally literate and creative people who can positively move the world forward using digital means. Each chapter in this part contributes to the idea that embedding technologies into STEM learning environments would provide tools for children to build and demonstrate their creative thinking and practices.

Authors Victoria Damjanovic and Jordan Simmons, in Chap. 17: *Integrating tangible technologies with young children's STREAM project*, delve into the impact that children's real-life digital experiences with their families and communities have on their learning and creativity. The authors focus on a single classroom of three-year-old children, and specifically analyses the teachers' and children's engagement with tangible technologies in use and embedded within the learning environment. The authors reflect on the use of technologies across subjects including science, reading, engineering, art, and mathematics and, in so doing, extend STEM to STREAM. The authors use the 4C's: creativity, critical thinking, collaboration, and communication, as their framework for analysis. Through this lens, evidence is presented of children demonstrating creativity while engaging with tangible technologies in meaningful and relevant learning experiences. The researchers used a qualitative approach, which included the collection of photographs, video, children's work samples, and anecdotal records to explore children's creativity with tangible technologies as they were learning across curriculum areas. The combination of evidence indicated that including tangible technologies integrated with children's inquiry projects, enabled the 4C's to be seamlessly embedded into multiple content areas and provoked relevant, real-world opportunities for learning.

In Chap. 18: *The creative in computational thinking*, authors George Aranda and Joseph Ferguson specifically comment on the creative nature of computational thinking in STEM through the PISA competency model of creative thinking. The authors present evidence of children's meaning-making when participating in a design-based task. Through in-depth analyses of video excerpts of the children undertaking unplugged programming tasks in the classroom, the researchers identified specific instances in which creative thinking and computational thinking overlapped. They discuss how creativity was also found to underpin children's agency within the activity. The evidence presented in this chapter suggests that computational thinking (including de-composition, abstraction, logical thinking and algorithmic thinking) can provide opportunities for children to be creative as they generate new and unique ideas or solutions in programming. The examples and evidence provided in this chapter should support teachers to identify and encourage the development of children's creative-computational thinking in STEM inquiry.

Author Fiona Scott in Chap. 19: *Young children's playful engagement and learning with a fairy-tale themed augmented reality coding app,* reflects on her study of young children's engagement and learning with the augmented reality coding application *Little Red Coding Club.* She analysed four early years settings, involving 30 children in South Yorkshire, England, through both video data of the children, and interviews with six early childhood educators. With an analysis scheme, the impact of the coding application on the nature of children's play, and emergent coding skills and knowledge was considered. Furthermore, *The A–E Framework of Creativity: A Framework for Young Children's Creativity* (Murcia et al., 2020) was used to map characteristics of creative thinking and behaviours demonstrated by the children while engaging with the app. It was evident through analysis that two modes of play in the app design fostered different dimensions of learning (engagement, critical thinking and creativity versus early coding skills and knowledge). The findings showed that children can be creative when learning early coding skills and knowledge if they are both equipped with the technical understanding of the conventions of coding and are provided with opportunity for 'freeplay' and the production of their own digital texts and artefacts.

In Chap. 20: *Preparing Greek pre-service kindergarten teachers to promote creativity: Opportunities using Scratch and Makey Makey*, authors Michail Kalogiannakis and Stamatios Papadakis argue that concepts such as creativity, computational thinking, algorithmic thinking and STEM are gaining momentum across the globe in terms of young children's learning and education. They propose that early exposure to computational thinking and STEM learning encourages children's interest across the various disciplines. However, they caution that pre-service teachers may not yet be fully equipped with the knowledge to include computational thinking and coding into the early years curriculum. Therefore, the focus of this study was on 23 pre-service teachers, and their learning experience with *Scratch 3* and *MaKey MaKey* (visual blocks-based programming and robotics). The authors designed, implemented and evaluated a semester-long teaching intervention that allowed the pre service teachers to engage with extensive hands-on learning activities, which enabled acquisition of computational thinking and coding skills. The program evaluation suggests the pre-service teachers valued the active learning, were intrinsically motivated, and achieved cognitive outcomes. Findings also showed that after completing the intervention, the participating teachers felt confident to introduce computational thinking and coding activities into preschool classrooms.

Collectively, the chapters in this final part on *Digital Creativity in Children's STEM Learning* propose that creativity is crucial to human potential and technologies are an undeniable part of the present and future. The research presented in these chapters suggests children's STEM learning can be enhanced, supported and even extended with the use of digital technologies. Education systems worldwide are incorporating digital technologies into children's STEM learning. However, further research, as evidenced in this section of the book, is needed to test and push boundaries as we explore children's creativity in digital contexts.

In conclusion, the collection of research brought together in this book provides evidence and insights that should inform how we move into the future of creative learning and development for young children. The selected international research presented in the book, was conducted in a wide range of early and primary years learning environments where new knowledge emerged and recommendations were made for expanding our engagement with children's creativity and STEM inquiry. Together, authors reinforced through their chapter writing that STEM disciplines are highly creative in nature and children's engagement can be enhanced by embedding creative pedagogies into learning environments. By taking a socio-cultural position, the thought leaders contributing to this book demonstrate that creativity is critical and integral to children's everyday STEM inquiry experiences where they have agency and the right to question, explore and construct meaning; empowering them as active learners and creative citizens.

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Part I
Creative Dispositions and Processes – Synergies Between Inquiry and Creative Approaches to STEM Learning and Teaching

Chapter 2
A Systematic Literature Review of Children's Creative Inquiry

Mathilda Marie Joubert

2.1 Introduction

There is a rich history of research on children's engagement with creative inquiry. The history of creativity can be traced back over 2000 years throughout antiquity (Glăveanu & Kaufman, 2019; Runco & Albert, 2010), but it is widely accepted that Guilford's seminal 1950 presidential address to the *American Psychological Association* (APA) created a watershed moment, heralding the genesis of modern creativity research (Fasko, 2001; Glăveanu & Kaufman, 2019). Guilford's speech to the APA was televised nationally in America and urged researchers to stop focusing just on the creativity of great thinkers like Einstein, and instead focus on the creativity of 'every man' [sic]. Since then, the field of creativity research has grown exponentially, and creativity has become a desirable educational goal.

Inquiry learning has a similarly rich history, rooted in the seminal work of John Dewey more than a 100 years ago. Dewey advocated for the importance of learning by doing, engagement in discovery and reflection, as opposed to mere memorisation of facts, and the resultant shift in teacher role from deliverer of knowledge to facilitator of learning (Barrow, 2006; Glauert & Manches, 2012; Hatzigianni et al., 2020; Lazonder & Harmsden, 2016). Dewey's work was embraced early within science education, and acceptance by other domains has been growing steadily since the 1960s, particularly enhanced by Bruner's discovery learning movement (Lazonder & Harmsden, 2016).

Definitions of creativity and inquiry abound, but there is general consensus that creativity involves the generation of original ideas that have value or are appropriate to the task at hand, whilst inquiry involves a process of learning through

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self-directed discovery, experimentation, problem-solving and reflection. Creativity and inquiry each have their discrete histories, yet these concepts regularly intersect with each other. There are many synergies between creativity and inquiry learning, including processes of play, exploration, problem-solving, agency, curiosity, reflection and reasoning, as articulated by Cremin et al. (2015). Glauert and Manches (2012) point out that creativity and inquiry are not contradictory, but have different emphases. Arguably the most pronounced difference is the focus on the generation of divergent, alternative or original ideas in creativity, which is of lesser importance in inquiry learning.

Creativity and inquiry often occur together in educational contexts. The purpose of this chapter is to provide an up-to-date, reliable and comprehensive view of how children's creative inquiry is being conceptualised in the scholarly literature through a systematic literature review. For this literature review creative inquiry is defined as the ability to generate new and alternative ways of addressing problems, answering questions or expressing meaning in the pursuit of learning. In this definition, the pursuit of learning is the value or purpose that is inherent to most definitions of creativity. This chapter investigates children's creative inquiry across different domains before focusing on the specific representation within Science, Technology, English and Mathematics (STEM) learning. We hope that this will provide a broad scholarly grounding for this book on children's creative inquiry in STEM.

This chapter first describes the methodology used to conduct this systematic literature review, including the search methodology which led to the identification of 206 peer-review journal articles and the screening procedure that identified the 78 studies included in the final analysis. Next a systematic analysis is presented that reports on the representation of studies based on: location of study, phase of education, domain, methodology, construct focus and point of view. Subsequently, a thematic analysis is presented through the lens of the Murcia et al. (2020) *A to E of Children's Creativity Framework,* which identifies aspects of the creative product, person, place, and process. Finally, the implications of the findings of this systematic literature review for educational research, policy and practice are discussed.

Creativity theories abound in the literature, yet Kaufman and Glăveanu (2019) conclude that "there is no (successful or widely accepted) grand theory of creativity … nor, truly, is there any particular need for one" (p. 38), arguing that the concept of creativity is too multifaceted to be captured in a single theory. Nonetheless, many scholars have attempted to frame different perspectives of creativity with numerous resultant models and frameworks being proposed. Some of the most prominent models include the Wallas (1926) *Stages of Creative Process Model* (preparation, incubation, intimation, illumination, verification), the Rhodes (1961) *Four Ps Model* (person, process, product, press), the Finke et al. (1992) *Geneplore Model* (generate, explore), the Amabile (1996) *Componential Model of Creativity* (domain relevant skills, creativity-relevant processes, intrinsic motivation), Csikszentmihalyi (1999) *Systems Model* (person, field, domain), the Kaufman and Beghetto (2009) *Four Cs Model* (Big-C creator, Pro-C professional, little-c everyday creativity, and mini-c subjective creativity), to the Glaveanu (2013) *Five As Framework* (Actors, Audiences, Actions, Artifacts, Affordances). Smith and Smith

(2010) point out that many of these models of creativity are not well contextualised within educational contexts to address children's creativity. The Murcia et al. (2020) *A to E of Children's Creativity Framework,* has been chosen to frame this literature review, because it particularly addresses the question of what children's creativity looks like within educational learning contexts.

2.2 The A to E of Children's Creativity Framework

Murcia, et al. (2020) proposed the literature-informed, empirically-tested *A to E of Children's Creativity Framework* (see Fig. 2.1) as a way of summarising key perspectives on children's creativity. The framework captures four different dimensions of children's creativity:

- Creative Products: two essential criteria are required for outcomes to be judged as creative: originality and fitness-for purpose, and both need to be present.
- Creative Persons: three perspectives on who does the original thinking are presented: children engaged by the educator's creativity, children engaging in creative doing and children engaging in creative thinking.
- Creative Places: the elements that educators can employ to create environments that enable children's creativity are organised into three categories: resources, communication and the socio-emotional climate.
- Creative Processes: the characteristics that children display when engaging in creative processes are summarised as the *A to E of Children's Creativity*: **A**gency, **B**eing curious, **C**onnecting, **D**aring and **E**xperimenting.

2.3 Methodology

A systematic literature review was conducted, based on the methodology advocated by Siddaway et al. (2019), to provide a reliable, evidence-based view of how children's creative inquiry is represented in the scholarly literature. A diagrammatic representation of the search methodology employed is provided in Fig. 2.2.

A database search was conducted to identify relevant sources for the review on *ProQuest*, which incorporates a range of educational, arts, social sciences and psychological databases, including *Art, Design & Architecture Collection*, *ERIC*, *ProQuest Central*, *PsycINFO*, *Public Health Database*, *SciTech Premium Collection* and *Sociological Abstracts*. The *Boolean* search terms used were "creativ*" AND "inquiry" AND "children" in the abstract or title of the study. Only studies written in English were included, and the search was restricted to peer-reviewed journal articles. The synergies between creativity and inquiry were of particular interest in this review; therefore both of these search terms had to be present for an article to be selected. The focus was also limited to research on young people and therefore

<table>
<tr><th colspan="5">PRODUCT: Criteria for creative outcomes</th></tr>
<tr><td colspan="3">ORIGINAL</td><td colspan="2">FIT-FOR-PURPOSE</td></tr>
<tr><th colspan="5">PERSON: Perspectives on who does the original thinking</th></tr>
<tr><td colspan="2">CHILD ENGAGED BY EDUCATOR'S CREATIVITY</td><td colspan="2">CHILD'S CREATIVE DOING</td><td>CHILD'S CREATIVE THINKING</td></tr>
<tr><th colspan="5">PLACE: Elements of an enabling environment</th></tr>
<tr><td colspan="2">RESOURCES</td><td colspan="2">COMMUNICATION</td><td>SOCIO-EMOTIONAL CLIMATE</td></tr>
<tr><td colspan="2">Intentional provocations</td><td colspan="2">Intentional learning conversations</td><td>Stress and pressure free environment</td></tr>
<tr><td colspan="2">Stimulating materials</td><td colspan="2">Hearing and valuing children's ideas</td><td>Non-prescriptive</td></tr>
<tr><td colspan="2">Adequate materials for everyone</td><td colspan="2">Open inquiry questioning</td><td>Non-judgemental</td></tr>
<tr><td colspan="2">Time for creative exploration</td><td colspan="2">Facilitating dialogic conversations</td><td>Allowed to make mistakes</td></tr>
<tr><th colspan="5">PROCESS: Characteristics of children's creative thinking</th></tr>
<tr><td>AGENCY</td><td>BEING CURIOUS</td><td>CONNECTING</td><td>DARING</td><td>EXPERIMENTING</td></tr>
<tr><td>Displaying self-determination</td><td>Questioning</td><td>Making connections</td><td>Willing to be different</td><td>Trying out new ideas</td></tr>
<tr><td>Finding relevance and personal meaning</td><td>Wondering</td><td>Seeing patterns in ideas</td><td>Persisting when things get difficult</td><td>Playing with possibilities</td></tr>
<tr><td>Having a purpose</td><td>Imagining</td><td>Reflecting on what is and what could be</td><td>Learning from failure (resilience)</td><td>Investigating</td></tr>
<tr><td>Acting with autonomy</td><td>Exploring</td><td>Sharing with others</td><td>Tolerating uncertainty</td><td>Tinkering and adapting ideas</td></tr>
<tr><td>Demonstrating personal choice and freedom</td><td>Discovering</td><td>Combining ideas to form something new</td><td>Challenging assumptions</td><td>Using materials differently</td></tr>
<tr><td>Choosing to adjust and be agile</td><td>Engaging in "what if" thinking</td><td>Seeing different points of view</td><td>Putting ideas into action</td><td>Solving problems</td></tr>
</table>

Fig. 2.1 The *A to E of creativity: a framework for children's creativity* (Murcia et al., 2020)

the search term "children" was added. No specific age group limitation was specified to capture all studies relating to children's creative inquiry. No alternative search terms were used for creativity and inquiry since these were the primary constructs under investigation. The literature review does not include related constructs like problem-solving, innovation, active learning or problem-based learning unless coupled with a focus on creativity and/or inquiry.

The initial database search yielded 206 peer-review journal articles containing the three required search terms in the title or abstract. These records were reviewed,

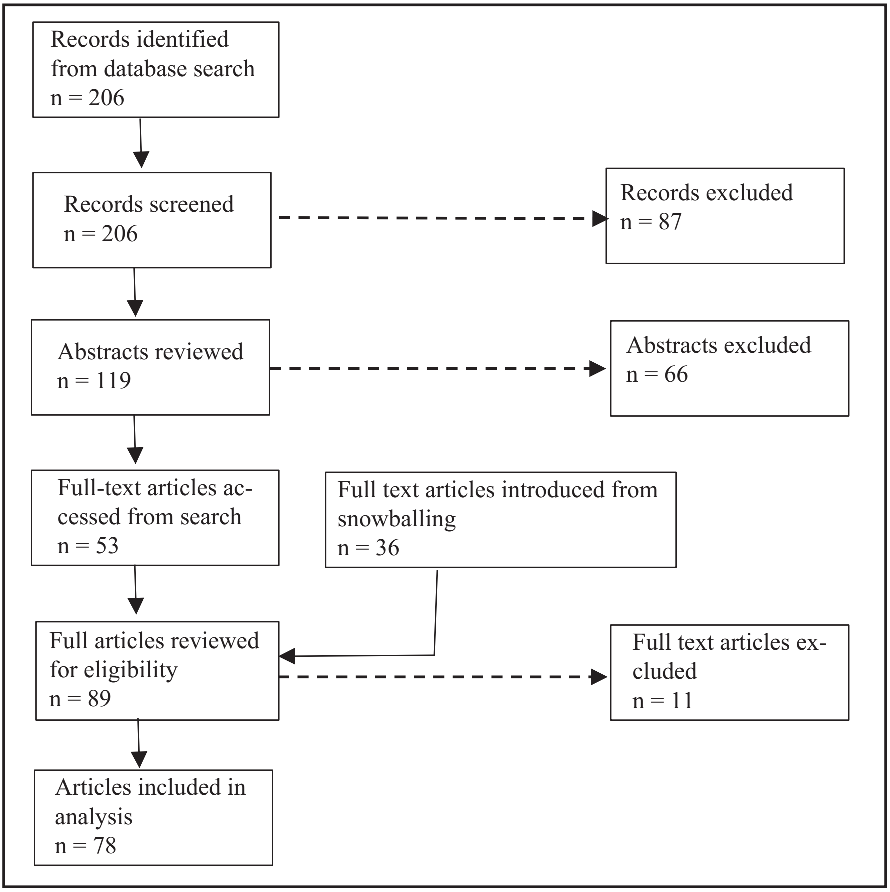

Fig. 2.2 Systematic literature review search process. (Adapted from Kupers et al., 2018)

and 87 were discarded when children's creative inquiry was not the focus of the article, but the three related search terms were just incidentally present in the title or abstract, e.g. an 'inquiry' into 'children's' nutrition using 'creative' approaches to motivate children to eat. Abstracts of the remaining 119 articles were reviewed. A further 66 studies were excluded once full abstracts were reviewed when quality or content criteria were not met.

Using a snowballing approach, 36 further studies were introduced at this point. The initial database search did not pick up these studies because one of the three search terms did not appear in the abstract. However, cross-referencing revealed that they did indeed address the core concepts of children's creative inquiry being reviewed. Nine of the new sources introduced at this point were not journal articles, whilst still meeting quality and content criteria, e.g. peer-reviewed book chapters or commissioned literature reviews for organisations like the *European Commission*.

Cooper (2003) points out that it is commonplace for rigorous systematic literature reviews to include both published and unpublished research.

A total of 89 full-text studies were reviewed. A further 11 studies were excluded after the full-text review for not meeting the quality or content criteria.

The 78 studies included in the analysis were first coded based on demographic markers: location of study, phase of education, domain, methodology, construct focus and point of view. Subsequently, a thematic analysis was conducted to identify key themes in the literature. The Murcia et al. (2020) *A to E of Children's Creativity Framework* was used as the structure for discussing the thematic review, since it provides an up-to-date, research-informed and empirically tested framework of children's creativity.

2.4 Systematic Analysis Results

The geographical location where each study originated is captured in Fig. 2.3. It is clear from the results that creative inquiry is a phenomenon with international currency. Studies from North America and Europe dominate, and 16 of the 26 European studies were from England. The strong representation of studies from English speaking countries is most likely a reflection of the literature search limitation to studies published in English. Ten of the studies were coded as non-specific, because the research was not situated in a particular context, e.g. literature reviews.

A summary of the phases in education explored in each study is provided in Fig. 2.4. Creative inquiry is evidently a phenomenon that spans the age range. The data indicates that research into creative inquiry is strongly represented in early years and primary learning contexts. The inclusion of the word 'children' in the search criteria may have limited the number of studies exploring creative inquiry in older children and adolescents.

The studies included in the analysis were coded based on the subject domain(s) represented. The results are summarised in Fig. 2.5. Thirty of the studies were not linked to a specific subject domain, e.g. many early years studies, and numerous

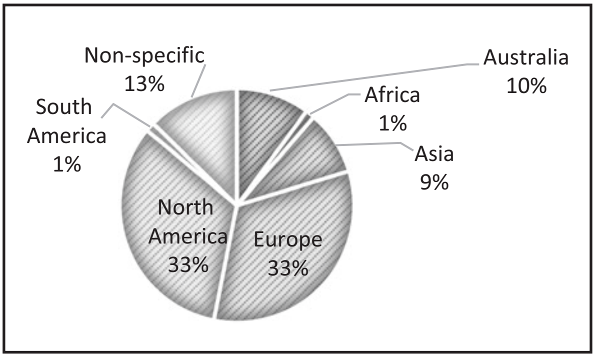

Fig. 2.3 Geographic origin of studies

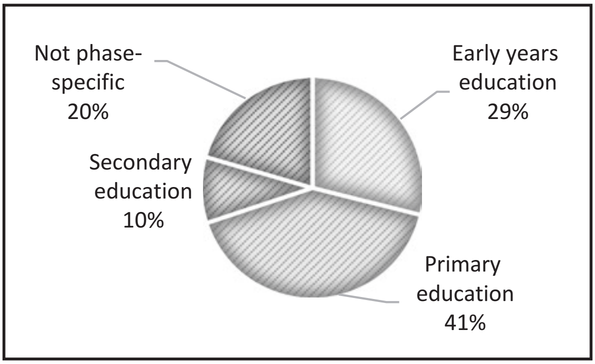

Fig. 2.4 Phase of education of studies

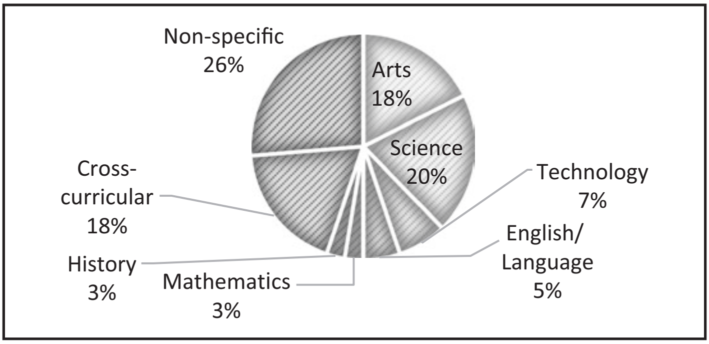

Fig. 2.5 Disciplinary domain of studies

studies were coded in multiple domain categories if creative inquiry in more than one subject domain was the focus of the study. The data indicates that creative inquiry is studied across a wide variety of subject domains. STEM domains and arts domains are strongly represented in the data, suggesting that when creativity and inquiry are studied together, creativity research's traditional arts bias disappears. Intentional use of cross-curricular teaching strategies as a vehicle for creative teaching and learning is also strongly represented in the scholarly literature.

The studies were coded based on the research methodology employed, adapting the categories used by Friedman-Nimz et al. (2005). The results are summarised in Fig. 2.6. There is a strong bias towards qualitative studies in the literature addressing children's creative inquiry. This could be explained by the strong representation of early childhood studies, studies from Western cultures, and studies within mainstream educational contexts rather than psychological laboratories. Friedman-Nimz et al. (2005) noted that creativity and gifted education literature was historically mostly quantitative, but the trend was shifting in the early 2000s, whilst Cremin et al. (2012) noted that early years research in Western cultures was mostly qualitative and mostly quantitative in Eastern cultures. Preiss et al. (2016) noted a bias

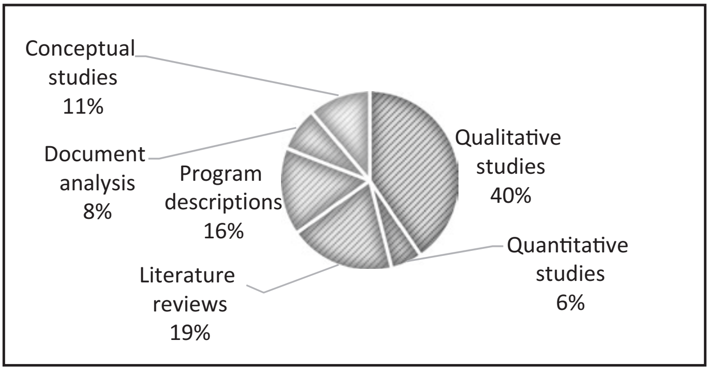

Fig. 2.6 Methodology employed

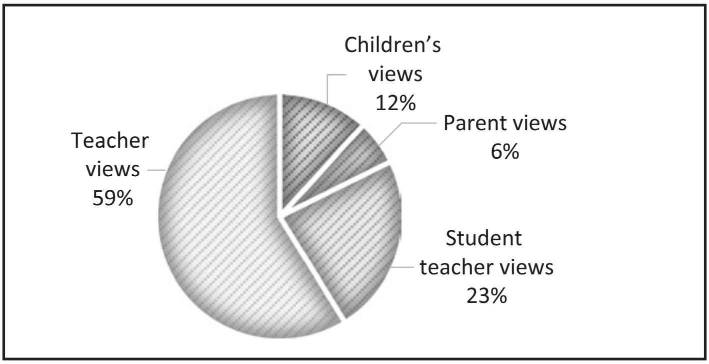

Fig. 2.7 Point of view represented

towards quantitative, psychometric studies in South America and Cremin et al. (2012) identified that a measurement focus was strong in psychological literature, whereas educational studies of creativity were more influenced by qualitative approaches. The high proportion of literature reviews is also interesting.

A small number of studies (17) investigated participant perspectives about creativity and/or inquiry. The results of the points of view represented in perspective studies are presented in Fig. 2.7. It is clear that there is a great sparsity of studies directly exploring children's perspectives on creativity and inquiry.

Whilst creativity and inquiry were set as the search criteria for this systematic literature review, not all studies address both of these constructs with equal weighting. Some studies focus on creativity with only incidental references to inquiry, or vice versa. A wide variety of other related constructs are also investigated alongside a focus on creativity and inquiry in the literature. Figure 2.8 indicates the primary constructs studied in the 78 studies included in the analysis. The results reveal that apart from the major focus on creativity and inquiry, other prominent related constructs in the literature include thinking skills, critical thinking, play-based learning

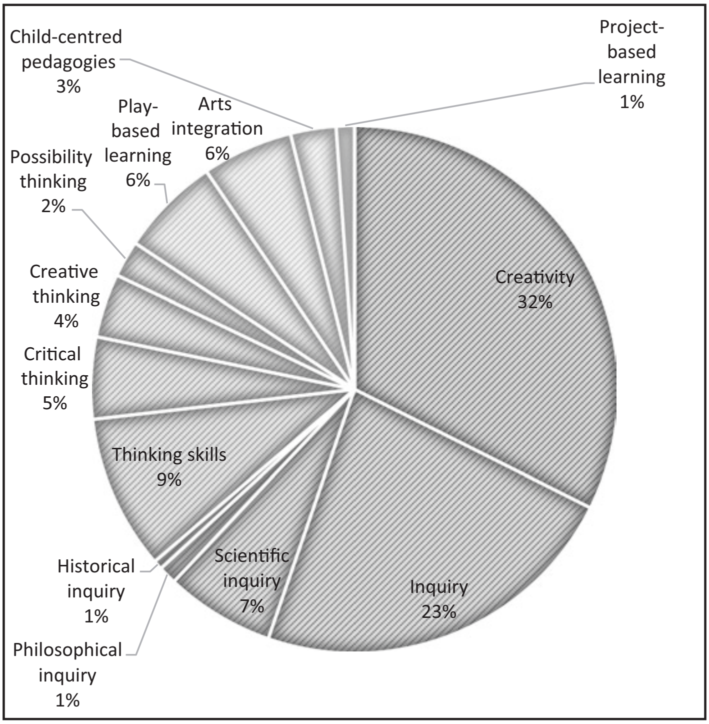

Fig. 2.8 Main constructs studied

and arts integration. The interrelationships between these related constructs are beyond the scope of this study, but worthy of further investigation.

2.5 Thematic Analysis Results

The 78 studies included in the systematic review were analysed thematically, using the Murcia et al. (2020) *A to E Framework of Children's Creativity* as the structure for discussing the results according to the themes of Creative Product, Person, Place and Process.

2.5.1 Product: Criteria for Creative Outcomes

There is remarkable consensus in the literature reviewed on the two key criteria required for outcomes or products to be deemed as creative according to the Murcia et al. (2020) framework: originality (also expressed as novelty or newness), and fitness-for-purpose (also expressed as appropriateness or value), with these two criteria forming part of most definitions of creativity (Glăveanu & Kaufman, 2019). Whilst there is agreement on what defines a creative outcome, there have been differing views on who can be capable of generating such creative outcomes, with several studies discussing the tensions between democratic versus elitist or genius views of creativity, even questioning whether children are indeed capable of creativity (Cremin, et al., 2012; Kupers et al., 2018; Pavlou, 2013). Glăveanu (2011) eloquently argues for a shift away from a deficit view of children, common in psychological literature, which questions the ability of children to fulfil the twofold definition of creativity, towards a cultural capital view that sees children as "the mere embodiment of creativity" (Vygotsky, cited in Glăveanu, 2011, p. 122). In the educational literature which dominates this literature review, there is an accepted view that children are capable of creativity, albeit at the mini-c level, which represents creative outcomes that are original and valuable at an individual, rather than a historic level (Beghetto, 2019).

Despite general agreement by researchers on the core criteria for creativity, teachers do not always share these views. In a systematic review of studies on teacher conceptions of creativity, Mullet et al. (2016) found that teachers' views of creativity were "limited, vague, or confused" (p. 27) and poorly aligned with researchers' views, an argument reinforced by Davies et al. (2018) that teachers do not fully understand creativity. Within a science learning context, McGregor and Frodsham (2019) identified the tension for teachers between valuing the correct answer and valuing a child's imaginative, but potentially wrong, explanations. Barrow (2006) also recognises that differing interpretations of inquiry have led to teacher confusion. This contradicts findings by Cheung (2012) that teacher beliefs around creativity align well with research. However, another interesting tension in the literature is the disconnect between espoused and enacted views of what constitutes creativity. Cheung (2012) identified that whilst teacher beliefs around creativity align with researcher views, their teaching practices do not support their beliefs.

2.5.2 Person: Perspectives on Who Does the Original Thinking

Murcia et al. (2020) discuss the person aspect of creativity through the lens of the child, distinguishing between three different perspectives: experiences where the child is engaged in learning by the educator's creativity (but not necessarily being creative themselves), opportunities for the child to engage in creative doing (i.e. creating something new by following a set of instructions), and experiences where the child engages in creative thinking themselves. The key distinguishing factor is the question: who does most of the original thinking? In contrast, the literature reviewed for this chapter tends to prioritise viewing creativity in education from the teacher perspective. The most common perspective of creativity in teaching and learning represented in the 78 studies reviewed is when the teacher uses creative teaching strategies to engage students in productive learning. This is particularly true for studies advancing an arts integration approach to teaching subject matter in other domains, e.g. STEM (D'Olimpio & Teschers, 2017; Hendrix et al., 2012; Inwood & Sharpe, 2018; Nichols & Stephens, 2013).

Several publications explored the distinction, first described by the UK's *National Advisory Committee on Creative and Cultural Education* (NACCCE, 1999) and Joubert (2001), between teaching creatively, where the teacher uses creative teaching methods to make the learning engaging to students, and teaching for creativity, where teachers teach in a way that students learn the subject content and develop their creative skills in parallel (Benson & Lunt, 2011; Davies et al., 2018; Durham, 2019; Harris & De Bruin, 2018; McGregor & Frodsham, 2019). Beghetto (2019) instead uses the terminology of teaching through creativity, teaching about creativity and teaching for creativity. Despite significant advances in describing and providing guidance to teachers on teaching creatively and teaching for creativity, there is consensus across the literature that teachers still lack procedural knowledge and deep understanding to embed teaching for creativity in their teaching practice (Beghetto, 2019; Davies et al., 2018; Harris & Ammermann, 2016; Ucus & Acar, 2019).

Another distinction in Murcia et al. (2020) is the difference between children's creative doing and their creative thinking, reflecting the difference between an expressive view and a cognitive view of creativity (Cremin et al., 2012). This distinction has also been described as the difference between a focus on ideas and inspiration, or a focus on creating through embodied action, thus asking: is creativity about the head (a perspective biased by psychological literature) or the hands (the dominant view in arts and craft disciplines) (Glăveanu & Kaufman (2019)? In the studies reviewed for this chapter, the expressive view is more prevalent in studies representing artistic domains and in early years inquiry learning contexts, and the cognitive view is more prevalent in the science domain studies and strongly aligned to scientific, historical and philosophical inquiry learning contexts. In creative production contexts, creative doing is strongly foregrounded in studies situated within STEM and other technology domains (Benson & Lunt, 2011; Chesky & Wells, 2017; Donohue & Schomburg, 2017; Hatzigianni et al., 2020; Maxwell et al., 2019). However, Smith and Smith (2016) reinforces the importance of balancing inquiry and 'fabrication' to ensure that learners engage in both creative thought and action. In summary, navigating the dynamic interplay between teacher creativity and child creativity, and between creative thought and action remain barriers to embedding creativity in teaching and learning and thus deserves further investigation.

2.5.3 Place: Elements of an Enabling Environment

Murcia et al.'s (2020) creativity framework identifies what teachers can do to create an environment conducive to creativity, classified into three categories: resources, communication and socio-emotional climate. Despite significant research into the features of an enabling environment and the pedagogies that can support creativity, the studies reviewed for this chapter indicate that teachers still lack clarity on the specific actions they can take to teach for creativity (Glauert & Manches, 2012; Harris & Ammermann, 2016; Preiss et al., 2016; Ucus & Acar, 2019) and their beliefs often fail to translate into their classroom practice (Cheung, 2012; Davies et al., 2018; Durham, 2019; Lucas & Venckutė, 2020). Teaching for creativity is a complex, multifaceted, phenomenon, full of tensions and contradictions, with no simple recipe. True to the nature of creativity, teaching for creativity involves tolerating ambiguity and uncertainty.

The multidimensional part that teachers play in creating an environment conducive to creative inquiry learning expressed through the literature can perhaps best be presented as a series of creative contradictions that need to be balanced carefully and contextually by the teacher. These creative contradictions fall into four areas:

- The role the educator plays: playing a passive role or an active role in "orchestrating" children's creative inquiry (Heindl, 2018); standing back, as a deliberate pedagogical choice or intervening by "meddling in the middle" (Craft et al., 2012; Cremin et al., 2012); being a play partner or allowing students to engage in free play and exploration (Cremin et al., 2012); and role modelling the creative process or playing a supporting act to children's creativity (Davies et al., 2014; Thompson, 2017).
- The tasks the educator sets: balancing play with work (Pui-Wah & Stimpson, 2004); pursuing academic learning goals or developing learner creativity (Beghetto, 2019; Ogu et al., 2018); establishing opportunities to develop creative thought or opportunities for creative action (Smith & Smith, 2016); facilitating creative action and embodied engagement or facilitating reflection on creative action and development of metacognition (Cremin et al., 2015; Glauert & Manches, 2012; Fels, 2008); encouraging logical reasoning and convergent thinking or encouraging fluency in divergent thinking (Glauert & Manches, 2012; Gregory et al., 2013); and fostering independence of thought or encouraging interdependence, dialogue and collaboration (Cooper, 2018; Cutcher & Boyd, 2016; Davies et al., 2013; Heindl, 2018; Thompson, 2017).
- The pedagogy the educator employs: providing freedom and flexibility or structure and order (Biermeier, 2015; Davies et al., 2013; Dobson & Stephenson, 2017; Ucus & Acar, 2019); providing student choice, direction and autonomy or planning and steering the learning process according to a deliberate plan (Cheung, 2012; Pavlou, 2013; Smith & Smith, 2016); providing scaffolding, heuristics or process constraints or providing space for student-led inquiry (Glauert & Manches, 2012; Lazonder & Harmsden, 2016); creating unpredictability and introducing uncertainty or driving towards closure and solutions (Beghetto, 2019; Cremin et al., 2012; Green & Somerville, 2015); and engaging in open-ended questioning or closed-ended questioning (Cheung, 2012; Thompson, 2017).
- The space the educator creates: creating a safe, supportive climate or deliberate cognitive challenge (Chen, 2001; Cremin et al., 2012); creating an environment, space and time for creativity to flourish organically or deliberately teaching cre-

ative thinking strategies (Benson & Lunt, 2011; Cremin et al., 2015; Harris & De Bruin, 2018); intentional provision of provocations or allowing time to experiment, play and explore (Biermeier, 2015; Craft et al. 2012; Ogu et al., 2018); dominance of teacher talk and guidance or student talk (Cremin et al., 2015; Hendrix et al., 2012; Maxwell et al., 2019; Schoevers et al., 2019); and prioritisation of teacher questioning or encouraging student questioning (Alfonso 2017, Cooper 2018; Ogu et al., 2018).

2.5.4 Process: Characteristics of Children's Creativity

At the heart of the Murcia et al.'s (2020) *A to E Creativity Framework* is a set of behaviours that children display when acting and thinking creatively, called the A to E of creativity: **A**gency, **B**eing curious, **C**onnecting, **D**aring and **E**xperimenting. Each of these categories is represented by the literature reviewed for this chapter. Some key observations are discussed below.

'Agency' is discussed as a major theme in 17 of the studies reviewed. 11 of these studies report on early years contexts, five on primary school contexts and two do not specify an age range. No studies situated in secondary education explore agency as a central theme. Whilst agency gains more attention in the education of younger learners, Davies et al. (2013) emphasise that there are creative benefits for students of all ages from enhanced agency: "there is strong evidence from across the curriculum and age-range that where children and young people are given some control over their learning and supported to take risks with the right balance between structure and freedom, their creativity is enhanced" (p. 85). Cremin et al. (2012) recognise that when learners engage in creative activity, they can experience flow (Csikszentmihalyi, 1996), but when learners have agency in creative activity, flow can be sustained. Despite acknowledgement in the literature that agency is an important enabler of children's creativity, Glauert and Manches (2012) conclude that most classroom inquiry processes are teacher-led, not student-led, contradicting the original intention of inquiry learning.

The characteristics involved in children 'Being curious' according to the *A to E Creativity Framework* are strongly represented in the literature reviewed, particularly in early years learning and science domain studies. The subcomponents of questioning and engaging in 'what if' thinking align well with the concept of possibility thinking (Craft et al., 2012; Burnard et al., 2006), which is driven by children's questioning, in particular children engaging in posing 'as if' and 'what if' questions. Lucas and Venckutė (2020) also note that key characteristics of creativity are "curiosity and intellectual restlessness" (p. 2). Whilst Murcia et al. (2020) found evidence of teacher questioning, but not student questioning in their digital technology case study, Ogu et al. (2018) describe how children's questioning was driving the scientific inquiry, and Alfonso (2017) explains how children's questions were used to "ignite the study" of a topic (p. 64). Cremin et al. (2015) note that teacher and child questioning are central to both inquiry learning and creative learning, but that the focus in the former is more on questioning and ideas, and in the latter more attention is paid to curiosity and play.

'Connection making' is recognised as a key subcomponent of creative inquiry (Cremin et al., 2012; Mullet et al., 2016; Thompson 2017). This includes making remote connections through play (Russ & Doernberg, 2019), making personal connections to the topics of study through creative learning (Harris & De Bruin, 2018) and children making connections to their own lives through inquiry learning, leading to their "connected, meaningful, and worthwhile participation in the world" (Serebrin & Wigglesworth, 2014, p. 21). The increasing shift in recent decades towards research recognising creativity as a social phenomenon (Cremin et al., 2012; Lucas & Venckutė, 2020), has made collaboration, or the ability to connect to others, another key focus in creativity literature, including the studies reviewed for this chapter. The systematic review by Davies et al. (2013) concludes that "there is strong evidence that pupil creativity is closely related to opportunities for working collaboratively with their peers" (p. 86). Beghetto (2019) postulates that the sociocultural view of learning may indeed suggest that all learning is, by definition, a creative act (at mini-c level), since learning is socially constructed.

In this review, collaboration is represented as a key component of creative inquiry learning across all education phases and various subject domains, including science, technology and mathematics. Benson and Lunt (2011) advocates the value of children collaborating, which is often counter-cultural in design and technology contexts that may prioritise individual work, whilst Ogu et al. (2018) explain that through interaction with their peers, children can learn more than they could have alone in a science inquiry context, activating their zone of proximal development (Vygotsky, 1962). The concept of children forming a 'community of inquiry' is also crucial in the philosophical inquiry tradition explored by D'Olimpio and Teschers (2017) and Green and Condy (2016). Finally, making connections through reflection and metacognition is another theme strongly represented (Chen, 2001; Cremin et al., 2012; Glauert & Manches, 2012; Hendrix & Eick, 2014; Pavlou, 2013; Pui-Wah & Stimpson, 2004; Spector & Ma, 2019). Cremin et al. (2015) note that the concept of reflection is better developed in inquiry literature than creativity literature.

'Daring' to be different as children take risks, explore alternative or divergent lines of thinking and practice tolerating uncertainty are critical characteristics of children's creativity, and also one of the crucial distinguishing lines between inquiry and creativity (Cremin et al., 2015; Glauert & Manches, 2012; Lucas & Venckutė, 2020; Murcia et al., 2020). In this systematic literature review, the characteristics of daring to be different were observed in various domains (arts, science, mathematics, history, technology) and across all phases of education. Encouragement to take risks can increase ideational fluency in computer games development tasks in secondary school (Eow et al., 2010) and learners can develop comfort with ambiguity through exposure to unpredictability and uncertainty that underpin creative pedagogies in primary science learning (Green & Somerville, 2015). Russ and Doernberg (2019) identified how divergent thinking and flexibility of thought were features of both creativity and play in early learning contexts. There are significant benefits for learners from engaging in divergent thinking in science learning contexts (Glauert

& Manches, 2012), and Lucas and Venckutė (2020) points out that these benefits can extend beyond the immediate learning context since creativity develops dispositions of "tolerance for uncertainty, risk, and ambiguity, and the capacity to be adaptable and flexible", which "facilitate higher learning, long-term employability, and upward social mobility" (p. 2).

Despite these advantages, the contribution of divergent thinking in science and mathematics learning contexts is often undervalued because of the valuing of 'correct' answers above the generation of original or alternative ideas (Glauert & Manches, 2012; McGregor & Frodsham, 2019). Standardised assessments can also be detrimental to the development of divergent thinking by valuing "convergence of thinking" based on one right answer (Harris & De Bruin, 2018, p. 227). In addition, teacher views on creativity can passively discourage divergent thinking. Mullet et al. (2016) demonstrates that, whilst researchers associate creativity with behaviours including openness, risk-taking, questioning of authority, and nonconformity, teachers associate creative behaviours in students with socially conformist behaviours, e.g. high intellectual ability, maturity and artistic ability.

<u>'Experimenting'</u> and its subcomponents identified in Murcia et al. (2020) e.g. playing with possibilities, tinkering and solving problems, are strongly represented in the literature reviewed. Experimenting through experiential learning has its roots in child-centred learning philosophies of Bruner, Dewey, Fröbel, Malaguzzi, Montessori, Piaget, Rousseau, Steiner, and Vygotsky represented in the early years learning studies. However, experimenting is just as important for the development of creativity in older students, as Cooper (2018) reminds us: "we learn to be creative by experimenting …" (p. 645).

Biases towards different subcomponents of experimenting are discernible in the literature. The concept of play is strongly represented in early years studies (Craft et al., 2012; Cremin et al., 2015; Dere, 2019; Desouza, 2017; Marsh et al., 2018; Russ & Doernberg, 2019) with Craft et al. (2012) even describing play as a logical necessity for possibility thinking in the early years. There is strong research evidence for a significant correlation between play and divergent thinking (Russ & Doernberg, 2019) and Hui et al. (2019) concludes that "an abundance of research findings supports the positive effects of play on imagination, problem-solving, and the thinking skills associated with creativity" (p. 71). Play is more closely associated with the concept of creativity than with inquiry (Cremin et al., 2015). It is also more closely associated with arts and technology domains than scientific domains, except where an arts integration approach is used as a vehicle for learning in science inquiry contexts (D'Olimpio & Teschers, 2017; Marsh et al. 2018; Ogu et al., 2018). Despite this early learning bias towards play, Davies et al. (2013) advocate for the benefits of play at all ages to facilitate creative skills development.

Tinkering is most strongly represented in digital technology and design technology contexts in the data. Smith and Smith (2016) describe how tinkering allows ideas to collide, with creativity occurring at these "collision points" (p. 31). Problem-solving is closely associated in the literature with scientific inquiry, critical thinking and science and STEM learning contexts (Chesky & Wells, 2017; Cremin et al., 2015; Donohue & Schomburg, 2017; Heindl, 2018; Marsh et al., 2018; Smith & Smith, 2016; Thompson, 2017). The benefit to children of engaging in problem-finding and problem-solving is articulated by Thompson (2017): "When the students are asked to both define and solve a problem, the thinking is more independent…" (p. 39). This links back to the first characteristic of children's creativity, agency, reinforcing the *A to E of Children's Creativity Framework's* interconnectedness.

2.6 Representation of STEM Studies

This analytic literature review explored the research literature on children's creative inquiry across different subject domains. When the information is filtered to only the 34 studies focusing particularly on creative inquiry in STEM contexts, 12 studies are situated in pure science contexts, ten in science & art integration, nine studies in technology and three in mathematics contexts. With regards to phase representation, eight of the STEM studies were situated in early years learning, 18 in primary and one in secondary learning contexts. Inquiry is a key focus in 23 of these studies and creativity a major focus in 20. There was overlap in each of these categories with some studies representing more than one of these foci. The thematic analysis filtered for STEM studies indicate that the following creative inquiry themes were represented in STEM studies: agency, questioning, play, collaboration and dialogue. Each of these themes was presented in studies spanning different STEM sub-disciplines, e.g. science and technology, and at different age ranges, including early years learning and primary settings. A theme focusing on children's engagement in creative production, as opposed to creative thinking, was strongly represented in technology contexts, but not in other STEM disciplines. Digital technology's role in enabling creativity, is another theme strongly represented in the technology literature (Hatzigianni et al., 2020; Marsh et al., 2018).

Whilst many studies describe children's creative behaviours in STEM learning contexts, the contribution of some creative behaviours, e.g. divergent thinking, are still too often undervalued, particularly in science and mathematics learning contexts (Glauert & Manches, 2012), and teachers often struggle to recognise or integrate creativity in science lessons (Davies et al., 2018). This reinforces the document analysis conducted by Heillmann and Korte (2010) who counted the number of references to creativity within European curricula and policy documents to create a subject ranking based on the relative representation of creativity in each subject domain. Mathematics scored the lowest and science, the third-lowest of all subjects.

2.7 Conclusion

This systematic analysis demonstrates that children's creative inquiry is a phenomenon studied worldwide, in all phases of education, across different subject domains and using a variety of methodologies, with a preference for qualitative studies. There is a great sparsity of studies directly reflecting children's point of view on creative inquiry, which should be a priority for future research. The interrelationships between creativity, inquiry and other related constructs, e.g. problem-solving, active learning, and play-based learning are worthy of further exploration.

The search terms used for this study could present a possible limitation. Because all three search terms (children, creativity and inquiry) had to be present in the abstracts, studies focusing exclusively on either children's creativity or children's inquiry may have been excluded. Only studies published in English were included, potentially biasing the data towards a Western perspective. Studies investigating related constructs, e.g. problem-solving, innovation, active learning or problem-based learning, would also have been excluded unless coupled with a focus on creative inquiry. Finally, the search was limited to children's creative inquiry, thereby possibly missing studies dealing with creative inquiry in older students where the word "children" may not have been used.

The thematic analysis of the 78 studies included in this review identified several important implications for future educational research, policy and classroom practice. Navigating the dynamic interplay between teacher creativity and child creativity, and between creative thought and action remains barriers to embedding creativity in teaching and learning and thus deserves further investigation.

There is a significant body of research into the features of an enabling environment and the pedagogies that can support creativity, yet research demonstrates that teachers still lack clarity on the specific actions they can take to embed creative inquiry and to teach for creativity. Teaching for creativity is a complex, multifaceted phenomenon, full of tensions and contradictions, with no simple recipe. True to the nature of creativity, teaching for creativity involves tolerating ambiguity and uncertainty. This chapter identified creative contradictions from the literature that need to be carefully and contextually balanced by educators to enable learner creativity. Teachers need to develop comfort with this ambiguity, reconciling the implied contradictions and extending their behavioural repertoire to confidently teach for creativity.

The five sets of behaviours characterising children's creativity presented in Murcia et al.'s (2020) *A to E Framework of Children's Creativity*: **A**gency, **B**eing curious, **C**onnecting, **D**aring and **E**xperimenting, are strongly represented in the literature. However, the contribution of some of these behaviours is still too often undervalued in STEM learning contexts. It is recommended that the underrepresentation of creativity in curriculum documents should be redressed, and that initial teacher training should focus on the contribution of creative inquiry in all STEM learning contexts. We hope that this book will make a valuable contribution to representing and enabling the inherent creative possibilities in a wide variety of STEM learning contexts.

Joubert (2001) identified five alliterating barriers impeding the embedding of creativity in education: language lessons (inconsistent language resulting in a lack of clarity and understanding on what creativity is), political problems (creativity regarded as conflicting with an academic standards agenda), ideological impediments (dualistic thinking between progressive and traditionalist pedagogies), bureaucratic burdens (slow public policymaking constraining pedagogical innovation) and creative constraints (a vacuum of visionary, creative leadership willing to take risks). This review identified another barrier: a rhetoric-reality rift.

Despite decades of focus on developing student creative inquiry capabilities in policy and research, there is still a disconnect between rhetoric and reality in classrooms. Teachers value creativity, but they find it hard to recognise creativity in the classroom; despite enthusiasm for inquiry learning, very little inquiry learning is observed in classrooms; teacher views still largely diverge from researcher views on creativity, with teachers prioritising conformist behaviours above original thinking behaviours; teacher classroom practices often contradict their beliefs when it comes to teaching for creativity; there is still limited understanding and a lack of confidence amongst teachers to teach for creativity; and creativity is generally not embedded in classroom teaching practice (Barrow, 2006; Cheung, 2012; Davies et al., 2018; Durham, 2019; Lucas & Venckutė, 2020; McGregor & Frodsham, 2019; Mullet et al., 2016; Ucus & Acar, 2019). There are, however, some glimmers of hope: teacher views can be shifted to align more clearly with researcher views through specific creativity teacher training, and teacher classroom practice can adapt to implement the pedagogies of creativity and inquiry through immersive professional learning experiences (Dole et al., 2016; Mullet et al., 2016; Myers, 2012). This remains an underrepresented perspective in the research literature, and we recommend further research focusing on how to facilitate teacher shifts in pedagogical practice to effectively embed teaching for creative inquiry in classroom contexts. Research into repairing this rhetoric-reality rift also needs to be implemented in pre-service and in-service teacher training.

Finally, this review has demonstrated that creativity and inquiry are occasionally overlapping yet mutually enriching pedagogical practices. The most exciting research and practice often happen at the intersections: between creativity and inquiry, between the cognitive and expressive focus of creativity, crossing the divide between active, play-based learning and rigorous academic learning, and where different subject areas collide. There are rich research traditions in early learning, arts education and philosophical inquiry fields that can enrich our understanding of creative inquiry in STEM domains. Let's celebrate creativity at these crossroads.

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Chapter 3
Teachers' Reflections on Their Changing Roles and Young Children's Learning in Developing Creative, Inquiry-Based Approaches in Science Education

Esmé Glauert and Fani Stylianidou

3.1 Introduction

This chapter is based on work conducted during the Erasmus+ KA2 project *Creativity in Early Years Science Education* (CEYS) (2014–2017), which built on the EU/FP7 research project *Creative Little Scientists* (CLS) (2011–2014). Funding for the CLS and CEYS projects reflected the high focus on science and creativity in European education policy (Council of the European Union, 2009). The Council of the European Union identified one of the Education and Training goals for *Europe 2020* as "Enhancing creativity and innovation, including entrepreneurship, at all levels of education and training" (Council of the European Union, 2009, p. 3). Strengthening science education had also been put forward as a key goal across Europe with both the Rocard Report (European Economic and Social Committee, 2007) and Osborne and Dillon (2008) advocating the importance of investigative approaches in engaging young students with science. In addition, there had been growing discussion of the need for greater attention in the curriculum to the nature of science (for example: High Level Group on Human Resources for Science and Technology, 2004). in particular the central roles of inquiry and invention, both triggered by curiosity, intuition, and imagination, all features closely related to creativity (as argued by Barrow, 2010). At the same time conceptions of children's creativity had begun to move away from traditional links with the arts to a focus on

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problem finding and problem solving (for example: Craft et al., 2012). Motivation has an important role to play in creativity too.

The work of the CLS and CEYS projects was also informed by growing recognition of the importance of science teaching in the early years, both for a child's development and for science learning. Young children's concern to explore the world around them from their earliest years can be nurtured and exploited through early science education. Moreover, quality science learning experiences provide important foundations for the development of key concepts, thinking, informed language and positive attitudes in science (see for example: Eshach & Fried, 2005). The projects built on new insights into learning and teaching, gained from close study of the learning of very young children and of classroom interactions made possible with new technologies. Over recent years there has been increasing recognition of young children's capabilities. A growing body of research in cognitive development and in early years science learning indicates that young children seek to explore and explain the world around them from their earliest years. They show awareness of patterns in observations and causal reasoning, albeit constrained by their conceptual knowledge, the nature of the task, and their awareness of their own thinking (Duschl et al., 2007; Goswami, 2015). This provides productive starting points for developing scientific reasoning. Work by Akerson and Donnolley (2010) indicates that young children can begin to recognise the empirical and creative nature of science.

Finally, the projects took place in a dynamic policy context. All nine partner countries (Belgium, Finland, France, Germany, Greece, Malta, Portugal, Romania, UK) across both projects were involved in processes of policy change. They were undertaken in a climate of debate about the importance and effectiveness of inquiry-based approaches (Minner et al., 2010; Welcome Trust, 2011), the role of the teacher in supporting young children's early explorations in science (Fleer, 2009) and the need to go beyond the rhetoric of creativity increasingly emphasised in international debate concerning the aims of education (Heilmann & Korte, 2010).

More specifically, the CLS research project sought to investigate the potential in policy and practice to promote creativity and inquiry in science education for children aged three to eight. The CEYS project, building on the framework and results of CLS, focused on developing materials for professional development to foster creativity and inquiry in science in partnership with early years teachers.

This chapter will first introduce key elements of the conceptual framework, developed by CLS and adopted by CEYS: the CLS definition of creativity in early years science; synergies between inquiry-based and creative approaches to learning and teaching; key features of inquiry-based approaches; and dispositions associated with creativity. It will then focus on one aspect of the work, the development of the *CEYS Curriculum Materials* by teachers through action research. The chapter will conclude by presenting and discussing findings from analysis of teachers' reflections on their learning journeys and those of their classes over time, focusing on children's learning progress and their own changing roles in relation to inquiry and creativity.

3.2 Conceptual Framework

The CEYS project drew on the *Conceptual Framework* developed for the CLS project (Creative Little Scientists, 2012). This was significant in offering a common framework and language to support planning, discussion and evaluation of learning and teaching processes, and provided a vital starting point for the development and design of the *Curriculum Materials*. Key components of the *Conceptual Framework* are outlined below.

3.2.1 Definition of Creativity in Early Years and Mathematics

The definition of creativity in early science in the *Conceptual Framework* was as follows: "Generating ideas and strategies as an individual or community, reasoning critically between these and producing plausible explanations and strategies consistent with the available evidence". This needs to be understood alongside the *Little c creativity* definition (Craft, 2001), as shown in Fig. 3.1 below. This signals both a focus on creativity as something of which we are all capable (Banaji & Burn, 2010), and a recognition of key roles of creativity in both generating and evaluating ideas and strategies in science and mathematics education. The importance of generation and evaluation of ideas *within a community* is also emphasised. This includes examination of ideas in the context of existing, widely accepted explanations and strategies.

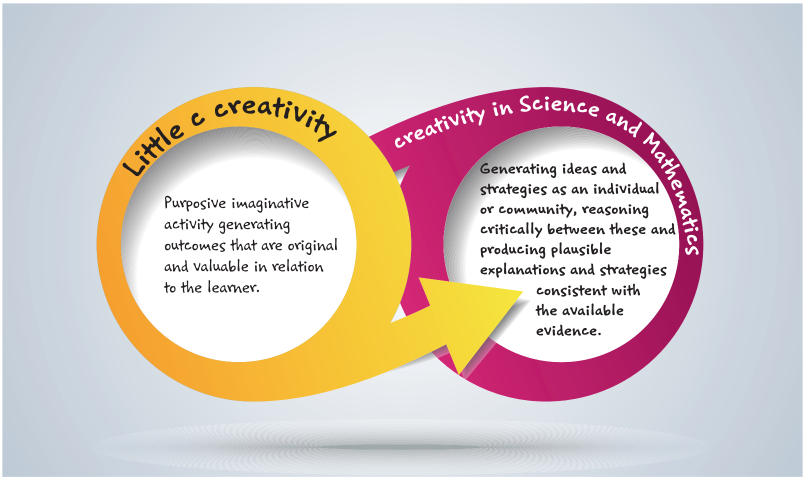

Fig. 3.1 Definitions of creativity (Creative Little Scientists, 2014, p. 5)

3.2.2 Key Features of Inquiry-Based Approaches to Learning and Dispositions Associated with Creativity

A central challenge was to determine how opportunities for inquiry and creativity would be identified. Based on a literature review encompassing science and mathematics in the early years, creativity in early years education, teacher education and comparative education, the *Conceptual Framework* set out key characteristics of the inquiry-based approaches and creative dispositions as shown in Table 3.1 below.

This was informed by an examination of features of Inquiry-Based Science Education (IBSE) and Creative Approaches (CA) discussed in the literature, both the subject of considerable debate (see for example: Minner et al., 2010; Chappell et al., 2008). In terms of features of IBSE, while a review of research revealed varied definitions (Minner et al., 2010; Asay & Orgil, 2010), a number of common processes could be identified. They reflect aims for science education that emphasise scientific literacy. In relation to CA similar processes were identified, linked with exploration, problem finding and solving, alongside dispositions associated with creativity, such as motivation, curiosity and imagination, which are also key in inquiry. Examining connections between these and the wider literature informed the definitions of creativity used across the project (shown in Fig. 3.1 above), and in addition provided the basis for examining synergies between *Inquiry-Based Science Education and Creative Approaches* to learning.

3.2.3 Synergies Between Inquiry-Based and Creative Approaches to Learning and Teaching

The *Conceptual Framework* also identified a number of synergies between *Inquiry Based Science Education and Creative Approaches* to learning and teaching as outlined below (Cremin et al., 2015). These provided a framework for examination of opportunities for creativity and inquiry in both policy and practice.

Table 3.1 Features of inquiry and creative dispositions

Learning activities (linked to key features of inquiry)	Creative dispositions
Questioning	Sense of initiative
Designing and planning investigations	Motivation
Gathering evidence	Ability to come up with something new
Making connections	Making connections
Explaining evidence	Imagination
Communicating explanations	Curiosity
	Ability to work together
	Thinking skills

- *Play and exploration*, recognising that playful experimentation and exploration is inherent in all young children's activity.
- *Motivation and affect*, highlighting the role of aesthetic engagement in promoting children's affective and emotional responses to science and mathematics activities.
- *Dialogue and collaboration*, accepting that dialogic engagement is inherent in everyday creativity in the classroom, enabling children to externalise, share and develop thinking.
- *Problem solving and agency*, recognising that through scaffolding the learning environment children can be provided with shared, meaningful, physical experiences and opportunities to develop their own questions as well as ideas about scientifically relevant concepts.
- *Questioning and curiosity,* recognising that creative teachers often employ open ended questions, and promote speculation by modelling their own curiosity.
- *Reflection and reasoning*, emphasising the importance of metacognitive processes, reflective awareness and deliberate control of cognitive activities, still developing in young children but incorporated into early years science and mathematics practice.
- *Teacher scaffolding and involvement*, teachers mediating the learning to meet children's needs, rather than feeling pressurised to meet a given curriculum.
- *Assessment for learning,* identifying and building on the skills, attitudes, knowledge and understandings children bring to school, supporting and encouraging children's active engagement in learning and fostering their awareness of their own thinking and progress.

3.2.4 Curriculum Dimensions – 'The Vulnerable Spider Web'

Finally, the *Conceptual Framework* not only identified characteristics of learning and teaching processes that have the potential to foster opportunities for creativity in science classrooms, but it also drew attention to the influence of wider factors, in particular, perspectives on the aims for science education, wider national and school contexts, and teacher characteristics. Here the *Conceptual Framework* adopted the curriculum dimensions associated with the *vulnerable spider web* from Van den Akker (2007, p. 39) as shown below.

- *Rationale or Vision*: Why are they learning?)
- *Aims & Objectives*: Toward which goals are they learning?
- *Content*: What are they learning?
- *Learning activities*: How are they learning?
- *Teacher role*: How is the teacher facilitating learning?
- *Materials & Resources*: With what are they learning?
- *Grouping*: With whom are they learning?
- *Location*: Where are they learning?

- *Time*: When are they learning?
- *Assessment*: How to measure how far learning has progressed?

These different dimensions that frame the curriculum are regarded as vulnerable because they are interconnected, in that what happens in one dimension can have an impact on another.

These key elements in the Conceptual Framework: the definition of creativity in science, features of inquiry and creative dispositions, synergies between inquiry-based and creative approaches to learning and teaching, and the dimensions of the vulnerable spider web provided an important common reference point and language across the CEYS project in the development of curriculum materials on inquiry and creativity for and by early years teachers.

3.3 Development of Curriculum Materials on Inquiry and Creativity *for* and *by* Early Years Teachers

The CEYS project, building on the framework and results of CLS, focused on developing materials for professional development to foster creativity and inquiry in science in partnership with early years teachers.

This chapter is focused on one aspect of the work of the CEYS project, the development of the *Curriculum Materials*, designed to exemplify and illustrate the development of creative inquiry-based approaches in early years science, in varied national and ***local*** contexts across Europe. Participating teachers in Belgium, Greece, Romania and the UK were involved in action research in their classrooms aimed at developing creative, inquiry-based approaches to learning and teaching. They were supported by a series of *Curriculum Development Workshops* run in each country. The teachers produced *Curriculum Materials* to record and illustrate their learning journeys alongside those of the children in their classes. These *Curriculum Materials* provide evidence and analysis of learning and teaching sequences *over time*, and offer insights into teachers' decision-making and children's learning, linked explicitly to key elements in the *Conceptual Framework.*

3.3.1 Curriculum Development Through Action Research

Curriculum development using action research was at the heart of the CEYS project. Action research is one way of implementing change and supporting staff and curriculum development. It involves collecting a range of evidence on which to base rigorous reflection. Common assumptions underpinning action research include:

- Teachers and schools work best on issues they have identified for themselves.

- They need time and space to reflect on, evaluate and to experiment with practice in order to respond to the circumstances and needs of particular children, schools and communities.
- Teachers and schools can best help each other by working collaboratively.
- Action research involves collecting a range of evidence (qualitative and quantitative) on which to analyse strengths and weaknesses.
- Action research contributes to a culture of self-evaluation and school improvement.

(See for example: Hitchcock & Hughes, 1995; McAteer, 2013; Reason & Bradbury, 2012)

The adoption of this approach was influenced by a view that any materials to be used by teachers should be designed in collaboration with them and with the involvement of all relevant stakeholders, so they are relevant and have the maximum potential for impact. Collaboration between schools and higher education institutions has the potential not only to improve initial teacher education, but also to contribute to school development and teachers' professional development (Snoek et al., 2008). The choice of action research as an approach to curriculum development was underpinned by the perspective that making links between research and practice is complex. Bringing together knowledge from practice with knowledge from research to gain insights and improve practices is a dynamic, interactive and democratic process, involving interpretation in context (Brown, 2015).

The choice of action research, with its cycles of action and reflection over time was also influenced in particular by Guskey's model of teacher development (Guskey, 2002). He argues that traditional models of professional development are often ineffective. He suggests first that they fail to recognise that most teachers' interests are focused on enhancing students' learning and on gaining practical ideas for the classroom. Second, they are often designed to promote change in teachers' attitudes and beliefs, assuming this will then lead to changes in practice. Guskey's alternative model of teacher development turns this around. He emphasises the importance of trying out new ideas in practice *first* and then noting change and improvement in students' outcomes. This, he suggests, promotes changes in teachers' beliefs and attitudes. So that change is primarily an experientially based learning process.

Finally, the selection of an action research approach was informed by perspectives on teacher professional development in science found in the literature. These indicate *the need to pay attention to practitioners' beliefs,* conceptions and attitudes towards science, not merely changing, but building upon existing' beliefs (for example: Schepens et al., 2009). They underline the *value of learning by doing and of partnerships* between teacher educators and practitioners (for example: Cochran-Smith & Zeichner, 2005), and emphasise *the importance of multiple inquiry-based experiences* in developing practitioners' understanding of inquiry-based science instruction and the opportunities and issues involved (Varma et al., 2009). Finally, the selection of an action research approach drew on the work of Rizvi and Lingard

(2010) in highlighting the *need to interpret policy and practice in context* to problematise what works and to identify and build on potential in everyday practices.

3.3.2 Sample and Ethics

Each of the five CEYS partners from four countries selected a minimum of five schools each, following induction workshops to introduce the project, and subsequent meetings with headteachers and potential teacher participants to explain the commitment required. 34 schools and 61 teachers from classes across the age range three to eight were recruited. All participating schools were non-selective and worked with relevant *National Curriculum* requirements.

A common framework of ethical procedures was adopted across the project, including voluntary participation based on informed consent from the schools, teachers, parents and children, including explicit agreement for all forms of data collection, principles of confidentiality and anonymity, and procedures to ensure data security. All partners were required to identify and meet ethical requirements in their own national and institutional contexts.

3.3.3 The CEYS Curriculum Development Process

Participating teachers carried out two cycles of action research in their classrooms over the course of a year. The action research cycle followed is shown in Fig. 3.2 below. The questions in the inner boxes were designed to support teachers' ongoing reflections about their values, learning and interactions with the research process and ongoing review of evidence to inform that process. Five *Curriculum Development Workshops* were held in each of the four CEYS partner countries to support teachers' action research. These were spread over the year to ensure long-term impact, implementation and sustainability of the desired change. They also had an important role towards the end of the project in supporting the development of the *Curriculum Materials*. Additional support was also provided by project partners across the year through Skype conferences and classroom visits.

The teachers framed their own research questions in relation to the *Conceptual Framework*, and whilst these questions developed in response to needs in their classrooms and schools, they were expected to link directly to one or more aspects of the framework. Each teacher was invited to select a small focus group of three children, reflecting a range of experience and confidence in science, and the diversity of their school community. They were asked to record close observations of the children's creativity and science learning in response to actions taken across the action research cycles completed.

Teachers recorded and reflected on evidence of learning and teaching and own ongoing professional learning during the *Curriculum Development Workshops* (see

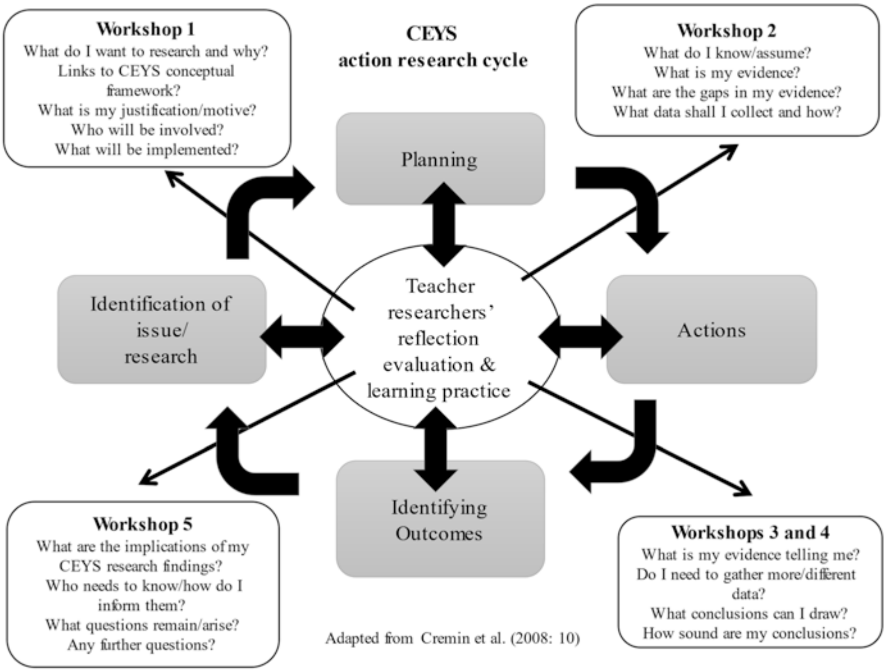

Fig. 3.2 The CEYS action research cycle (adapted from Cremin et al., 2008, p. 10)

Fig. 3.2) in their *Teachers' Portfolios*. The latter included reflective prompt sheets and supporting reference materials linked to the curriculum dimensions in Van den Akker's (2007) spider web and the factors associated with creative, inquiry-based approaches. All teachers were asked to fill in the prompt sheets to record their reflections at least once in the Autumn term and once in the Spring or Summer terms. The questions included in the prompt sheets are shown in Appendix 1.

These written reflections provided the foundation for the *Curriculum Materials* teachers produced to record and share their learning journeys and those of their focus children across the project. A common format was developed to inform the production of the *Curriculum Materials*, shown in Appendix 2.

3.4 Data Analysis: Impact of the CEYS Curriculum Development Process

In this chapter we will focus on results from analysis of the following data sources:

(a) From the *Curriculum Materials,* the teachers' reflections on:

- *their children's progress* – in relation to inquiry and creativity and linked to the initial aims of the project including any unanticipated outcomes and children's own reflections on their learning;
- *their own roles* – with links to the synergies between inquiry-based and creative approaches to learning and teaching;
- *the classroom environment* – in relation to other aspects of the design components associated with the *vulnerable spider web* that contributed to the development of children's inquiry skills and creative dispositions.

(b) From the *Teachers' Portfolios,* the teachers' ongoing professional reflections in relation to the following questions:

- In what ways is your thinking about science and creativity changing?
- What challenges have you and the children faced and in what ways have you overcome these?

Both sets of data were analysed in relation to key components of the *Conceptual Framework* as follows:

(a) Teachers' reflections included in their *Curriculum Materials*:

- *Children's progress in relation to inquiry and creativity*. Teachers' comments were coded in relation to characteristics of the inquiry-based approaches and creative dispositions (shown in Table 3.1 above):
  - Learning activities: questioning, designing and planning investigations, gathering evidence, making connections, explaining evidence, communicating explanations
  - Creative dispositions: sense of initiative, motivation, ability to come up with something new, making connections, imagination, curiosity, ability to work together, thinking skills.
- *Teachers' changing roles. Teachers' reflections on their changing roles were coded according to the synergies between creative and inquiry-based approaches (as outlined in The Conceptual Framework on p. 5 above): play and exploration; motivation and affect; dialogue and collaboration; problem solving and agency; questioning and curiosity; reflection and reasoning; teacher scaffolding; assessment for learning.*
- *Classroom environment*: Any additional comments on the classroom environment were coded in relation to the dimensions of the *vulnerable spider web*: aims and objectives; content; materials and resources; grouping; timing; location.

In each case the presence or absence of each characteristic was noted.

(b) Teachers' responses in the *Teachers' Portfolios* were analysed according to changes in their practices and challenges experienced noted, in relation to *planning, teaching, learning, assessment* and *contextual factors.*

3.5 Results

3.5.1 Curriculum Materials

31 teachers produced Curriculum Materials.

Teachers' reflections on children's progress.

Table 3.2 indicates the number of teachers who commented on evidence of children's progress in relation to each of the *features of inquiry.*

Teachers' reflections overall included examples of commentary in relation to all the *features of inquiry.* Progress was most often noted in relation to children's *questioning* and *communication of explanations.* For example:

> Children's curiosity and their involvement in their observations was shown also by the many questions they asked: What are the little fibres in the soil? How high will the wheat grow? ….Many children were doing parallel observations at home too, where they... involved their parents in the investigative work. (Investigating materials)
>
> Discussing alternative views and explanations was of high importance. Children would ask questions including 'how do you know that?' (Crime Scene Investigation)

Table 3.3 indicates the number of teachers who noted evidence of development in children's *creative dispositions.*

Comments on children's progress in terms of their *motivation, curiosity and abilities to work together* were most prominent. For example:

> Once they had the opportunity to work with many ingredients they started to cooperate, they were interested in the solutions proposed by their peers and came up with new ideas. (Make Bread Right Now)
>
> The children were very motivated. They felt this was a team effort as a scientific community sharing their strengths and knowledge. They saw ways in which their ideas were incorporated across the sessions. (Skeletons)

Teachers made limited commentary on developments in children's imagination and thinking skills. This may reflect the broad nature of these terms, their interconnections with other elements in the framework and the focus in this project on creative dispositions in *science.* For example, thinking skills are associated in particular with the learning activities *making connections* and *explaining evidence*. Imagination often underpins the creative dispositions *sense of initiative* or *coming up with something new*.

Table 3.2 Children's progress: Features of inquiry N = 31

Learning activities	Questioning	Designing and planning investigations	Gathering evidence	Making connections	Explaining evidence	Communicating explanations
Number of teachers	21	10	11	12	13	16

Table 3.3 Children's progress: Creative dispositions N = 31

Creative dispositions	Motivation	Making connections	Curiosity	Ability to work together	Come up with something new	Sense of initiative	Imagination	Thinking skills
Number of teachers	22	12	20	16	8	7	2	4

3.5.1.1 Teachers' Roles

Table 3.4 records how many teachers referred to each synergy between inquiry-based and creative approaches in reflecting on their professional development across the project.

There were examples of teacher reflections in relation to all the synergies. *Fostering questioning and curiosity* and *teacher scaffolding* were mentioned by a majority of teachers. A number of teachers also noted the role of *assessment* in guiding their interventions. For example:

> I learnt how to use questioning to keep the learning going when the children became stuck, while guiding the learning sequence, while the children retained ownership over key aspects. (Life cycle of the frog)
>
> It was an open-ended project for me as I needed to tune into the children's conversations and scaffold their ways of thinking and create a dialogue to foster their creative dispositions. (An icy adventure)

3.5.1.2 Classroom Environment

Table 3.5 indicates the number of teachers who referred to contextual factors, related to the dimensions of the *vulnerable spider web*.

Teacher commentary on contextual factors focused mainly on *materials and resources, grouping* and *time.* There were also references to *location* in noting the benefits of linking learning in and outside the classroom. They referred to the key role of resources in stimulating and supporting learning. For example:

> I sought to develop children's creative thinking linked to science by providing sufficient time for them to wallow, think, ponder and wonder over what they experienced. (*Bath Bombs*)
>
> My role as a teacher to facilitate children's curiosity with an enabling environment with opportunities for children to pursue their own interests through open ended resources and making links to first hand experiences at home or at school. (*Properties of Materials*)

Teachers selected their aims and objectives at the start of their action research projects, related to the needs of their children and their own professional concerns, making explicit links to the *Conceptual Framework* and connections to school and national curriculum requirements. Teachers' reflections on their learning journeys tended to focus on the strategies they employed to achieve these aims and objectives building on ongoing assessment and evaluation, in line with the guidance provided to support the development of their *Curriculum Materials* shown in Appendix 2. The lack of explicit commentary on aims and objectives may reflect this, although the aims, objectives and rationale for each teaching and learning activity are made explicit in the body of the *Curriculum Materials*. Teachers' shifting emphases and reflections related to aims and objectives were more in evidence in their reflections in their portfolios, particularly in relation to planning, as indicated below.

Table 3.4 Teachers' roles: Synergies between inquiry-based and creative approaches N = 31

Synergies	Play and exploration	Motivation and affect	Dialogue and collaboration	Problem solving and agency	Questioning and curiosity	Reflection and reasoning	Teacher scaffolding	Assessment for learning
Number of teachers	11	9	10	11	18	9	16	14

Table 3.5 Classroom environment: contextual factors N = 31

Contextual factors	Aims and objectives	Content	Materials and resources	Grouping	Timing	Location
Number of teachers	0	0	14	12	11	7

3.5.1.3 Reflections and Interconnections

A number of common themes emerged from teachers' reflections, illustrating the dynamic interconnections among children's learning activities, creative dispositions, synergies between creative and inquiry-based approaches, and contextual factors. Teachers noted that the provision of rich resources with time and scope for decision making stimulated children's curiosity and motivation. They commented on ways in which this led to an increase in children's questions and agency, fostered cooperation in solving problems and encouraged children to share ideas and explanations within the classroom community. Teachers recorded examples of children extending investigations independently in the wider classroom environment, and at home with their parents. They highlighted the importance of teacher scaffolding to extend and sustain learning, building on observations of children's responses.

3.5.2 Teachers' Portfolios

42 teachers submitted their portfolios, providing a total of 101 reflections submitted and analysed overall. Their reflections offer additional insights into teachers' perspectives on their changing views and practices over the course of the project.

3.5.2.1 Planning

Teachers reflected on the need for careful planning of the activities, learning opportunities and science investigations with a view to engage children actively and allow them different ways to apply and extend their skills. They found this challenging, as it involved changing their linear view of planning to a more flexible and interconnected one. They also learned to focus their planning more on anticipating children's questions, actions and ideas, while nourishing their curiosity. They acknowledged the importance in planning to allow children more space and time to explore, while at the same time trying to capitalise on 'accidental' learning opportunities. For example:

> I am thinking more about what I want children to learn – such as skills, and trying to plan for different ways for them to apply and build on these.
>
> I am planning carefully the investigation in order to give children time for questioning and come with ideas from previous experience.

> I have had to change my rather linear view of how to 'deliver' the curriculum and adopt a more interconnected 'systems' view – learning is more like a web that [than] a straight path.
>
> Creativity has to do with the structuring of activities but can also appear spontaneously. You simply have to practice in spotting and exploiting it.

3.5.2.2 Teaching

As a result of their involvement in the project, teachers expanded their views about the teaching of science to early years children. They demystified the nature of the science experiences they needed to provide for children and learned to give more value to the roles of questioning, making cross-curricular links and encouraging collaboration. They showed greater appreciation for the importance of stepping back, while building on opportunities for extended play and exploration. Finding, however, the balance between standing back and guiding children forwards was a constant challenge. The quest for the appropriate way and time for scaffolding children's ideas, actions and questions was a regular concern. For example:

> Sometimes I make things too complicated: science can be experienced with a simple activity. I want to work more with questions from the children. I want to let them try out their own creative ideas. They should experience that they can fail, everyone does!
>
> I started thinking that in children's minds science and creativity are connected at different levels. I tried to secure this by guiding less, standing back more and giving more time and space to children-initiated ideas and actions.
>
> In my science teaching it was a challenge to manage properly the inquiry activities so that to allow children [to] find solutions to problems by themselves. I want to devote more time to children for they come up with questions or to lead them to ask questions. I want to work more on drawing conclusions so that I can motivate children to participate.

3.5.2.3 Learning

Teachers' thinking about learning also changed on the same lines. They reported they realised that children are much more capable of science learning and doing, than they had previously believed. They also learned to appreciate the importance of paying attention to children's actions and initiatives and not only to their words, as the former often betray a much deeper kind of understanding and learning. They reflected on the value of experiential learning and on children's ability to steer it in line with in their own interests. Teachers noted problems in fostering children's abilities to formulate 'researchable' and clear questions and to come up with explanations. Also, despite the obvious learning advantages of children working collaboratively, teachers found managing successful group work challenging. For example:

> The most important thing, I think, is that now I realise that science is accessible and understandable by pupils of Year 1.
>
> Children are noticeably more engaged in the activities, as they have more freedom in steering their direction of their own learning.
>
> Understanding that even though children are not verbalising questions they are still asking/trying to answer questions implicitly through their explorations.

> Children's difficulty with formulating questions…; they need to be more specific and not change topic so easily.

3.5.2.4 Assessment

Teachers reasoned that as a result of their action research project they now paid more attention to assessment, which they found challenging. They came to identify better opportunities for formative assessment and enhanced their use of different media (photos, drawings, picture books, etc.) for this purpose. As with children's learning, teachers also increased their trust in children's role in assessment, both of their peers' work and of their own.

> Formative assessment is a useful tool for me, because I can discuss with them in groups or individually and have "evidence" of their thoughts either through photos or through their drawings.
>
> Assessing children's understanding is complex; one mode of expression may not be enough. In some cases, despite the fact that the pupils had recorded their experience by simply drawing the experiment they had done, when I went to the group and asked some questions, I realized that their understanding was much greater...
>
> I use more frequently portfolios for children's formative assessment; I involve them in project work asking them to evaluate their colleagues' results.
>
> Collecting photos and evidence—need to think about what photos tell me in relation to learning. How are my lessons connecting? What's the link between them?—VIP (very important) to pin down for analysis and self-reflection.

3.5.2.5 Contextual Factors

Teachers said they appreciated more the value of appropriate and varied resources, though finding time to prepare them was a challenge. The importance of making time and space for children's play and exploration was reaffirmed, as well though as the difficulty of organising space for investigative work. Grouping was acknowledged as having impact on children's motivation, though its organisation and management was not straightforward. For example:

> It is more open that I imagined, it should not be limited by your resources/materials—it is about understanding and exploring an idea and how this can be filtered into the classroom and children's play—but should also be structured and organised with appropriate resources to help.
>
> Children need more time for play and exploration, but curriculum and timetables constrain us. Creativity is being lost and science requires it to progress.
>
> My main challenge is setting—as work is done as a whole class rather than small groups. Lack of adult support for proper supervision and ensuring that groups are on task at all times.

Finally, teachers also acknowledged challenges related to their own professional development: lack of science knowledge and experience, lack of confidence or insecurity. For example:

I feel safer when using a step-by-step plan or another helping tool.

Sometimes children ask difficult, very technical or scientific questions (and I don't always have the answers).

It was a challenge to let go, to let the children experience things on their own without me interfering.

3.6 Discussion and Implications

Teachers' reflections in their *Curriculum Materials* and *Teachers' Portfolios* provided insights into ways in which they were opening up their practices to enhance opportunities for inquiry and creativity in children's learning, in particular through providing rich contexts and materials to foster children's motivation, curiosity and questioning; offering greater scope for children's decision making and scaffolding children's questioning, dialogue and collaboration. Teachers also showed greater appreciation for the central role of creativity *in* science and the potential for development of children's creativity *through* science.

As suggested by Guskey's (2002) model of teacher development, teachers' *Curriculum Materials* and *Teachers' Portfolios* provided evidence of the impact of the curriculum development process on their beliefs. As illustrated in the examples above, teachers included commentary on their growing recognition of young children's capabilities, highlighted by Duschl et al. (2007) and Goswami (2015). They noted shifts in their perspectives on learning and teaching from 'delivering' content to more interactive and responsive approaches as advocated by Siraj-Blatchford and Sylva (2004) and Fleer (2009). Teachers referred, for example, to giving time for questioning, picking up on spontaneous events and building on children's ideas and experiences. They highlighted their increased understanding of the importance of classroom assessment and growing adoption of varied approaches to assessment, including self and peer assessment. This resulted in teachers positioning the children at the centre of their planning and teaching. Being better able to anticipate, but also to provoke and trust children's ideas, questions and actions, increased teachers' confidence to step back and allow children to steer their own learning.

However, while teachers indicated developments in their views and practices, they also drew attention to challenges they experienced that have implications for programmes of continuing teacher development and school provision. For example, teachers referred to the need for greater subject knowledge and for skills in managing group work, questioning, assessment and feedback. They drew attention to limiting contextual factors such as time, space and resources that had an impact on opportunities for inquiry and creativity.

More generally, findings illustrate the significance of an explicit conceptual framework to guide professional development. The *Conceptual Framework* used was a product of extensive research and validation. Teachers' references to the concepts embedded in the *Conceptual Framework* in communicating and reflecting on children's learning and their own professional development suggest it provided a common language for identifying and then capitalising on opportunities for fostering inquiry and creativity within their everyday practices. It offered a reference point for recognising and building on what they were already doing, as a foundation for further development. In addition, the links to the *Conceptual Framework* in the guidance provided for the *Curriculum Materials* and *Teachers' Portfolios* encouraged teachers to make features of inquiry and creativity explicit, both in the teaching strategies they were adopting, and in examining evidence of progress in learning and teaching over time. Teachers' reflections suggested that the CEYS action research cycle and iterative processes of action research over a year also provided a support framework for teachers in initiating and sustaining developments in their practice. They included evidence of teachers' growing confidence and sense of self-efficacy across the course of the project, suggested by Kinskey (2018) as an outcome of engagement in action research.

Overall, findings offer indications of how the combination of an explicit conceptual framework with an action research approach to curriculum development may contribute to teachers' professional development. They illustrate the potential of learning both *from* and *through* research as advocated by Brown (2015), bringing together knowledge from research and knowledge from practice, to offer new insights into classroom practices and promote developments in learning and teaching.

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Appendicies

Appendix 1: Prompt Questions to Support Teachers' Reflections on their Changing Practice and Evidence of Children's Learning

- **Actions**: What changes have you made to your practice when developing creativity in science in relation to the spider web curriculum dimensions?
- **Impact**: What impact is evident in children's strategies, creative engagement and attitudes to science (linked to the *Conceptual Framework*)?

- **Evidence**: How do you know the work has impacted on the children? What is your evidence?
- **Professional reflection**: In what ways is your thinking about science and creativity changing?
- **Professional reflection**: What challenges have you and the children faced and in what ways have you overcome these?

Appendix 2: Format of the Curriculum Materials

The curriculum materials vary in presentation but they share a number of common elements for example:

Initial information (provided in the first page(s))

- Title of the Learning Journey
- Details of the ages of children in the class—note the examples cover a wide age range in both preschool and primary settings.
- A list of the particular *learning activities* (features of inquiry), *creative dispositions* and *synergies* (teaching approaches common to inquiry based and creative approaches) the teacher was seeking to promote (linked to the definitions of creativity outlined above).
- *Background*—key features of the background to the example, such as aspects of the school setting, age group, school policy for science, curriculum links (as appropriate).

Setting the Scene—brief outline of the focus and rationale for the project and implications for planning and teaching for example:

- *Focus*—The aspects of children's creativity and inquiry the teacher focused on—the differences the teacher was seeking to make and aspects of their own practice they aimed to develop (linked to the synergies).
- *Rationale*—The teacher's rationale for the focus—based on their assessments of children's inquiry skills and creative dispositions and/or evaluation of their own practice.
- *Implications for planning and teaching*—The implications for teaching approaches with links as appropriate to the curriculum design components associated with the 'vulnerable spider web'.

Overview of the learning journey—an outline of the sequence of activities involved in the project and the time frame. The time frames vary considerably—some projects took place over a few days, others over several weeks. This is indicated in the background details provided.

Developing the Learning Journey—explanation and reflections on the learning journey over time, illustrated by examples of learning and teaching including:

- *Starting points*—an indication of how the project began: this might include for example: a motivating stimulus, experience or event or observation or elicitation of children's questions/interests
- *Sequence of activities*—how the project developed over time.

For each stage in the learning journey teachers were encouraged to draw on records and discussion of their action research processes to:

- *Explain the decisions they made. How did each activity build on evidence of children's responses?*
- *Explain each activity*. Provide images to illustrate key features such as: nature of activity and resources, teacher interventions and questions, children's recording, comments, actions, inspiring moments.
- *Highlight examples of children's inquiry skills and creativity* and ways in which *they* fostered children's inquiry and creativity (linked to definition of creativity in science, the synergies and other creativity enabling factors linked to the spider web).
- *Indicate how this led to the next activity*—brief reflections to indicate connections

An example is shown in Fig. 3.3 below that illustrates some of the common elements included.

- The activity and rationale are indicated
- The photograph gives a flavour of the nature of the activity.
- The comment boxes provide examples of teacher/child commentary or questions.
- The thought bubbles include teacher reflections on learning/their own teaching.
- The arrow at the bottom suggests implications/next steps.

Reflections on the Project Including

- *Reflections on children's progress*—based on analysis of children's progress in relation to inquiry and creativity and linked to the initial aims of the project. In some instances, this includes any unanticipated outcomes and children's own reflections on their learning.
- *Teachers' reflections on their own roles*—analysis in relation to the aims of the project with links to the synergies between inquiry-based and creative approaches
- *Reflections on the classroom environment*—other aspects of the design components associated with the 'vulnerable spider web' that contributed to the development of children's inquiry skills and creative dispositions
- *Next steps for learning and teaching*—based on evidence of learning.
- *Reflection questions for the reader*—designed to encourage readers to consider applications to their own practice.

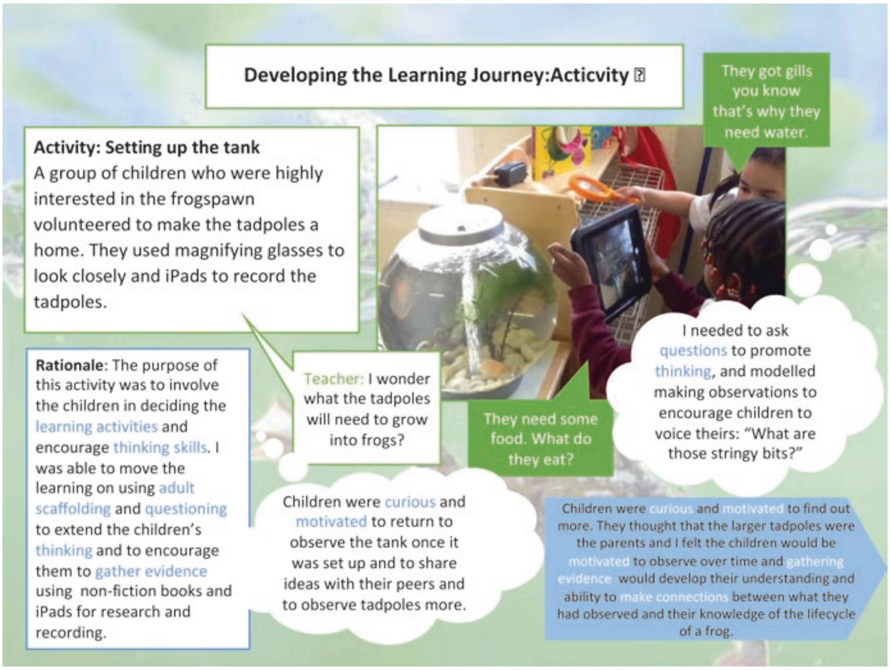

Fig. 3.3 Example of a page format from the 02_UCL_IoE Curriculum Materials: Life Cycle of a Frog (Creativity in Early Years Science, 2017, p, 87)

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Chapter 4
Developing Children's Questioning Skills for Inquiry in STEM

Marta Carli, Anna Fiorese, and Ornella Pantano

4.1 Introduction

Questioning is a creative act (Murcia et al., 2020; Chin & Osborne, 2008; Burnard et al., 2006). When students ask questions, they engage in higher order thinking, establish relationships between new ideas and prior knowledge, and construct meanings (Shodell, 1995; Cuccio-Schirripa & Steiner, 2000; Chin, 2001). Asking questions is also one of the 'core practices' of science education (National Research Council (NRC), 2012). Children's questions are often driven by curiosity, which is one of their distinctive characteristics; however, in classrooms settings, students ask few spontaneous questions, and even less in the search of knowledge (Dillon, 1988).

An element that can either enhance or hinder children's questioning is the learning environment. A judgmental environment, or one where children's questions are not welcomed, can stifle children's creativity (Biddulph et al., 1986; Chin & Kayalvizhi, 2002). The design of the learning environment also includes the pedagogical approach adopted in the classroom. Several accounts have reported that Science, Technology, Engineering and Mathematics (STEM) disciplines are still too often taught using transmissive-prescriptive pedagogies, particularly in primary school (European Commission, 2007; National Academies of Science, Engineering & Medicine, 2019). To overcome the limitations of these methods, pedagogies based on inquiry have been called for by many international documents (National Research Council [NRC], 1996; NRC, 2000; European Commission, 2007). Inquiry-based learning (IBL) includes a variety of instructional strategies through

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which students engage in scientific practices (Crawford, 2014; Osborne, 2014; NRC, 2012). This approach assigns the students an active role in the construction of their knowledge, increases their interest towards science, and contributes to the development of both science knowledge and skills and of general competencies (Crawford, 2014). To summarise the features of IBL, Pedaste et al. (2015) have developed a synthesised ‘inquiry cycle’ that combines the strengths of different IBL frameworks. This inquiry cycle has been used as the basis for our case study and is explored in more detail later in this chapter.

The purpose of the current study was to explore what characteristics of a STEM learning environment can develop children’s questioning skills. We begin by defining ‘asking questions’ as a scientific practice and we review the literature for the strategies that enhance children’s questioning. We then describe our action-research case study conducted in a fourth-grade classroom of primary school (children aged nine to ten), describing the methods and strategies used to set up a question-enhancing environment, and analysing children’s questions to understand to what extent these strategies were successful in fostering children’s ability to ask knowledge-based, investigable questions. Finally, we discuss our results, and we map our study onto the conceptual framework for creativity that shapes this book.

4.2 Background

4.2.1 Asking Questions for STEM Inquiry

Science is always rooted in a question. For this reason, ‘Asking questions’ is one of the ‘scientific practices’ that should be developed by science education, according to the *Framework for K-12 Science Education* (NRC, 2012). More specifically, students should be trained to formulate scientific questions, which, in the school context, means “questions that can be answered empirically in the classroom” (ibid., p. 57). Such questions can be driven by curiosity about the world, by experience, or by the need to find a solution to a problem. Student questioning is particularly valued in ‘open inquiry’ settings (Banchi & Bell, 2008), which are not, however, the only authentic type of inquiry (Crawford, 2014). In order to include the whole spectrum of inquiry-based activities—with varying levels of teacher scaffolding—Herranen and Aksela (2019) have grouped all inquiry approaches that include student-generated questions under the notion of *Student-Question-Based Inquiry* (SQBI).

Despite the importance of student questioning acknowledged by the literature, teacher questioning often dominates, and children have few opportunities to develop questioning skills (Reinsvold & Cochran, 2012; Osborne, 2014). In order to promote a change towards a more authentic student-centred pedagogy, Stokhof et al. (2017) suggested a range of strategies that teachers can adopt to support the generation, formulation and answering of student questions.

The goal of the 'generating' phase is to encourage students' questioning; this is an open, divergent phase which needs a question-welcoming classroom culture. In this phase, teachers can elicit student's questioning by engaging them with experiences that are relevant for their life and by providing adequate stimuli that evoke cognitive conflict or wonderment (Stokhof et al., 2017; Biddulph et al., 1986).

The 'formulating' phase is a more convergent one where teachers help the students refine their questions. One of the suggested strategies for this phase is to encourage the students to write down their questions (Chin & Brown, 2000), so that they can be categorised in order to identify the ones that can be used to structure an investigation. This process can be repeated at different stages of inquiry, and, at the end of an inquiry cycle, they can drive the next steps of the investigation (Harris et al., 2012). Collaborative practices such as negotiating the questions in a small group have also been strongly recommended (Stokhof et al., 2017; Herranen & Aksela, 2019). Chin (2004) argued that, when students engage in collaborative work, the question posed by an individual can stimulate similar questioning processes in other members of the group; as a result, group questions are usually more focused and refined than those asked individually. Modelling the formulation of questions is another suggested strategy (Stokhof et al., 2017; Biddulph et al., 1986). For instance, White and Gunstone (1992) proposed encouraging the students to formulate questions beginning with "What if…", "Why does…", "Why are…", "How would...", as such questions are more likely to be based on deeper thinking than simple recall. Finally, questioning can be supported by visual tools and organisers of variable complexity (Stokhof et al., 2017), especially when the children are not experts (Lord, 2011).

In the 'answering' phase, teachers can support students by asking them procedural questions concerning planning and conducting experiments (Harris et al., 2012). In this regard, Chin (2006) proposed a specific strategy called self-questioning, which should also gradually increase students' autonomy. Her proposal is grounded in Vygotsky's theory of self-regulation (Vygotsky, 1962), which describes the shift from an 'external' speech, where the activity of the child is directed by an external agent, to 'self-regulation' where it's the internal speech that drives the child's behaviour. In the intermediate stage, children internalise the external agent's messages by talking aloud to themselves. A teacher who has the habit to guide children's work using questions can therefore promote a shift from external to internal questioning, so that it gradually becomes the children's own habit, by carefully scaffolding this intermediate stage.

Moving from these insights, Stokhof et al. (2019) developed a 'scenario' to guide effective students' questioning comprising five phases. In the first and last phase, teachers use mind maps (an initial 'expert mind map' as a reference for designing the learning path and a final 'classroom mind map') to guide students' questioning and evaluate students' learning. The three central phases are devoted to formulating, generating, and answering students' questions, by adopting the above-mentioned strategies.

4.2.2 Evaluating Children's Questions

In order to evaluate the 'quality' of students' questions for STEM inquiry, we can adopt either a quantitative or a qualitative point of view. The latter evaluates the orientation and complexity of the questions and it is more meaningful when we aim to investigate children's questioning in relation to the development of creativity.

Dori and Herscovitz (1999) proposed to classify children's questions according to the level of the cognitive process required to answer them, using taxonomies such as Bloom's (Bloom, 1956; Anderson & Krathwohl, 2001). Based on this criterion, a first level of categorisation consists in dividing the questions into 'lower-order' and 'higher-order' questions. The classification by Hofstein et al. (2005) belongs to this type of categorisation: it defines 'low-level' questions, referred to facts or basic explanations, and 'high-level' questions, which require further investigation to be answered. Higher-level questions are more influential in constructing knowledge compared to lower-level questions. Similarly, Di Teodoro et al. (2011) distinguished 'surface' and 'deeper' questions, describing deeper questions as questions that provide students the opportunity to create, analyse or evaluate.

Watts et al. (1997), instead, classified students' questions according to their role in the process of conceptual change. They distinguished 'consolidation' questions, aimed at confirming understandings, 'exploration' questions, aimed at expanding knowledge, and 'elaboration' questions, aimed at evaluating claims and reconciling cognitive conflicts.

Scardamalia and Bereiter (1992) differentiated between 'basic information' and 'wonderment' questions. The former are oriented to the type of basic information normally conveyed by textbooks. Wonderment questions, instead, are those generated by an authentic curiosity and can be oriented to understanding, prediction, planning, or clarification of anomalies and inconsistencies. Chin and Brown (2000) have associated 'wonderment' questions with a deeper approach to learning and they have found that these questions are at a higher cognitive level.

Finally, a categorisation more directly related to classroom inquiry was proposed by Chin and Kayalvizhi (2002), who introduced a distinction between 'investigable' and 'non-investigable' questions, depending on whether or not they lead to inquiry cycles that can be carried out in the classroom. This definition is in line with the one by the *Framework for K-12 Science Education* reported above, where being 'empirically answerable', or not, is always understood in the classroom context. 'Investigable' questions include different types of questions: 'comparison' questions, aimed at making a selection among a number of items to be tested; 'cause-and-effect' questions, related to causal mechanisms and relationships; 'prediction' questions, aimed at testing a hypothesis; 'design-and-make' questions, related to problem solving; and 'exploratory' questions, dealing with the preliminary stages of inquiry. 'Non-investigable questions', on the other hand, include questions seeking for basic facts, but also, at the opposite end, complex questions that are not directly accessible to the students (either because they are too general or because investigating them requires sophisticated knowledge, skills or equipment), and finally, questions that cannot be answered by science. We notice that, in Chin and Kayalvizhi's (2002) definition, questions that can be answered by research by secondary sources are considered 'non-investigable questions', although this activity is considered authentic inquiry by several accounts, such as the *National Curriculum for Science in England* (Department for Education, 2014). However, here the authors are not discussing what inquiry is and what it is not; their categorisation refers to questions that can lead to practical investigations in the classroom.

4.2.3 Questioning, Inquiry, and Creativity

Among the possible definitions of creativity, Murcia et al. (2020) defined it as 'the ability to generate original ideas that are appropriate to the task at hand'. This definition contains the two core features of creativity on which researchers generally agree: originality (or novelty) and value (or appropriateness) (Runco & Jaeger, 2012). Based on a careful examination of the literature, the authors have also developed an innovative framework, the *'A' to 'E' of children's creativity*, constructed as an adaptation of the *Four Ps of Creativity* proposed by Rhodes (1961) and also presented in Chap. 1 of this book. The new framework also contains four 'Ps', which are: 'product' (criteria for creative outcomes: originality and fit-for purpose), 'person' (perspectives on who does the original thinking: educator, child's creative doing or child's creative thinking), 'process' (characteristics of children's creative thinking) and 'place' (the elements that support creativity in an educational context). We spend some more words on the 'process' and 'place' dimensions since they are relevant in our study, the former being connected with the practice of 'questioning' and the latter to the learning environment, which in our case is an inquiry-based setting.

The characteristics of children's creative thinking included in the 'process' dimension of the *'A' to 'E' framework* are grouped into five clusters: Agency, Being Curious, Connecting, Daring and Experimenting. Each of these clusters contains a set of more specific actions: for instance, 'Being curious' includes questioning, wondering, imagining, exploring, discovering and engaging in 'what if' thinking. This latter element is related to the notion of 'possibility thinking' suggested by Craft (Craft, 2002, 2007; Craft et al., 2012) as a driving feature of creativity and described as the process through which children make the transition from 'what is' to 'what might be' or 'what can I do with this'; or, equivalently, it involves the posing, in multiple ways, of the question "What if…?". 'Question posing' has been identified as one of the seven key features of possibility thinking by Burnard et al. (2006), alongside with play, immersion, innovation, risk-taking, being imaginative, self-determination and intentionality. Chappell et al. (2008) have described a taxonomy of question posing that includes the framing of the question being posed (from 'leading' questions that drive children's activity, to 'follow-through' questions related to the details of execution of an idea), their degree of possibility (from 'broad' to 'narrow': the broader the inherent possibility, the more creativity is fostered), and their modality (including verbal and non-verbal forms). The authors also identified nine types of 'question responding', including predicting, testing, evaluating, compensating, completing, repeating, accepting, rejecting and undoing. This categorisation is relevant to our study since it describes a set of actions that can be initiated by a scientifically investigable question.

The 'place' is related to the learning environment that an educator can set up to facilitate children's creative thinking. Among the 'resources' she can use are intentional provocations, stimulating materials, adequate materials for everyone and time for creative exploration. The educator can also work on her communication by setting up intentional learning conversations, hearing and valuing children's ideas, open inquiry questioning and facilitating conversations between children. Finally, it is essential that the educator creates a pressure free, non-prescriptive and non-judgemental environment. These characteristics of a learning environment resonate well with those of inquiry-based settings. In fact, inquiry-based learning has been listed among the pedagogies that can foster the development of creativity. Inquiry-based and creativity-oriented pedagogies share a child-centred perspective that highlights the role of experiential learning. In the context of the EU project *Creative Little Scientists* (CLS, 2011–2014, also presented in Chap. 2 of this book; Creative Little Scientists, 2014a), Cremin et al. (2015) have identified a number of synergies between inquiry based learning (IBL) and creative approaches to learning, including:

- *Play and exploration*, as investigations (particularly open-ended ones) support the development of creativity.
- *Motivation and affect*, as wonder and interest can lead to scientific inquiry.
- *Dialogue and collaboration*, as the social and collaborative nature of creative contexts can enhance understanding of scientific processes.
- *Problem-solving and agency*, as engagement with problems, which is essential in IBL, fosters children's agency and ownership of learning.
- *Questioning and curiosity*, recognised as essential in driving both inquiries and creative processes.
- *Reflection and reasoning*, related to creativity as the generation and evaluation of ideas.
- *Teacher scaffolding and involvement*, on which the efficacy of both IBL and creativity approaches depend, and which include providing a 'rich' environment, promoting group work, and the opportunity for children to engage in exploring different materials and resources.

Based on these elements, the consortium of the CLS project have developed a definition of creativity specifically tailored for science: in this context, creativity can be understood as 'Generating ideas and strategies as an individual or community, reasoning critically between these and producing plausible explanations and strategies consistent with the available evidence' (Creative Little Scientists, 2014b). This definition, connected with the one above by Murcia et al. (2020), resonates well with the definition of 'good' questions for investigations shaped by the literature on questioning for inquiry. In fact, according to these definitions, questions that are both 'wonderment' and 'investigable' are 'creative' in that they are original (they aim at extending knowledge) and appropriate (they lead to an investigation); they are connected with possibility thinking since they are of the 'what if', 'what might be', or 'what can I do' type, while, for instance, basic information questions are restricted to 'what is'; and they foster the generation of strategies for setting up a classroom inquiry.

Moving from this background, we set up a case study in order to investigate what strategies a teacher could adopt in order to help the children develop questioning skills in the context of STEM disciplines. Our research hypothesis was that an inquiry-based learning environment, enhanced by the use of a specific scaffolding strategy, could increase the quantity and quality of the questions posed by the students.

4.3 Our Case Study

In order to test our research hypothesis, we designed an inquiry-based learning unit on the topic of light, which was then implemented in a fourth-grade classroom (children aged nine to ten) of 24 pupils (12 male, 12 female) in a rural primary school in Italy.

We adopted an action research approach. The teacher who conducted the experimentation (2nd author) was a student teacher during her master thesis internship. Before the intervention, she observed the children and how the classroom teacher used to conduct science lessons. The classroom timetable featured science lessons twice a week (2 h a week). These lessons were usually conducted using traditional science teaching, where facts and principles are taught using a transmissive-prescriptive approach, mainly following the textbook. Experimental activities were occasionally proposed, just as a verification exercise, carried out personally by the science teacher while students played the role of observers. The inquiry-based learning unit conducted by the student teacher thus constituted a novelty for the children.

The learning unit comprised five lessons in total. The first introductory lesson was aimed at launching the topic and at gathering information about the children's initial knowledge and questioning skills. In the following three lessons, the children were divided into small groups (four to five pupils) and they were involved in three inquiry cycles, each one developing a different aspect of the topic (light propagation; interaction between light and objects; reflection from plane mirrors). The groups were formed with the help of the classroom teachers (not only the science teacher but also the teacher of Italian, who used group work more often during her lessons) based on their knowledge of the children, with the aim of favouring a constructive climate within each group. In order to facilitate group dynamics and to favour active participation of all the children, each child was assigned a role in the group: one or two children were in charge of the materials used during the investigations, one read the lab worksheets aloud, one was responsible for writing down all the questions, one was the 'spokesperson' and another one was in charge of the general management of the group. The roles changed from one lesson to another so that each child could experiment with different roles.

Each inquiry cycle was completed within a lesson and was structured in different 'inquiry phases' (Pedaste et al., 2015):

- *Orientation* or *Engage*, aimed at stimulating children's interest and curiosity about a topic or a problem.
- *Conceptualisation*, aimed at identifying the concepts involved in the problem, and further sub-divided into a *Questioning* phase (leading to the formulation of a research question), and a *Hypothesis Generation* phase, where a testable hypothesis is generated.
- *Investigation*, where children try to find an answer to their research question through the sub-phases *Exploration*, *Experimentation* and *Data Interpretation*.
- *Conclusion*, in which the students resume their research question and see whether their results provide an answer and/or supports their hypothesis.
- *Discussion*, including the two sub-phases *Communication* and *Reflection*, the latter intended as a process of personal reflection on the inquiry, and the possible elaboration of new questions for a further inquiry cycle.

The children were encouraged to write down their questions both at the beginning and at the end of each inquiry cycle. Scaffolding strategies aimed at facilitating the formulation of questions were introduced and/or removed gradually in order to evaluate their effect on children's questioning; they are summarised in Table 4.1 together with the cycle(s) in which they were used.

A detailed description of each inquiry cycle is provided in the 'Results' section, where children's questions are reported and analysed, in order to better link the content of each lesson to the questions that were formulated. Finally, the last lesson was devoted to an 'authentic task' related to the topics of the unit.

Table 4.1 The strategies used to facilitate children's questions

Strategy	Inquiry cycle(s)	Description
Stimulating materials	All cycles	An engaging or surprising experience was proposed at the beginning of each cycle.
Self-questions (Chin, 2006)	All cycles	The planner used by children to structure their investigation contained some questions formulated on the model of Chin's (2006) self-questions.
Modelling	2nd cycle	The teacher provided examples of 'investigable' questions. This scaffolding strategy was removed after the 2nd cycle in order to 'fade out' direct teacher's support.
Collaborative questioning	2nd and 3rd cycles	The children, divided into small groups, formulated questions collaboratively as well as individually.
Question hands (Lord, 2011)	2nd and 3rd cycles	The children were provided with the printed shape of a hand, in which they had to write five different questions, one for each finger. Its aim was to encourage the children to formulate multiple questions, going beyond the spontaneous ones.

4.4 Methodology

We monitored children's questions as the learning path developed, in order to look for evidence of an evolution in their questioning skills.

For each inquiry cycle, we analysed the questions that the children reported in their notebooks, labelling each question according to two categorisations:

1. *'Basic information'* vs *'Wonderment' questions*. This categorisation refers to the one by Scardamalia and Bereiter (1992) (see Table 4.2) and is aimed at evaluating the depth of children's approach to learning (Chin & Brown, 2000).
2. *'Investigable'* vs '*Non-investigable' questions*. This categorisation refers to the one by Chin and Kayalvizhi (2002) and it is aimed at identifying questions that can be answered empirically in the classroom (see Table 4.3).

We highlight once again that, in this context, by 'investigable' we mean 'classroom-investigable', in line with the definition by Chin and Kayalvizhi (2002) and by the *Framework for K-12 Science Education*. In our definition we have also specified that we focus our attention on 'practical' investigations, i.e., investigations where pupils directly manipulate or engage with the materials they are studying (Millar, 2010). Although we acknowledge research by secondary sources as an authentic investigation type, this kind of investigation was not considered in this study where the children could actually set up practical classroom investigations with the materials and objects they had at their disposal. In the following we will use the term 'investigable' with no further specification for simplicity.

The two categorisations described above are not independent. In fact, 'Basic information' questions are always 'non-investigable' as they are oriented to obtaining factual or procedural information that can be easily retrieved in a textbook or by asking the teacher (e.g., "What's inside the box?"). In this category we included questions referred to knowledge that children should possess already, e.g., repeating the conclusions of an inquiry cycle. We will label these questions simply as 'basic information'. At the opposite pole, 'wonderment', 'investigable' questions are the ones that not only reflect an authentic curiosity and can bring to an advancement in knowledge, but that can also be answered empirically in the classroom (e.g., "Are there other ways to modify the direction of light?"). Finally, a question can be of the 'wonderment' type but 'non-investigable', when it expresses a genuine curiosity to which, however, it is not possible to answer in the classroom setting, either because

Table 4.2 'Basic information' vs 'wonderment' questions

Type	Description
Basic information questions	Questions oriented at the kind of information normally conveyed in textbooks. This category includes 'uneducated questions', i.e., yes/no questions having a similar motivation to obtain basic factual information.
Wonderment questions	Questions oriented at generating explanations and to extend knowledge in terms of understanding, prediction, application, planning of inquiry, or reconciliation of a cognitive conflict.

Table 4.3 ‘Investigable’ vs ‘non investigable’ questions

Type	Description
Investigable questions	Questions that can be answered by ‘practical’ classroom investigations. They include questions dabout comparison, cause and effect, prediction, design-and-make, and exploratory questions.
Non-investigable questions	This category includes basic information questions, complex information questions that are not accessible to ‘practical’ classroom inquiry, and questions that cannot be answered by science.

it is very broad (e.g., “What is light?”), or because it requires knowledge or tools that are not accessible to the children (e.g., “Why can’t we make light bend?”). These are questions which might be answered by research by secondary sources, which was not, however, considered in the context of this study.

4.5 Results

In the following we describe each lesson, discussing the strategies that were used and reporting and analysing the questions that were formulated by the children.

4.5.1 Introductory Lesson

The teacher started by presenting the ‘big questions’ guiding the learning unit (“What is light? Where does light come from and how does it move in space? How does light behave when it meets objects?”). In order to create a non-judgmental climate, the questions were proposed one at a time, inviting the children to write their ideas on post-its which were then collected and used to build a cognitive matrix representing the initial knowledge of the classroom.

After that, the teacher proposed the ‘dark box’ experience: an object and a flashlight were placed inside a black box, where a hole had been made for the children to look inside. The teacher could turn the flashlight on/off or move it so that light was either reflected on the object or not. The purpose of the experience was to identify the elements needed for vision (eye, light, object) and sketch their relationships.

Through this lesson we also wanted to gather information about the children’s initial questioning skills. For this reason, it was conducted using a transmissive-prescriptive approach, in which the teacher demonstrated the experiment without involving the children in inquiry. The children were asked to write down their questions individually, but no specific scaffolding materials were provided. Since these methods resemble the ones the children were used to, the quality of the formulated

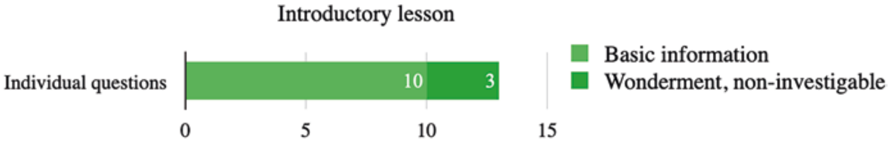

Fig. 4.1 Number and type of questions formulated during the introductory lesson. The actual number of questions of each type is reported in the bars

questions can be used as a benchmark against which to compare the questions that emerged during the inquiry-based lessons.

Of the 13 individual questions that were formulated, ten were of the 'basic information' type (e.g., "Is there a torch inside the box?"). The remaining three were 'wonderment' but 'non-investigable' questions, since they were very broad or unrelated to the experience (e.g., "Why can't we distinguish colours?"). Figure 4.1 summarises the number and type of questions formulated during this lesson.

4.5.2 First Inquiry Cycle

The first inquiry cycle was dedicated to light propagation. As the initial engaging experience, a laser was pointed to the wall and then flour was used to make the light path visible. During and after the experience, the children were encouraged to write down their questions individually. Of the 12 individual questions that were written, seven were 'basic information' ones (e.g., "Why was flour illuminated?"); among the 'wonderment' questions, only one was 'investigable' ("Can we do the same using steam?").

After that, flashlights and flexible plastic tubes were provided, and the children investigated light propagation in groups. In order to support the children's investigation and to scaffold the shift from external to internal questioning, three 'self-questions' (Chin, 2006) were reported in the children's planner:

1. How can we organise our investigation in order to answer our question?
2. What is the best way to collect information from our investigation?
3. How can we interpret this information to answer our research question?

At the end of the cycle, all of the 14 individual questions reported by the children were 'non-investigable'; five of these were of the 'wonderment' type ("Why can't we make light bend?") while the others were 'basic information' ones. Figure 4.2 compares the number and type of questions at the beginning and at the end of the cycle.

These results support the fact that 'wonderment', investigable questions hardly emerge spontaneously from the children. For this reason, in the second cycle we introduced more specific scaffolding strategies.

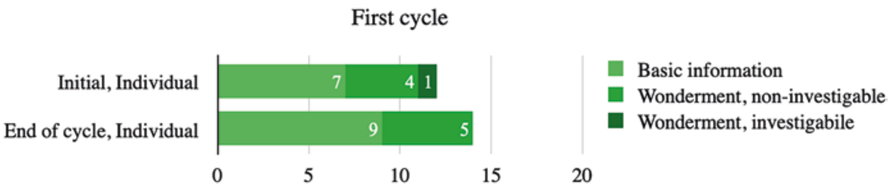

Fig. 4.2 Number and type of questions formulated during the first inquiry cycle. The actual number of questions of each type is reported in the bars

4.6 Second Inquiry Cycle

The second inquiry cycle regarded the interaction between light and objects. As the initial experience, a flashlight and different objects (a steel bowl, a glass jar, coloured cardboard) were shown to the children, and they were asked to write down their questions individually. The analysis of these questions reflected the situation already observed in the previous cycle, with only five questions asked, all but one of the ‘basic information’ type.

After that, the teacher introduced two scaffolding strategies, i.e., modelling and collaborative questioning, the latter supported by ‘question hands’. The teacher ‘modelled’ the formulation of investigable questions by proposing some examples of this type of questions herself. Then, the children formulated questions collaboratively and reported them on a ‘question hand’; in order to minimise the possibility that some questions were lost in the process, one child per group was specifically assigned the task of writing down all the questions. In the following we will refer to the questions that have been formulated this way as ‘group questions’.

After the introduction of these strategies, a drastic increase was observed in both the number and the quality of the questions. In fact, 19 group questions were formulated, including seven ‘basic information’ questions (e.g., “What is the steel bowl for?”), one ‘wonderment’ but ‘non-investigable’ question (“Why isn’t light reflected by paper?”), and 11 ‘wonderment’, ‘investigable’ questions (e.g., “Can light be reflected by all of these objects?”). The questions formulated at the end of the cycle were even more, both at the individual and at the group level. Most of the questions were of the ‘wonderment’ type (17 of the 19 individual questions, and all of the 20 group questions); nine individual and 14 group questions were also ‘investigable’ (e.g., “Can other objects reflect light in a different way?”). Figure 4.3 compares the number and type of questions at the beginning and at the end of the cycle.

4.6.1 Third Inquiry Cycle

The third inquiry cycle was about light reflection from plane mirrors. The lesson started with the teacher shining a laser into an open box (grazing to the surface so that the light path was visible); on opposite sides of the box, some centimetres apart,

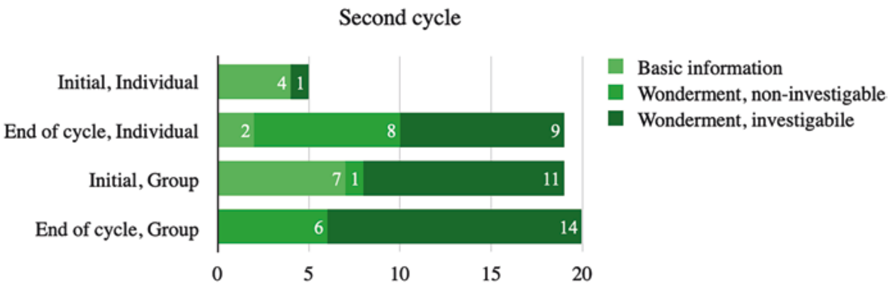

Fig. 4.3 Number and type of questions formulated during the second inquiry cycle. The actual number of questions of each type is reported in the bars

she had glued two mirrors so that the laser was reflected on them and reached the other end of the box. This time, the children formulated more individual questions (18) than in the previous cycles. There was a higher number of 'wonderment' 'investigable' questions (six, e.g. "If two mirrors make three rays, how many rays would there be with three mirrors?"), even though 'non investigable' questions were still the majority (12) and seven of them were 'basic information' ones.

The teacher then showed the children the materials available for their investigation (flashlights, mirrors, a sheet of paper with a goniometer printed on it, black cardboard with a slit cut in it) and proposed the question hands activity, but this time she removed her modelling, in order to encourage the groups to work independently ('fading'). Less 'group questions' (ten) were collected this time. This may be due to fading out the support of modelling, or to the fact that the goal of the investigation (finding a rule for reflection) was more focused. However, six of the group questions were 'wonderment' 'investigable' questions (e.g., "What happens to the light after it is reflected on the mirror?"); the others were of the 'basic information' type.

At the end of the cycle, less questions were formulated compared to the previous cycles (13 individual, eight group questions), but most of them were 'wonderment' questions (nine individual, seven group questions); the majority of these ones (six) was also 'investigable' (e.g., "Can we modify the light path using other objects?"; "If we bent the tube and we put a mirror inside, could light reach the end of the tube?"). Figure 4.4 compares the number and type of questions at the beginning and at the end of the cycle.

At the end, the children collaboratively constructed a concept map representing the knowledge of the classroom at the end of the learning path.

4.6.2 Final Lesson

The unit was concluded by engaging the children in an authentic task, consisting in designing an instrument to see around corners or obstacles. The groups were given a box and two mirrors, and they were free in the design of their project. Moving

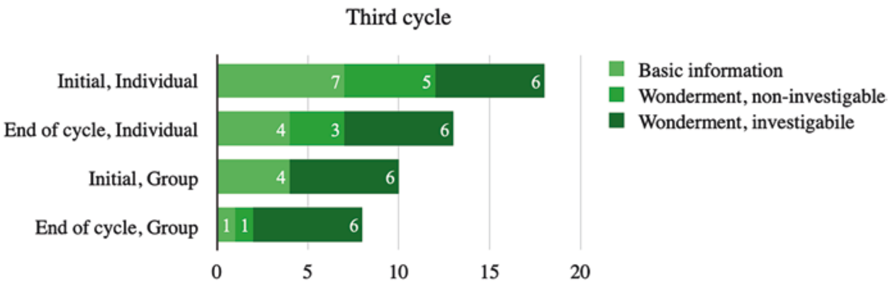

Fig. 4.4 Number and type of questions formulated during the third inquiry cycle. The actual number of questions of each type is reported in the bars

from their initial observations, the children started to formulate questions at different levels. Some of these were of the procedural type (e.g., "Can we cut the box?"; "Can we use adhesive tape?") while others regarded the children's hypotheses about the project (e.g., "If we cut the box above and on the other side, and we put one mirror on each side, what may happen?"; "If we take the box and we make a hole on one side, and then we put one mirror on one side and the other mirror on the other side, can we reach our goal?"). The fact that the children spontaneously asked themselves questions in order to proceed and that they set their own task accordingly can be regarded as evidence of a maturation in their attitude towards questioning. The projects were shared and discussed with the rest of the classroom, and a real instrument was built combining the ideas of all the groups.

4.7 Discussion

The evaluation of the children's initial questioning skills showed that the children asked few spontaneous questions, and those few were oriented at obtaining factual or procedural information. Since the pedagogy adopted during this meeting (transmissive-prescriptive) simulated the one normally used by the teacher, it could be inferred that this pedagogy does not contribute to the development of children's questioning skills. After a few lessons conducted with an inquiry-based approach and introducing adequate scaffolding materials, a change in the children's questioning skills was observed. Figure 4.5 highlights and quantifies this change by reporting the number of questions of each 'type' at the end of each inquiry cycle.

In total, 18 children out of 24 formulated at least one 'wonderment question' over the different inquiry cycles. The children who had the most difficulty in formulating and writing down the questions were pupils of foreign origin, who demonstrated general difficulties with the Italian language.

Looking at Fig. 4.5, we notice that 'group questions' are, on the whole, at a higher level than those formulated individually, supporting the claim that working collaboratively can stimulate the development of questioning skills. In fact, the

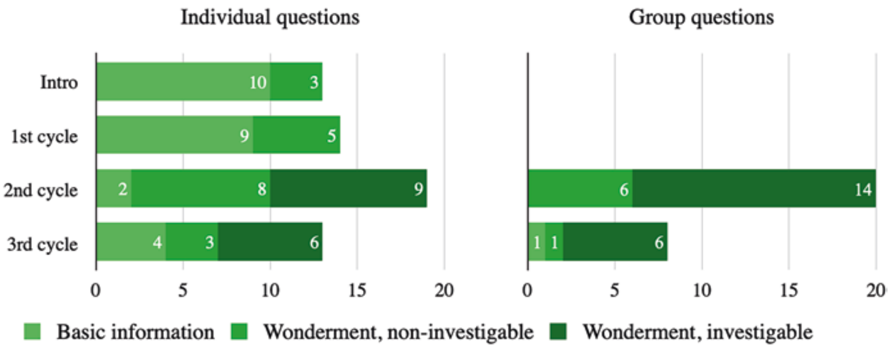

Fig. 4.5 Number and type of questions formulated after each of the three inquiry cycles, compared to the introductory lesson. The actual number of questions of each type is reported in the bars

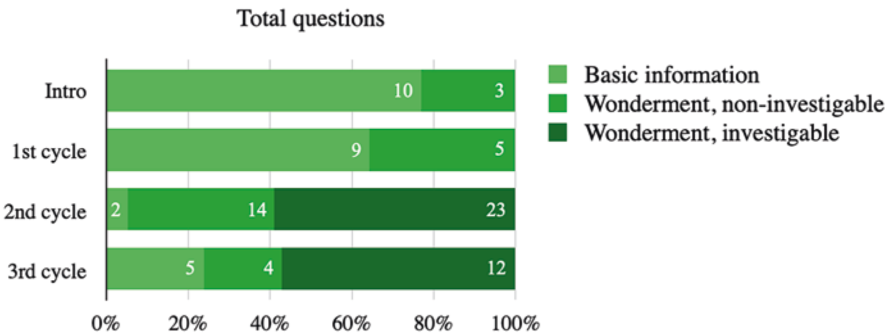

Fig. 4.6 Fraction of questions of each type formulated after each of the three inquiry cycles, compared to the introductory lesson. The actual number of questions is reported in the bars

number of wonderment questions accounts for 70% of the group questions formulated after the second inquiry cycle, and for 75% of the group questions formulated after the third inquiry cycle, compared to less than 50% for the individual questions. We also notice that, in the second inquiry cycle, after the introduction of modelling and question hands, a drastic increase in the total number of questions and in the fraction of 'wonderment' questions was observed, and the majority of these was also 'investigable'. During the third cycle, a decrease in the number of final questions was observed. This might be due to the fact that the focus of the experience (light reflection) was tighter than in the previous inquiry cycle (light-objects interactions in general), in line with what suggested by Chappell et al. (2008) about the relationship between creativity and the 'breadth of possibility' in question posing. However, the fraction of 'wonderment' and 'investigable' questions remained significantly high, suggesting that the 'quality' of the questions did not decrease. Figure 4.6, which shows the *fraction* of (individual + group) questions of each type and their absolute number, highlights what we have just claimed.

Scardamalia and Bereiter (1992) noted that, generally, students tend to formulate 'basic information' questions for unfamiliar topics, and 'wonderment' questions for more familiar ones. The increase in the fraction of 'wonderment' questions may therefore also indicate the children have actually developed new knowledge about the topic, a statement reinforced by an analysis of the disciplinary content of the questions; for instance, there was an increased use of specific language (light is 'reflected', the 'direction' of light, the 'light path'). Moreover, some of the questions asked at the end of the third inquiry cycle recalled and integrated not only the contents, but also the practical activities experienced in the previous ones (e.g., "If we bent the tube and we put a mirror inside, could light reach the end of the tube?"). This suggests that the children improved in asking 'wonderment' questions as they became more familiar with inquiry. The children had never previously experienced this approach to learning, and they became more and more confident on how to proceed as they understood the method. These results confirm the depth of learning suggested by the presence of a large fraction of 'wonderment' questions and indicate that both familiarity with the content and the possibility of engaging with practical experiences are important to develop questioning skills.

To conclude this section, we now map our study onto the *'A' to 'E' Framework* that shapes this book (Murcia et al., 2020). Our perspective on who does the original thinking (the 'person' in the framework) was on the children, and mainly on children's creative thinking. We investigated in particular children's questioning, one of the elements of the dimension of being curious in the 'process' of children's creative thinking, by evaluating the questions they reported in their notebooks or in the question hands (a 'product'). In our study, questioning was connected with other elements of this dimension, such as wondering, exploring, discovering, and experimenting. At the end of the unit, we also found evidence of another dimension of creative thinking, connecting, as the children recalled and integrated concepts and ideas from all the inquiry cycles.

Our study mainly explored the third element of the framework, the 'place'. In fact, our research question regarded the characteristics of a learning environment that increase the quantity and quality of the questions posed by the children. We found evidence of the efficacy of all the dimensions proposed in the framework. Concerning the resources, we used both intentional provocations (modelling and self-questions) and stimulating materials (questions hands), and we allowed time for creative exploration. As for communication, we worked mostly on open inquiry questioning, which was the focus of the research. Finally, paying attention to a non-prescriptive, non-judgmental environment where children's questions and interactions were welcomed and encouraged was another distinctive element of a favourable socio-emotional climate. In fact, the strategy that most of all seems to have positively impacted the quality of the questions was collaborative questioning.

4.8 Conclusions

In this chapter we have presented a case study that we carried out in a fourth-grade classroom (children aged nine to ten), the purpose of which was to see whether an inquiry-based learning environment could increase the quantity and quality of the questions posed by the children. To this end, we developed a learning unit on the topic of light, featuring different inquiry cycles, and we used specific scaffolding strategies (modelling, question hands) to help the children formulate 'investigable' questions.

The analysis of the questions generated by the children during the different inquiry cycles suggests that the adopted approach not only stimulated the children's curiosity and 'wonderment', but also their ability to formulate empirically answerable questions. As the children engaged in the different inquiry cycles, the quantity and—most of all—the quality of the formulated questions increased. In fact, the majority of the questions formulated by the children at the end of the unit were 'wonderment' questions, i.e., questions that reflect a genuine interest and a deep approach to learning, and most of these questions were also investigable through practical classroom inquiry. Though it was not possible to observe a complete development of the children's questioning skills during the short time of the intervention, there is evidence supporting the beginning of a development of this skill, and, overall, of a growth in children's creativity.

Too often teacher questioning dominates. In our experience with pre-service primary teachers, many of them interpret 'asking questions' as 'engaging the children through questioning strategies', rather than encouraging the children to formulate their own questions. The latter is, however, a crucial skill not only for developing science competencies, but also for responsible citizenship. Our research demonstrates that the quality and quantity of children's questioning can be improved through effective pedagogy, and that this is connected with a development in different dimensions of creative thinking. Besides being a fundamental resource for the personal growth of the children, these competencies will enable them in the future to address the complex issues that characterise our society, and to participate in its life.

Ethical Statement The project was carried out in the context of an agreement between the School and the University of Padua (agreement no.: 2120/11-64966) for hosting student teachers during their master thesis internship. The data were collected and the results were disseminated in accordance with the ethical rules of the agreement; in particular, no personal or sensitive data were collected.

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Chapter 5
Creativity and Motivation in Early Years Science as it Relates to Cognitive Styles

Nina Skorsetz

5.1 Introduction

In the science education research community in Germany, there is little discussion about the connection between creativity and science in kindergarten-age children, even though fostering science at early ages has been a national goal for roughly 10 years. Their government and education foundations encourage early science education in kindergartens and primary schools. In Germany, children attend kindergarten from the ages of three to six before they go to primary school (year one). The idea is that fostering the motivation to do science at an early age establishes a foundation that will be expanded upon in school and result in interest in working in that career field. Science education research in Germany has mostly focused on teacher professionalism and their self-efficacy as well as students' motivation and learning inquiry (e.g. Kunter et al., 2013).

Baron-Cohen's (2009) Empathising-Systemising (E-S) theory for capturing individual cognitive styles is relatively new to research on motivation in science education. The theory has its origins in autism research and describes two dimensions, the Empathising and Systemising Quotient (EQ and SQ) values which, can be scored using a standardised questionnaire (Billington et al., 2007). People with high SQ scores are 'systemisers' and tend to look for the systems behind things. 'Empathisers' instead orientate themselves to other people's feelings. The theory has been used in other empirical studies in the field of science education. However, Zeyer et al. (2012) distance themselves from the question of the neurological causes that were criticised in Baron-Cohen's (2009) theory. They use the ratio of EQ and SQ (the so-called 'brain type') to explain children's motivation in scientific contexts and

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found that adult systemisers are more motivated to do science than stronger empathisers (Zeyer et al., 2013). Similar results have been shown for young children (Skorsetz & Welzel-Breuer, 2018; Skorsetz, 2019). The motivation of five and six-year-old preschool children was tested in two different pedagogical science learning contexts: structured-instructional and play-based. Children with a high systematic cognitive style were found to be motivated to do science independent of the type of learning setting. Connections between children's motivation and the possibility of being creative in scientific learning settings have not been found, although theories often describe motivation as a condition for creativity (e.g. Steele et al., 2017).

In order to close that gap, this chapter first examines scholarship on the relationship between motivation and creativity in the field of early year's science, specifically focused on scientific learning settings in day-care centres. Next, it describes the reanalysis of our initial data; we categorise the children's actions and statements in order to identify whether the design of the learning environments influences the amount and kind of creative actions. Data were correlated with each other to draw conclusions about the connection between the children's motivation and their "brain type". Finally, we interpret the results and discuss the outlook for further studies.

5.2 Creativity and the Motivation to Do Science

5.2.1 Creativity and Motivation in Science Learning Settings

Motivation is a complex concept of several constructs (intrinsic and extrinsic motivation, goal orientation, self-determination, self-efficacy and fearfulness). According to Glynn and Koballa Jr. (2006), motivation is an internal state that evokes, guides and sustains behaviour such that it cannot be observed directly but only via behaviour (Barth, 2010).

Scientific literature describes children as innately motivated learners. They are curious and discover their environment through inquiry (Lück, 2012; Patrick & Mantzicopoulos, 2015; Oppermann et al., 2017). According to Kahlert (2016), these assumptions describe children as basically willing to learn, but the motivation can differ from one domain to another. According to Patrick and Mantzicopoulos (2015), it seems fundamentally important for motivation in elementary science that the children experience various natural phenomena, scientific ways of thinking and working in the form of productive and systematic learning situations.

In German day-care centres, science education is often provided in the form of scientific learning settings (Kauertz & Gierl, 2014). These settings are structured similarly in terms of time and space, in which preschool teachers guide the children towards a specific learning goal (Einsiedler, 2009; Vosniadou et al., 2001). Settings often start with the collective observation of a natural phenomenon (Wagenschein et al., 1997).

Independent exploration in unstructured settings is seen as important for children's learning processes (Vosniadou et al., 2001). Hammond et al. (2013, p. 294) confirm these assumptions in an international study: "play-based programs tend to more effectively promote creativity and academic achievement than direct instruction programs".

On the contrary, Windt (2011) shows that openly structured learning arrangements promote less learning growth than guided experimentation situations. Her openly structured learning situation seems more like a materials offer than a learning environment, as the researchers failed to detect whether the children were aware of the learning goal.

Different German educational perspectives inform the designs of learning environments. In one, the child is seen as a competent individual who deals with their environment socially and constructively. The learning process is organised in a series of structured experiments systematically built on one another (Fthenakis, 2009; Lück, 2012). The other is based on a 'self-education approach'. Pedagogical specialists in kindergartens are seen as competent partners, who support the child's needs in their individual learning processes, in which the child is also an active participant. Early scientific education has great potential for self-education, if it is designed to mimic everyday life, so that children explore the direct environment in a play-based setting (Schäfer, 2009; Welzel, 2006).

The German-Swiss research project "Professionalisation of pedagogical specialists in kindergartens" (PRIMEL) examines the influence that the day-care centre as well as the room and material equipment have on scientific learning processes (Kauertz & Gierl, 2014). They identify two forms of learning environments in Germany—either an experiment is carried out closely or the children philosophise about the causes, followed by an instructional guided experiment. They mention a different approach in Swiss kindergartens, which the authors call 'experience-oriented' (ibid., p. 178). This often includes stories, role playing or figurines, such as hand puppets. But this project does not record the effects on motivational processes or the influence of learning environments on children's motivation or creativity.

Steffensky et al. (2012) compare these approaches to identify differences in the knowledge gain. In a pre-post design, 245 children in their final year of kindergarten took part in various learning environments. The first learning environment included experiments on the characteristics of water, which were discussed with the children before and after the experiment. The second type of learning environment simulated an everyday situation that was introduced by a framework story and then encouraged the children to playfully use their imaginations. The children's observations and ideas were discussed during the conversation. Finally, in the third type of setting, the two procedures were combined by discussing an everyday situation and then carrying out an experiment on a similar phenomenon. Results showed that only the third type of learning environment increased the children's knowledge. The study did not identify the setting in which children are most motivated nor how the results relate to the design of the learning arrangement and the possibility of being creative in it.

Creativity is often defined as the production of novel and useful ideas (Steele et al., 2017). In school science class, students learn knowledge and comprehend processes that are new to them, but not new for science and society (Newton & Newton, 2010, p. 112). Scientific learning settings in kindergartens proceed similarly in a specific social setting, where the children often 're-experience' an existing research process. If, in this process, the children understand a phenomenon, produce a plan of action, generate alternative interpretation ideas or solve problems that are new to them, it belongs to the creative process frequently referred to as "divergent thinking" (Steele et al., 2017).

Therefore, an expanded definition of creativity in science education is necessary. Newton and Newton (2010) interviewed 16 pre-service teachers in order to capture their definition of creativity in elementary science. In their statements, the researchers identify five categories, each with varying amounts of sub-categories. Four of these categories describe students' creativity-related actions and statements during science lessons. The fifth category is about creative teaching strategies.

Category 1a is defined as "students construct tentative descriptions". Here, creativity is defined as the *"making of predictions"* (ibid., p. 115). Category 1b is "students experience the world and generate explanations". Here, creativity is described as "*construction of a plausible explanation*". The second category is about using scientific information for imagination. The third category is divided into three sub-categories "generate tests/design process/generate possible solutions to a problem". Here, creativity is described as "*generate a test of their predictions and explanations to solve a problem*". The fourth category is non-cognitive—"students develop positive feelings about science during lessons: the wow-factor". Here, creativity is more about *"atmosphere and engagement"*.

The last category shows that creativity is about more than cognitive processes and actions in scientific settings. In scientific processes, the affective part of creativity, such as emotions and motivation, are also important. From their results Newton and Newton (2010, p. 119) conclude that some teachers have a very narrow definition of children doing science, e.g. making models according to instructions. A useful and wider definition of creativity in early year's science could be: "the interaction among aptitude, process, and environment by which an individual or group produces a perceptible product that is both novel and useful as defined within a social context" (Hammond et al., 2013, p. 292).

In conclusion, the question arises how motivation and creativity are related in early year's science education. Interest is one of the most important aspects of intrinsic learning motivation and shown in the time that pupils spend on a task (Artelt, 2005, p. 233). Creativity on the other hand seems to be "preceded by profound interest in an engagement with a task" (Steele et al., 2017, p. 100). Thus, engaged children have the possibility to act creatively in the way defined above within a science learning setting.

5.2.2 *Creativity, Motivation and the Empathising-Systemising Theory*

One critically discussed way to measure children's motivation to do science is to capture their cognitive style. Beginning in 1999, the British psychologist Simon Baron-Cohen developed his E-S theory while searching for an explanation for the development of autism. The theory assumes that children who are prenatally exposed to increased levels of testosterone tend to be more interested in systems and structures than in people and their feelings. Baron-Cohen (2009) concludes that people's brains can be assigned to two dimensions, the EQ and SQ values, which can be scored using a standardised questionnaire. People with high SQ scores are called 'systemisers' and tend to look for the systems behind things. Systemisers like factual texts as well as collecting and sorting things. They prefer group activities over close friendships and often create order through tables or (ranking) lists. On the other hand 'empathisers' orientate themselves to other's feelings and like fictional stories, two-way relationships and animals, and they are often helpful. For a more detailed overview of the typical characteristics, see Skorsetz (2019). Baron-Cohen's research group also finds that the proportions of a person's EQ-SQ dimensions are more predictive than their gender of whether they choose to study science or the humanities (Billington et al., 2007).

Further empirical studies distance themselves from the prenatal testosterone exposure hypothesis and instead use the described characteristics in people's behaviour for research on the individual motivation to do science. For example, adolescent systemisers prefer to study science rather than those with high empathiser scores (Zeyer et al., 2012). Unlike adolescents, young children do not have to decide between science and the humanities. Therefore, our previous study examines the motivation with which children study natural phenomena. Confirming E-S theory, which describes the dimension composition as innate (Baron-Cohen, 2009), results show that even young children demonstrate individual EQ and SQ values (Skorsetz & Welzel-Breuer, 2018; Skorsetz, 2019). According to Zeyer et al. (2013), who conclude that empathisers may need different approaches to scientific learning, the results were correlated with data on the children's motivation in two different learning environments for the same natural phenomenon (here 'absorbency'). In a design-based research approach (The Design Based Research Collective, 2003) the first rather *structured-instructional* learning environment was designed according to Lück's (2012) instructional approach, which assumes that the child co-constructs new knowledge with others, e.g. in an experiment structured by instructions with subsequent interpretation. In this learning approach the children compare the water absorbency features of cotton, aluminium foil and superabsorbent crystals (from a baby diaper). After the experimental phase, an interpretation phase is intended in order to find explanations and to increase the knowledge.

To motivate empathising children for science, Zeyer et al. (2013) suggest re-organising the lessons or learning environments to include first-person perspectives and context-based approaches. So, the second environment was structured to be more *play-based* (Schäfer, 2009). In this learning environment, the materials are available for free exploration and a hand puppet verbalises the problem to solve in a framed story (the floor of his cave is wet). The preschool teacher still structures the setting, however. Additional materials, such as kitchen paper, cotton and fleece socks as well as dishcloths, are provided and can also be tested for their absorbency.

The study tested 99 children in two cohorts. They attended one of the two learning environments described above within small groups and were videotaped. The recordings from both environments were analysed for activities that indicate their motivation as "time on task" (Artelt, 2005) in the form of the duration and frequency of their viewing focus (Skorsetz & Welzel-Breuer, 2018; Skorsetz, 2019).

According to E-S theory, correlated data shows that a high SQ value means that these children are motivated regardless of the design of the learning environment. Surprisingly, children with a high EQ score look at material not currently being used in the exploratory, play-based learning environment for significantly longer and seem distracted although this setting was expected to maintain the 'empathisers' motivation by the fictional story.

In comparing the two environments, the motivation-related activities of all children were examined independent of the EQ and SQ values. All children were more distracted in the instructional learning environment than in the more play-based environment, as well as more focused and in contact with the materials in the latter environment. This could be interpreted as all children are less motivated in more structured environments (Skorsetz & Welzel-Breuer, 2018; Skorsetz, 2019). If motivation enhances creativity (e.g. Steele et al., 2017), the question arises as to whether the children in the more open and play-based settings are also more creative and whether there are correlations with their brain type.

5.3 The Study

5.3.1 Goal and Research Question

E-S theory does not explicitly describe the relationship between creativity and motivation, but it may provide an explanation if we look at the creative possibilities in the inquiry process in the different learning environments and find coherences between cognitive style (or 'brain type') and the amount or kind of creative actions shown by the children.

Hence, we pose the following research question:

> To what extent are creative actions and statements related to preschool children's EQ and SQ scores in slightly different structured learning environments for early science education?

5.4 Method

To answer the research question, we reanalysed the *descriptions of action* for every setting with a transcript of the children's verbal and nonverbal (inter)actions (Skorsetz & Welzel-Breuer, 2018; Skorsetz, 2019). In the original study 29 science learning settings with 99 different five to six-year old children were recorded.

We created a category system based on the definitions of creativity that Newton and Newton (2010) compiled in their interviews with early education teachers. Following the qualitative content analysis according to Mayring (2015), two independent coders categorised every action or statement, because as external agents, we are unable to decide whether one child's action or statement is new for that child.

In the first instructional learning environment, they analysed the interpretation phase that followed the exploration phase and that was introduced by the preschool teacher asking the question "Which object do you think will best soak up the water?" In the second learning environment, they analysed the exploration phase that started after the story and lasted until the end because there is no specified interpretation phase.

When children's actions were coded differently, the coders discussed their coding in an argument-based validation process (Bortz & Döring, 2006) until they reached a consensus. During that process codes were expanded inductively (Table 5.1) so that the following broad categories emerged. No example of the second category "use of scientific information for imagination" from Newton and Newton (2010) was found in the data.

Finally, the codes were grouped according to category, child and setting. We used two-sample t-tests in order to identify significant differences between values.

Table 5.1 Categories of children's creativity in scientific learning settings

I.		**Examples**
1. Predictions	1. Spontaneously, verbally, but also using onomatopoeic expressions	"The water won't go in there."
	2. Using technical terms	"That probably sucks the best."
2. Explanations	1. Spontaneous, verbal, also (short) answers	"That does too."
	2. Using technical terms	"Sucks in!"
	3. Nonverbal	Nodding
	4. Onomatopoeic	Slurping sound
II.		
1. Planning statements	1. On the experimentation process in general	"Then I'll just take the socks, if only those left."
	2. On the experimental process related to the phenomenon of absorbency	"I try that …because it works for babies."
III.		
1. Judging/emotional statements	1. Positive	"Wow, amazing…"
	2. Negative	"Yuck, smells like..."

Finally, we correlated the questionnaire results, i.e. the children's EQ and SQ values, with the video analysis (Spearman, two-tailed) in order to identify possible correlations.

5.5 Results

In the descriptions of actions of the two learning environments, different numbers of codes could be assigned for positions in which the children were creative. In the first, more structured learning environment, a total of 639 codes were assigned to 51 children, resulting in an average of 12.43 creative actions per child. Two children showed no creative behaviour in this learning environment.

In the second, more play-based learning environment, every child showed at least one creative act. A total of 741 codes were assigned to 47 children, resulting in a mean of 15.77. The subsequent t-test with independent samples showed that the two mean values (all creativity categories cumulated) do not differ significantly. Some mean values of the individual categories reveal significant differences in some cases as shown in Table 5.2.

In the instructive learning environment significantly more statements use technical terms (I.2.2), but more spontaneous assumptions were found in the play-based learning environment (I.1.1), where significantly more planning statements (II.1.2) and positive emotions (III.1.1) were expressed as well.

In the next step we correlated creative actions and the EQ and SQ values of the children to determine the degree to which they are related. There was no significant correlation based on all codes cumulated between creativity and EQ/SQ values—neither with regard to the separate learning environments nor overall. The results also show no connection between the children's gender and their creative actions.

Significant correlations (see Table 5.3) between the individual categories and the EQ or SQ values for the first, more instructive learning environment reveal that the higher a child's EQ score, the more non-verbal explanatory statements they made. This connection is not evident for the more play-based learning environment. However, another significant correlation was found for this environment: The higher a child's SQ score, the more explanatory statements they used.

Table 5.2 Significant categories t-test (mean values)

	Structured-instructional setting	Play-based setting
I.1.1 Predictions	0.94	2.40
I.2.2 Explanations	1.31	0.49
II.1.2 Planning statements	0.37	1.43
III.1.1 Judging/emotional statements	0.55	1.21

Note: Two-sample *t*-test; *p < .0.05

Table 5.3 Significant correlations

	Structured-instructional setting	Play-based setting
Code	I.2.3 Explanations	I.2.1 Explanations
EQ	0.034*	0.021
SQ	0.184	0.041*

Note: p > .05* (Spearman-Rho, two-tailed)

5.6 Discussion and Conclusion

Re-analysing the data served to find coherences between the children's cognitive style and their creative actions in different organised settings. Results from the previous study show that according to Billington et al. (2007) and Zeyer et al. (2013) children with a high SQ score demonstrated their motivation to deal with natural phenomenon in both learning environments, i.e. regardless of the didactic-methodical arrangement. No such relationship was found for children with a high EQ score.

In order to answer the research question, the new results concerning creative actions and statements revealed that systemisers manage to proceed more reasonably and use technical terms in the more play-based learning environment. On the other hand, children with a high EQ score, i.e. empathisers, are able to express themselves creatively in the more instructive structured learning environment, but only in actions such as pointing to materials and answering questions non-verbally.

Following the idea that motivation enhances creativity (Steele et al., 2017), results from the previous study on children's motivation in the two learning environments show that *every* child was more motivated in the more play-based structured learning environment than in the instructive environment (Skorsetz, 2019). Re-analysing the data with a focus on creative statements and actions, we preliminarily conclude that both learning environments enable roughly the same amount of creativity, since the mean values of codes do not differ significantly. Nevertheless, the individual categories show that a different didactic-methodical structure promotes different creativity dimensions. The rather instructive learning environment leads the children to use more technical terms. In the more play-based learning environment, the children express themselves more spontaneously and emotionally.

These results confirm Patrick and Mantzicopoulos' (2015) idea that, for motivation, children should experience various natural phenomena in productive and systematic learning situations, in addition to Hammond's (2013) notion that play-based programmes foster creativity.

Based on these results, we tentatively conclude that a motivating and creativity-promoting scientific setting should contain a real problem and inquiry possibilities with the phenomenon or the materials followed by an organised and structured interpretation phase where the preschool teacher and the children work together to explain or describe the phenomenon. Our study indeed has some limitations: in retrospect, the learning settings did not differ significantly rather than being truly contrasting, and only a small portion of the settings were analysed; the determination of the brain type could be inaccurate because parents filled out the questionnaires for their children.

Therefore, the connection between motivation and creativity in learning environments in early science education should be examined further, since the didactic and methodical designs likely influence the development of possible creative actions—more cognitive or more emotional, spontaneous actions. The references to connections between the cognitive style ('brain type') and the use of creative possibilities in learning environments on natural phenomena should be further explored, as it will likely yield further fruitful indications for a motivated and creative learning process.

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Chapter 6
Child-Focused Primary Science Inquiry: Can the Right Balance Be Found Between Creativity, Curriculum Objectives and Assessment Requirements?

Lynne Bianchi and Sarah Earle

6.1 Introduction

For many, creativity and assessment pull in opposite directions, with creative approaches designed to open out possibilities, and assessment of curriculum objectives designed to narrow attention to more comparable outcomes. In this chapter we will explore the relationship between science inquiry, creativity and assessment. We will share two case studies of ongoing primary science projects from the UK, which aim to foster creative science inquiry, within the curriculum and assessment framework. Conclusions for practice will be drawn regarding supporting teachers to maintain the balance between creativity, curriculum and assessment in the classroom.

6.2 Science Inquiry

'Inquiry' or 'to enquire' means 'to ask' and is inherent in the way humans think about the world around them. From a young age, children will use facial expression and sound to seek a response and develop the skill of question-asking, which through practice and modelling underpins the process of inquiry, and the way scientists work. Harlen (2018) identifies a scientific inquiry as one that "concerns questions about the natural and made world and leads to the developing understanding

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of what is there around us" (p. 33). Science inquiry involves raising questions and gathering evidence to answer those questions.

Inquiry is inherent in the concept of scientific literacy, whereby a person demonstrates a range of competences, knowledge and attitudes that enables them to engage with science-related issues and with the ideas of science (OECD, 2013). A scientifically literate person is able to:

1. Explain phenomena scientifically:
   - Recognise, offer, and evaluate explanations for a range of natural and technological phenomena.
2. Evaluate and design scientific inquiry:
   - Describe and appraise scientific investigations and propose ways of addressing questions scientifically.
3. Interpret evidence and data scientifically:
   - Analyse and evaluate scientific information, claims, and arguments in a variety of representations and draw appropriate conclusions.

(OECD, 2013, p. 7)

In England, scientific inquiry is an explicit part of the National Curriculum, with objectives listed under a 'Working Scientifically' section (DfE, 2013). The curriculum states that inquiry "must always be taught through and clearly related to the teaching of substantive science content in the programme of study" (DfE, 2013, p. 5), meaning that inquiry is taught as part of topics within biology, chemistry and physics such as: plants, everyday materials and electricity. By placing inquiry in context, rather than as a stand-alone 'wow' moment, the aim is to support the meaningful development of both process skills and conceptual understanding, avoiding surface level 'activity-led' engagement (Ofsted, 2019). Ideally, this approach would enable teaching activities to move beyond demonstrations and support children to apply their learning through investigations within which they have autonomy. However, an investigation may become more teacher-led where children are 'recipe' following to get to the 'right' conclusion, for example, if the aim is to illustrate a particular concept. Curriculum sequencing is integral here, with decisions to be made around whether child-led investigations should follow lessons on 'substantive content', or whether exploratory inquiries are utilised to build understanding of the world around us.

In England, the time available for science is often limited due to pressures to focus on English and mathematics, which form the basis of national school performance indicators (Wellcome Trust, 2017). Time pressures due to performativity culture (Davies et al., 2013) are compounded by the need to 'get through' the National Curriculum content, meaning the opportunities for creative inquiry are curtailed (Davies et al., 2018).

6.3 Creativity

Creativity is a complex concept and one which lacks a widely agreed definition (Mullet et al., 2016). However, in this chapter we are particularly focused on the difference between creative teaching and creative learning (Davies et al., 2014). Davies, Newton et al. (2018) found that when asked about creativity in the classroom, most teachers in the study described a creative experience, topic or provocation for the children, which signifies creativity on the part of the teacher rather than creativity on the part of the child. In contrast, creative learning, with divergent thinking processes that encourage child agency, is the focus for this chapter.

When considering children's creativity in science, we do not suggest that these are discoveries that are new for humankind, but the exploration which provokes new thinking for the child. Cremin et al. (2015) define this as 'little-c' creativity "purposive imaginative activity generating outcomes that are original and valuable in relation to the learner" (p. 416).

This invitation and opening out of children's scientific ideas and possibilities points to the creative and divergent thinking which can be developed as part of science inquiry. Although it should be noted that teachers may need to be persuaded of the creativity inherent in the scientific process, since many teachers see creativity as a feature of 'arts-based' subjects (Mullet et al., 2016), with a focus on a creative product rather than the creative process.

Craft et al. (2012) describe how 'possibility thinking', where options are introduced by and with the child, can result in the child taking a leading role in their learning. They explain that adults may provide a frame by setting up an environment, yet if the child initiates the line of inquiry and develops the possibilities, they are the leading agent in the creative learning process. Furthermore, Cremin et al. (2015) highlight the debate in the literature regarding whether a teacher is constraining or enabling when they scaffold children's inquiries (p. 408). Craft et al. (2012) discuss this 'meddling in the middle' to be when the adult must seek to balance co-authoring with standing back and allowing the children to fully lead, as such treading a fine line between scaffolding and taking control. The optimum role for the adult will vary depending on the age and experience of the child, together with the teacher's aims for the interaction.

6.4 Creativity in the Science Inquiry Process

Although creative processes are inherent in the inquiry process, it may not be explicitly recognised where or how the child is creatively or imaginatively engaged in the process of working scientifically. The primary science inquiry process can be seen as a cycle, with exploration and investigation leading to further questions. The inquiry process can be simplified to a 'Plan-Do-Review' Cycle (TAPS, 2021) to provide teachers and children with a step-by-step approach to questioning and

Fig. 6.1 The science inquiry process in a 'Working Scientifically Wheel' (TAPS, 2021)

planning, setting up enquiries, observing and measuring, recording, interpreting and reporting and evaluating (Fig. 6.1).

The science inquiry process can be contrasted with the aligned discipline of engineering. In this discipline a problem-based learning approach draws the learner towards asking questions, imagining possibilities, planning and creating solutions that can then be tested and improved.

Whether considering a science inquiry Plan-Do-Review cycle, or an engineering design cycle, there are opportunities for 'little-c' creativity throughout (Cremin et al., 2015), with divergent thinking encouraged to create new solutions or methods. However, in the reality of the primary science classroom, such opportunities may not be explicitly described as creative, or creativity used as an undefined or overarching concept. Although creative learning is often a genuine aspiration, it risks being an assumed outcome for children, and not explicitly discussed or described in science lesson planning. The value of science inquiry is that it provides stimulus for creative thinking to be encouraged, manifesting itself in the ways that children can be more agentic in inquiry activities, have more opportunities for decision making and possibility thinking (Craft et al., 2012).

Creativity in primary science requires enough freedom for children to make decisions (Murcia et al., 2020), thus child agency has a key role to play here. Lucas and Spencer's (2017) five-dimensional model of creativity includes: being inquisitive, persistent, collaborative, disciplined and imaginative as elements. Within each dimension they describe how individuals would behave and act, although it is notable that 'decision-making' does not feature within their frame. We propose that children's decision-making is key to creativity in primary science, supporting them to engage creatively in their science inquiries.

Whether an inquiry is more child-led or teacher-led is dependent on who is making the decisions about how it will be carried out in the classroom. Correia and Harrison (2020, p. 371) describe three categories of pedagogical approach:

- Directed – teacher leads inquiry and decision-making.
- Guided – child as apprentice, with opportunities for decision-making.
- Independent – child leads inquiry and decision-making.

This classification is useful because it draws attention to child agency, noting that how: "teachers introduce and organise inquiry in their classrooms affects the degree of autonomy and choice that the learner is allowed to exhibit within the inquiry activity" (ibid. p. 358). With a guided inquiry approach, opportunities for children's creativity in inquiry can be planned for, with the teacher mapping out in advance elements which will be open choice and curriculum elements which will be scaffolded for the children. Children can demonstrate and develop scientific habits of mind and creative thinking in inquiry when there are planned opportunities to make choices and decisions of their own. What such a guided inquiry approach can look like in the classroom will be explored through consideration of the GSSfS and TAPS projects.

6.5 Science Inquiry and Assessment

In England, science inquiry is assessed using the National Curriculum for Science (DfE, 2013) which lists objectives that need to be taught in blocks of two or three years (Key Stages). These objectives act as the assessment indicators for teachers to judge whether the children are 'meeting age-related expectations'. Such classroom assessment may be used summatively for reporting purposes, or formatively to support learning (Assessment Reform Group, 1999; Gardner et al., 2010; Wiliam, 2018). The 2013 curriculum objectives replaced a previous system of levels (DES, 1988) which contained larger progressive summative descriptions. Whilst the 2013 curriculum objectives are more specific, they are also numerous, which can make it difficult for teachers to judge whether children are 'meeting expectations' in so many areas. There are also ongoing concerns regarding a lack of assessment expertise in the profession (Gardner, 2007), with a lack of experience and guidance for teacher assessment leading to reliance on tests which focus on the more easily comparable factual information, rather than the inquiry process.

Inquiry can encourage children to generate and explore ideas leading down many avenues of new learning, however, the freedoms that it creates for children to pursue different lines of inquiry can appear to challenge teaching approaches aligned to knowledge-led curriculum objectives. English schools also often have complex data tracking systems which require regular input of summative data, leading to the undervaluing of formative assessment as frequent summative 'testing' continues to dominate (Mansell et al., 2009). National school accountability measures have arguably resulted in narrow comparisons between outcomes for children and schools. In order to compare children's learning across schools reliably, the outcomes need to be clearly defined, which may be contrary to creative inquiry which is more likely to lead to diverse outcomes.

Nevertheless, whilst creative science inquiry is not 'easy' to assess, it is more manageable when there is a shared understanding of its features (Harlen, 2013). Building such a shared understanding can mean that teachers are more confident and informed to plan opportunities for children to be actively involved in inquiry (Serret et al., 2018). Refining teaching practice in this way would seek to develop children's autonomy and decision-making skills, and address curriculum and assessment requirements. In this chapter, we argue that it is possible to find such a balance between the demands of creative science inquiry, curriculum and assessment.

A further tension in assessment, which is at the core of the creativity debate, is how open (divergent) or closed (convergent) an assessment can be (Torrance and Prior, 1998). Divergent assessment supports a creative approach, it is where children are asked to share what they know, understand or can do; for example, eliciting ideas about living things or selecting materials for an open-ended inquiry. Such activities will have divergent outcomes as the children's ideas could go in many directions. This provides useful information to assess a child's starting point, but makes comparison between children harder. In contrast, convergent assessment aims to find out if children know, understand or can do a particular thing; for example, whether the children know the names for the parts of a plant or that only one variable is changed in a fair test. These activity outcomes are likely to look similar, with labels for root, stem, leaf and flower identical across the class for those who answer correctly. This closed assessment helps to 'tick off' curriculum objectives or assessment criteria, but may not show in-depth understanding or be suitable for the more creative aspects of inquiry such as raising questions.

Both divergent and convergent assessment activities can be utilised in the *creative* classroom, the debate is perhaps whether priority should be given to each style at different points in the topic sequence. There is also the question of whether there is something in between divergent and convergent, a more guided or focused approach, as will be discussed below.

6.6 Creative Scientific Inquiry in Practice: Two Case Studies

In order to explore creative scientific inquiry in practice, examples are drawn from two UK primary science projects. Firstly, the *Great Science Share for Schools* (GSSfS) is exemplified by responses selected from a survey of 152 teachers. Secondly, 142 teacher survey responses are explored from the *Teacher Assessment in Primary Science* (TAPS) project. Each project and its data collection methods and key findings will be introduced in turn.

6.7 Supporting Inquiry in the Great Science Share for Schools (GSSfS)

The GSSfS (https://www.greatscienceshare.org) is an annual campaign that has been designed and developed by the Science & Engineering Education Research and Innovation Hub at The University of Manchester. Created in 2014, this campaign is designed to raise the profile of child-focused primary science by engaging teachers and children in an annual campaign that requires them to undertake and communicate the outcomes to science inquiries. This is facilitated through face-to-face or on-line sharing of children's own scientific questions, where they are invited to communicate their activity with new audiences, including peers, adults, community members, or the general public.

GSSfS has become a recognised part of the school calendar in many UK schools, adding value through its focused promotion on providing stimulus for children to be given opportunities to ask, investigate and share their own scientific questions. The campaign is inclusive and non-competitive which has resulted in children from 5–14 years being supported in school by teachers to spend more time on science inquiry within curriculum time, which has also extended to home learning. The focus on children taking the lead in asking and sharing their scientific questions promotes children to be agentic in their approach, often supported by teachers who co-author and support the planning and undertaking of the inquiry itself.

We are including this campaign as an example of where we have seen a shift in approach by teachers from directed science inquiry to guided and independent inquiry. Survey and case study data is collected annually, using a post-campaign evaluation on-line questionnaire that seeks the responses from teachers or educators who have registered children's involvement. In addition, children are encouraged to share basic outlines of their inquiry plan and outcomes that offer insight into the nature and context for the scientific inquiries they have designed and led. The case examples used here to exemplify children's science inquiries are selected from over 250 questions submitted via the campaign website during the 2020 campaign.

6.7.1 Findings from the GSSfS

The following few examples are selected to offer insight into the guided nature of children's inquiry experiences.

> Aged 4, Sammy explored the question "Would a stickman drawn in a bowl with a whiteboard marker wash away?" She explained that, "My mummy and me drew a stickman on the bottom of the bowl with a whiteboard marker. She then slowly helped me tip some water inside the bowl and covered the stickman." Together they found out that, "When the water was poured over the stickman, it lifted from the bottom of the bowl. The stick man stayed whole and floated. When I shook the bowl it looked like the stickman was dancing." Further going on to ask, "What made it float?"

> Aged 8, Alex explained that he had noticed that his pennies were dirty. He questioned, “How do I make my pennies clean?” and described, “I am going to put coins into different liquids. I predict that lemon would clean the best and I think that coke will clean the worst.” He explained that “I got 6 pennies from the same year (2006). I labelled 6 cups with 6 different liquids; lemon, coke, milk, water, hand soap and vinegar. I put a coin into each liquid and waited for 30 minutes. I then removed them and wiped to get the liquid off. I found that the lemon and hand soap cleaned the most. I would like to know why lemon and hand soap cleans pennies the best? I also would like to know how long will my pennies stay shiny for and why do they go dull?”

> Aged 11, Jo, asked “Are rainbows real?” and investigated this as follows—“I used a glass of water, a pencil, white paper and a torch. First, I dipped the end of the pencil in the water. It appeared to bend and look bigger. Then I put a glass which was half filled with water on the edge of a chair. I put white paper on the floor and shone my torch through the glass of water and onto the paper. IT WAS AMAZING! I made a rainbow. The water bent the light from my torch and split it into colours of the rainbow, just like rain does. I honestly didn’t think it would be that easy. So yes, rainbows ARE real even though we can’t touch them.”

In these examples, we can see scientific habits and skills developed in school settings being applied to questions that the children had interest to explore. The focus of the GSSfS on encouraging children to explore ‘their own’ questions has seen a move to teachers giving more opportunity for children to do this. Evaluation reports undertaken in 2019 surveyed participating teacher experiences of the campaign using an on-line questionnaire. This sought to identify the type of activity undertaken and teacher’s impression of the impact of the GSSfS campaign on children’s science learning experiences (LookOut, 2019). Responses gathered from 155 teachers, reflected that 86 per cent of teachers agreed that the science investigations conducted as a part of GSSfS were more child led than those regularly done in school. Teacher post-campaign interview findings as part of this evaluation demonstrate the mix of decision making between children and teachers in the inquiries undertaken. Teachers explained that the choice of which science investigation and method was a joint decision between them and children, however teachers encouraged children to make the final decision about resources and approach. They recognised that there were ‘naturally occasions where this needs to be guided’ and that teachers reported that it was, “essential that children make their own decisions and be allowed to make their own mistakes” (ibid. p. 18).

When explaining teaching approaches used to engage in the GSSfS, some described tools such as ‘question boards’. This was a teacher-designed approach in which children are encouraged to ask questions about science and the question board offers an opportunity to post any and all questions that children ask so that they do not get missed or forgotten when falling outside a lesson in which they can be addressed. If a question cannot be discussed there and then, it is written up on a sticky note and posted on the question board. These questions are then dealt with at a specific time in the week, which may include discussion of how and why the question was posed, where an investigation should take place, what type of investigation or inquiry should be used to answer it and what variables should be measured.

Table 6.1 illustrates outcomes when teachers were asked to rank the impact that participating in the GSSfS had on six different areas. From this it is notable that

Table 6.1 Teacher rankings of the impact of GSSfS

Statements	Average impact ranking (0 = none; 5 = high)
Your (teacher) knowledge and understanding about asking scientific questions	3.3
The profile of science questions in your school	4.4
The opportunities for children to ask their own scientific questions in your classroom	4.6
The engagement of parents/community with science in your school	4.0
Children's science attainment	3.8
Children's aspirations towards science	4.4

teachers reported positive influence it had on encouraging children to ask their own scientific questions in the classroom.

Offering children greater opportunity to take a lead in the science investigation is a positive outcome of the campaign. In accordance with Correia and Harrison's (2020) suggestions, most teachers explained that they actively pursued a collaborative approach with the children, which is also reflected in Fig. 6.2.

What has not yet been discussed with this group of teachers is the ease or difficulty of adopting a partially negotiated approach to children designing their own science inquiry for assessment judgements. GSSfS has focused on supporting inquiry to take place, rather than assessment, although inevitably this is a rich opportunity in which teacher assessment can take place.

6.8 The Teacher Assessment in Primary Science (TAPS) Project

The TAPS (https://pstt.org.uk/resources/curriculum-materials/assessment) project, funded by the Primary Science Teaching Trust, has been working collaboratively with teachers across the UK since 2013 to develop support for valid, reliable and manageable assessment. A key part of the project has considered a Focused Assessment approach, whereby an element like planning or conclusions is selected as a focus within the context of a whole inquiry. It is the focused element which is recorded by the children, for example, completing an inquiry plan, making a prediction on a post-it note, drawing a graph or writing an evaluation. By focusing the child's recording and teacher observation or judgements on one element of the inquiry, the practical inquiry becomes more manageable for teachers. It also helps to enable some of the decision-making to be handed over to the children. For example, if the focus is on evaluating, then the children can be encouraged to try out their own ideas for the inquiry, making their evaluations more meaningful. Whilst, if the focus is on drawing results tables, then children might need to be supported to carry

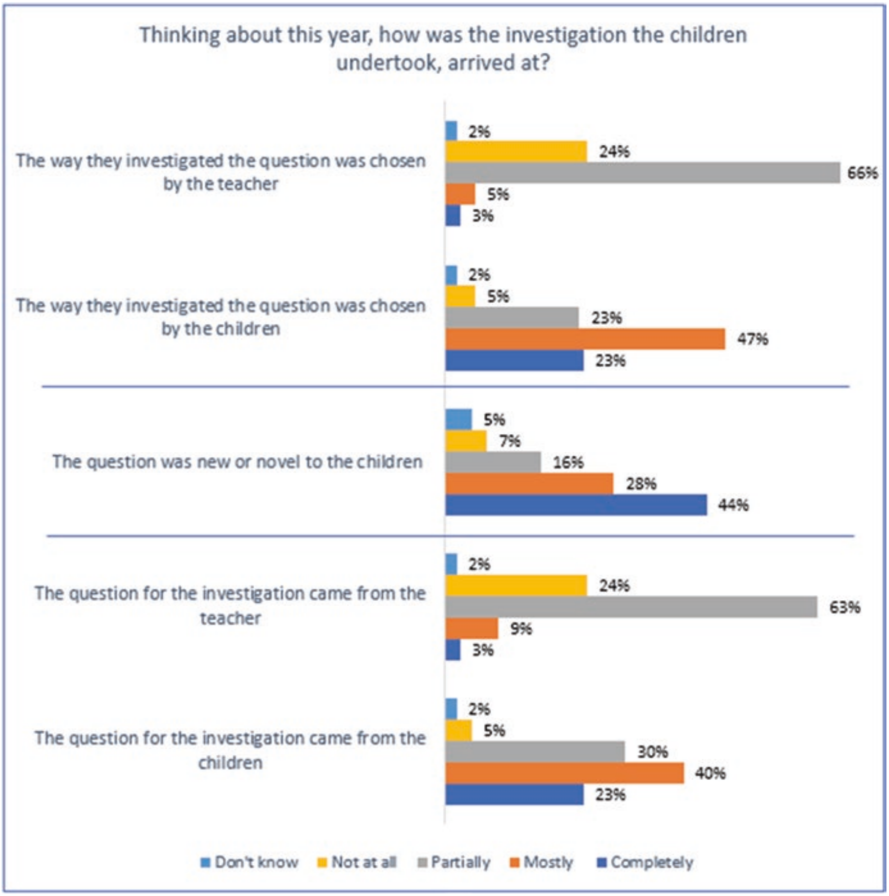

Fig. 6.2 Teacher reflections on child-led nature of GSSfS investigations

out an inquiry which results in numerical data, but could make their own decisions about which variable to change or which area to survey.

This Focused Assessment approach includes a mix of convergent and divergent elements, for instance, where the clarity of the results table meets agreed (convergent) success criteria, but the inquiry findings or way it was carried out may be quite different (divergent). A practical example is a 'craters' investigation (dropping balls into sand to mimic meteors hitting the moon), where the expectation of a completed results table could be fulfilled, whilst still giving the children choice about whether they change the height or size of the ball, etc., and whether they measure the diameter or depth of the crater. This could be described as a type of guided inquiry, with a convergent element included to support assessment judgements, whilst other more divergent elements mean that children are able to take an active role in decision making.

The TAPS Focused Assessment approach is being tested and refined in practice. The approach was introduced to primary school teachers (for children aged 4–11) in nine regions across England on a two-day training course. After Day 1 (Sep–Oct 2019), the teachers were asked to carry out an inquiry lesson with their class. On Day 2 (Jan–Feb 2020), they completed a feedback form detailing their experience.

6.8.1 Findings from the TAPS Project

One question asked the teachers whether they had focused on a Plan, Do or Review element of the inquiry (TAPS, 2021); these answers were tallied to provide a frequency. Responses from teachers (n = 142) indicate that selecting a focus is something which is possible for each element of a science inquiry (Table 6.2).

In order for this approach to be helpful for formative assessment purposes, the teachers need to gain useful information about their children's learning, thus they were asked: "What did you notice/find out about your children? (Any surprises?)" During thematic analysis, a range of themes related to children's science learning and their creativity emerged, which are pertinent to this discussion.

Teacher (T) responses revealed that many had recognised children's agency and decision making as an enabler of creativity, for example:

> They loved the experiments as they were in charge—they could make decisions as it was not me telling them what to do! Their use of scientific language and reasoning was strong—after rocket mice exp, a LA child found a small plastic bottle and I said 'we could have used that for our experiment', to which she replied 'but that wasn't the variable we were testing'. (T46)

> All keen to do practical experiments, some have unique ideas but it was good to test these (e.g. curry powder melts ice because it's hot). (T99)

> Children were given more freedom and autonomy. They rose to the challenge and impressed me with their presentations. (T31)

Some teachers were able to gain useful formative assessment information from the open-ended activities, so that they could decide what to do next, for example:

Table 6.2 Teacher described focus for TAPS inquiry lesson carried out with their class between day 1 and 2 of training (n = 142 from nine regions in England, Jan–Feb 2020)

Described focus for TAPS inquiry lesson	Frequency
Plan focus e.g. asking questions, planning, predicting	43
Do focus e.g. observing, measuring, recording results	43
Review e.g. interpreting, concluding, evaluating, reporting	39
Two areas described	5
Teacher's description unclear	8
Focus on eliciting knowledge rather than inquiry	4

> More children knew certain vocabulary than I anticipated. They enjoyed more independence. Measuring time was more difficult for them than I thought, as well as using an actual stop-watch. (T110)

> Groups of 4 [were] able to carry out investigations with minimum teacher's input by following investigation frames (in particular from planning to recording). Variables was not a concept well understood. (T34)

The 'investigation frames' described by Teacher 34 are a sticky note planning board, where the variables can be moved around to create different fair test inquiries (Goldsworthy et al., 2000). The use of these planning boards were described by 33 teachers in this sample, with many noting how these had created more opportunities for children's decision making. Others found that the Focused Assessment approach was a new way of working for the children and so the class initially struggled to be independent, for example:

> Found 'open' session challenging (T68)

> Early in the year, quite a bit of scaffolding required. Aiming to reduce this as assessment focuses are repeated. (T26)

> They were not given much of an input/support for spinners results—struggled to record their data. Moved on to meteors after discussing results and their results were much clearer and they were able to analyse them. (T87)

These responses could indicate that this is a new way of working which teachers and children may need to develop over time, with more scaffolding or guiding at the beginning of the school year, and support being gradually withdrawn as science inquiry skills develop. A final theme emerging from this data was that the focused assessment approach may support children who have identified special educational needs or those who normally struggle with written reporting in science, for example:

> I focused on specific recording in books which meant that children had a lot less writing to do. I noticed a positive change in the children, especially those that struggle with writing. (T50)

> The children who normally struggle with recording were uninhibited by using post-its and were able to get the most accurate results and observations as a result. (T104)

> Yes! Children who are usually quiet and not able to write very much contributed a lot in their discussions and in the groups. Those who usually complete all their work struggled to link the predictions/questions to the results/conclusion. (T18)

Such comments indicate that the Focused Assessment approach provided teachers with information which they were not expecting, challenging assumptions about children's science learning and their development of creativity.

6.9 Conclusion

Exploration of the GSSfS and TAPS projects have provided the means to test theoretical ideas about enhancing children's 'little c' creativity (Cremin et al., 2015) and agency in inquiry. Through science inquiry models that move towards guided inquiry in primary school settings, there are early indications that children's decision-making and agency can be enhanced within the curriculum requirements, supporting creative thinking (Murcia et al., 2020). Emphasis on children's agency in inquiry could support teachers to move from thinking about creative teaching to creative learning (Davies et al., 2018). It is evident however that there is still an ongoing tension between creative inquiry and curriculum assessment requirements, although these programmes offer inspiration to the possibility of achieving a balance.

Through the work of GSSfS and TAPS, we have found that the following precursors can support teachers to the balance between creative inquiry and curriculum assessment requirements:

- Provide regular and guided opportunities for children to be agentic through the process of enhancing the opportunities for them to make decisions about key features of their inquiry—in particular about *what* they inquire, *how* they go about it, what they record and share.
- Secure understanding of the inquiry process, e.g. shared understanding of progression in the Plan, Do and Review cycle.
- Consider assessment purposes (formative and summative) and focus (e.g. concepts and skills) in planning and implementation of the inquiry experience.
- Adapt the level of direction and guidance within science inquiry lessons so that not all parts of an inquiry need to be handled the same way, thereby creating a balance between creativity and assessment.

Flexibility when planning, and during the lesson, is likely to be necessary, in order to be able to respond to lines of inquiry that emerge as children increasingly make decisions for themselves. Teachers need to be attentive to the fact that they will make ongoing adjustments of children's learning within the lessons, an essential feature of formative assessment and responsive teaching. To include children in the decision making, releasing some control of the lesson, can initially be felt to be a big step for many teachers who feel the pressure of 'getting through' the curriculum, managing resources and behaviour. School senior leaders therefore need to offer supportive structures such as those described in the programmes above.

The tension between creativity, curriculum and assessment will inevitably always provide ongoing challenges, yet it is encouraging that by utilising support such as that provided by GSSfS and TAPS, it is possible to support creative primary science learning. Balancing opportunities for creativity, within a curriculum and assessment requirements, requires us to value both the benefits brought by guided inquiry, within which children have more agency and decision making opportunities, and by formative assessment, which is used to identify and feedback on progress. Creativity is not limited to 'arts-based' subjects (Mullet et al., 2016); by providing a range of opportunities for child-focused investigations and divergent thinking, we can make the most of the inherent creativity in primary science inquiry.

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Chapter 7
Working with Inquiry Activities to Encourage Creative Thinking

Christine Harrison and Sally Howard

7.1 Introduction

Inquiry is considered an inspiring way of learning science as it focuses on children's interests and stimulates active learning by enabling learners to explore their own ideas and conduct investigations (Braund & Driver, 2005). Children bring to school ideas formed about the world through their actions, observations and thinking in their daily lives and these forms the starting points for inquiry learning and the development of their scientific understandings (Harlen, 2013), capabilities and attitudes. Inquiry learning enables learners to link observations with ideas they hold from previous experiences, allowing new observations to consolidate or challenge previously held ideas. This process influences thinking and learning as children utilise their curiosity to work out how what they see connects with how they believe the world works.

It is well argued that through inquiry activities, children can develop a wide range of skills and competencies (Anderson, 2002; Furtak et al., 2012; Minner et al., 2010) while also fostering their confidence and capabilities to apply these skills in novel contexts (National Research Council, 1996, 2012). Through inquiry activities, learners become more active and agentic in their learning and teachers are able to guide student learning. Hmelo-Silver, Duncan et al. (Hmelo-Silver et al., 2007), coherently argue teachers' central position in scaffolding learning and how teachers are responsible for timely intervention to guide and scaffold developing ideas. Such

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timely intervention and 'on the fly' input during inquiry activity plays a crucial role in shaping science learning, while allowing for some aspects of learner agency within the inquiry process (Harrison et al., 2017).

This chapter explores how inquiry activities in science learning contexts can encourage learner creative thinking. It focuses on the children's creative thinking and the opportunities shaped by their teacher within the inquiry process, to use their imagination, consider possibilities and foster meaning-making. It takes the view that inquiry-based science education centres on the children's creative thinking, where learners begin with ideas, consider possibilities and share their thinking as they engage with activities. We will start with a literature-informed discussion on the nature and role of inquiry in science learning before exploring challenges in the wide-scale implementation of inquiry-based practices in science classrooms, followed by an exploration of fostering creativity through play and possibility thinking. The background of the SAILS and *Ninja Science* projects will be introduced before presenting three vignettes from the projects. Each of these vignettes is analysed to identify how science inquiry learning can create opportunities for children's creativity. The final discussion emphasises the role of the teacher in facilitating children's creativity in inquiry learning contexts.

7.2 The Role and Nature of Inquiry in Science Learning

The very nature of inquiry introduces opportunities for new ways of thinking to explain phenomena and events where pupils make connections between their existing knowledge and what they encounter (National Research Council, 2012), often introducing a degree of unpredictability for learners. Such activities challenge thinking by engaging children in investigating scientifically orientated questions where they learn to give priority to evidence, evaluate explanations in the light of alternative explanations and learn to communicate and justify their decisions (Crawford, 2000, 2014, 2016). Through inquiry activities, teacher-learner and learner-learner on-the-fly interactions create opportunities for children to articulate and share emergent ideas (Harrison et al., 2017), both building and challenging their scientific thinking. This approach tends to advance critical thinking and reasoning skills (Blanchard et al., 2008) and can motivate and engage students to learn (Crawford, 2014).

Osborne et al. (2004) argue that learners are better able to engage higher order thinking when they are involved in substantive dialogic exchanges between two or more people. Inquiry activities provide the opportunity for a wider range of questioning types by the teacher, leading to learner-talk that draws on discussion and dialogic exchanges, which research claims is central to learning (Alexander, 2006; Mercer et al., 2004; Johnston, 2009). Teachers' questions and attention to learner responses help reveal initial ideas (Chin, 2007) as learners engage with activities, and this is particularly evident in inquiry activities. While close-ended questions generally enable teachers to check 'if' learners know or understand something, open-ended questions often enable teachers to probe 'what' learners know and understand (Torrance & Pryor, 2001).

Crawford (2000, 2014) advocates for the role of teacher questioning within an inquiry-based science approach as the means to encourage dialogic exchanges between peers, and between the teacher and learners. Crawford (2014) argues that, through teachers' use of open-ended questions, it is possible to probe learners' understanding and lead them into elaborating on their thoughts and engage in discussions between each other. This creates opportunities for learners to open up the space where their thinking can be heard and shared with others and, through the classroom discourse, interactions implicitly convey to learners whether their initial ideas are considered to be productive lines of thought or highlight aspects that require further consideration. This legitimises creative thinking as a worthwhile and valued part of classroom learning, encouraging and shaping future classroom behaviours. The types of questions used and the ways in which teachers facilitate this, impacts on learner thinking (Alexander, 2006) and autonomy, in terms of the degree of freedom to explore and test ideas, and decide what to do next (Harrison et al., 2017). Howe and Mercer (2007) have shown that positive learning outcomes arise from learners engaging in dialogue where they have to justify their views and discuss and resolve differences in opinion and perspectives.

While inquiry-based science develops pupils' skills around questioning and evidence collection and consideration, it can also allow learners to be more involved in the decisions that are taken within the investigative process. In many classrooms, the teacher makes most of the decisions, setting the inquiry question, method of data collection and form of analysis, with learners simply collecting and recording data within the activity (Harrison, 2014). In some classrooms, teachers allow learners to engage in inquiry decisions, from setting the question, choosing methods to deciding how much evidence to collect, and making sense of the evidence. Giving opportunities for decisions and choices to be made by the learners, not just the teacher, can bring to the fore the opportunities for divergent thinking and creative approaches. This creative and divergent thinking by learners is nurtured best when the teacher feels able to set-up a learning environment that supports risk-taking by them, and their learners. Harrison (2014) suggests that where teachers hold the control, learner agency is inhibited and can have a limiting effect on learners conceptual understanding and curb the development of a wide range of inquiry skills. In contrast, where authentic questions arise from the learners' genuine interest and become the focus of investigation, there is greater opportunity for learner affordance, which leads to more 'open' inquiries with opportunities for creativity and divergent thinking. However, it also needs to be recognised that relinquishing teacher control and enabling more open inquiries is more demanding on the teacher and the learners in the first instance, until they both become more skilled and confident in working differently.

7.3 Barriers to Implementing Inquiry-Based Science

An inquiry approach has proved its efficacy at both primary and secondary levels in increasing learners' interest and attainments levels (Minner et al., 2010; Osborne & Dillon, 2008) while at the same time stimulating teacher motivation (Wilson et al., 2010). Globally, an interest in using more inquiry-based approaches in classrooms has been evident for several years (Furtak et al., 2012; Lazonder & Harmsen, 2016; Grangeat et al., 2021). For example, the European Union (EU) has funded several STEM education projects that involve inquiry-based approaches in schools (European Commission, 2007)) and while this has strengthened awareness of the benefits of inquiry learning, there is still some way to go in terms of teacher confidence in this approach, partly caused by a lack of pedagogical knowledge about how to implement strategies and routines to make inquiry learning more effective and also because of concerns about appropriate assessment practices to service an inquiry approach (Harrison, 2014).

The *Rocard report* (European Commission, 2007) highlighted the importance of an inquiry-based approach to science in an attempt to engage more learners to continue with science in the upper years of school and at university. Inquiry as an approach to teaching the big ideas within STEM is generally embraced by teachers and educationalists around the globe (Anderson, 2002; Crawford, 2007; Hollins & Reiss, 2016; National Research Council, 2013). However, there is much literature that suggests teachers often hold naïve ideas as to what inquiry-based science involves (Abrahams & Millar, 2008; Capps & Crawford, 2013) and struggle to enact effective inquiry-based practice. Some claim these difficulties are due to a lack of a unified definition of inquiry (Anderson, 2002) resulting in the conflation the goals of any practical science activity with practical inquiry-based activities (Harrison, 2014; Osborne, 2014).

While teachers from around the globe frequently claim child-centred inquiry is centrally placed within their inquiry-based practice, reports of practice often reveal that if inquiry is occurring in classrooms, then it tends to be teacher-centred (Capps & Crawford, 2013; Capps et al., 2016), with teachers controlling all or most of the decisions, and often missing key aspects that distinguish practical inquiry from any other practical activity. Such missed opportunities include learners not being more intimately involved in making sense of evidence to answer questions or understand the phenomena under focus. In addition, opportunities for learners to reflectively evaluate the way they plan, shape and enact an inquiry activity, are often missing (Capps et al., 2016), reducing opportunities for learners to reflect on their thinking and choices within different aspects of the inquiry-process (Minner et al., 2010).

7.4 Fostering Creativity Through Play and Possibility Thinking

A good proportion of young children's lives can involve activities where adults model how to do things through directives and compliance, with little room for learner agency. On the other hand, when children are encouraged to learn through play, this empowers them to access and explore content that they find interesting (Haughton & Ellis, 2016), and consider the roles of others in a shared learning space. Play is well recognised in early years settings as a platform for learning. Most importantly, child-initiated play opens up the opportunity for making choices and, with this, decision-making. While chid-initiated play opportunities foster imagination as they 'play around' with objects and ideas, pursuing their own interests, in their own way, and for their own reasons (Haughton & Ellis, 2016), learning tends to be incidental rather than the focus, i.e. the process of play is more important than the end result. While recognising there is a need for a balance between both child-initiated play and exploration, and adult involvement, early years practitioners are able to provide opportunities to develop 'sustained, shared-thinking' (Haughton & Ellis, 2016) through classroom interactions. Collectively, through extended narratives, there are openings to clarify concepts, evaluate activities and enhance thinking.

Thinking creatively includes children developing their own ideas, making links between ideas, knowledge and experiences (Craft, 2000), and developing a range of skills for doing this. Though inquiry activities, the teacher is able to open up space for imagination to flourish, for new ideas to be explored and novel ways of working to be initiated. In this way, inquiry-based science provides opportunity for children to use their creative thinking and imagination, especially where aspects of learner agency are deliberately factored into activities. Inquiry activities can provide a segue between children's play activities and more formal educational approaches in that they allow some aspects of learner agency to function alongside support and direction from adults. This can allow children to make some choices within the inquiry process, maintaining a sense of belonging, engagement and sustaining curiosity.

It is through agentive opportunity that even young children can draw on their ideas, explore ideas, make choices, use materials and artefacts in new ways, and take 'risks'. In such learning environments, it is reasonable to argue that children can more easily draw on their creative thinking and have confidence in trying out their ideas. This process is more likely to occur within a collaborative learning environment where children's ideas are valued, and the learning journey is a joint venture with peers.

Nurturing children's creativity requires opportunities where learners are motivated to actively engage with the processes of meaning-making. Craft (2011) believed that creativity encompasses a wide array of cognitive and affective capacities that are key for children's development and learning. She describes creativity as an everyday and lifelong imperative that involves problem-solving capability with 'possibility thinking'—the transformation from 'what is' to 'what might be'—at its centre. This notion of 'possibility thinking' is the means in which children explore and refine problems through a process of exploratory meaning-making. Craft (2000) argues that possibility thinking emerges through interactions with objects and others, and the means whereby puzzlement is stimulated, and questions arise. 'What if' thinking is often experienced unconsciously in the flow of engagement, such as in the exploratory phases of an inquiry, and is, in essence, the transition in understanding from 'what is this?' to 'what can we do with it?'. This develops learners' capabilities as confident explorers and decision makers and is in harmony with Crawford's (2007, 2014) notion that effective inquiry-based learning embraces the 'struggle' and 'grappling' that learners do, in their process of making better sense of evidence.

Craft (2000) conceptualises creativity as being twofold; big 'C' creativity and little 'c' creativity. big 'C' or high creativity, occurs in relation to the "extraordinary contributions and insights of the few" (Craft, 2000, p. 56), such as Einstein and his ideas of the theory of relativity, Vincent Van Gogh's painting of sunflowers, or Rudolf Nureyev's dancing and choreography. In contrast, little 'c' creativity is about inspiring everyone into a can-do mindset, wherein little 'c' is a concept that emphasises individual agency (Craft, 2000, p. 126), accepting every child is capably of little 'c' creativity. This form of creativity and creative thinking capability is the cornerstone of children coping with every-day challenges as a process of conscious invention and resourcefulness. It includes using information in new ways, responding imaginatively through exploration at a physical and cognitive level, and creating discoveries that are new to them. Creativity centres on being curious and explorative, and at the core of creativity is 'possibility thinking' (Craft, 2000, p. 57).

7.5 Background to the Inquiry Projects

The *Strategies for Assessment of Inquiry Learning in Science* (SAILS) was a large project funded by the European Union under the *Framework Seven Programme* (2012–2015) to support teachers across Europe to adopt *Inquiry Based Science Education* (IBSE) and assessment practices. The project involved more than 2500 science teachers in 12 partner countries. The project aimed to "prepare teachers, not only to be able to teach through Inquiry Based Science methods, but also to be confident and competent in the assessment of their students' learning" (SAILS, 2016, p. 4). The project directly addressed the concerns raised above that teachers often struggle to enact effective inquiry-based practice. It involved developing strategies for assessing inquiry learning in science as an active aspect of their teaching, while developing teachers' understanding of formative assessment approaches. This project resulted in the development of inquiry and assessment units which showcase IBSE and sharing practice across different partner countries.

The *Ninja Science Project* is a collaboration between researchers from King's College London and the Consortium of Local Education Authorities for the Provision of Science Services (CLEAPSS, an organisation that provides Health and

Safety advice for teachers) intended to support greater use of practical activities in science learning in primary schools. It involves 12 primary schools and their staff and supports classroom teachers in recognising, rewarding and developing practical skills in children.

7.6 Vignettes

This section looks at three vignettes that arose from the above-mentioned projects the authors were involved in and describe science inquiry activities in a number of classrooms. The intention is to provide illustrations of inquiry in practice to highlight the opportunities for creativity within the inquiry process that fosters learners' creativity and to outline some of the teachers' creative practices that make these activities work in the classroom context.

Vignette 1: Racing Green Water

The first vignette involves a Year One class (5-year-olds) and is called Racing Green Water. The children had previously been working on properties of materials with their teacher in a whole class inquiry where the teacher demonstrated, with their help, how to investigate and come to a collective decision about the best material for *Paddington Bear's* raincoat. Four different materials were investigated—wool, plastic, cotton and felt. A cup of water was slowly poured onto a piece of material, that had been fastened over the top of a jar, and the amount passing through each material was observed and compared. The teacher helped the class decide that plastic was the best material for the raincoat because it did not allow water to pass through it and introduced the word 'waterproof' to describe the plastic material.

The teacher introduced the Racing Green Water Activity by talking through the raincoat activity with *Paddington Bear* and asking children to explain how they had helped the bear make a decision about the best material for a raincoat to keep dry in a rainstorm. She then announced that *Paddington* now wanted to find the **best** material for his kitchen mop. Children came up and explained and demonstrated what a mop does in the kitchen, talking both about cleaning the floor and wiping up spills.

The children returned to their tables where the teaching assistant had placed a small dish of green water (water plus food colouring) and a strip of paper towel and a strip of kitchen cloth for each pair of learners. The children were asked to put one end of each strip into the green water at the same time to observe what happened to the green water. Great excitement ensued as the green water started to move along the two material strips with several children pointing at the front edge of the green water in each material strip and describing what they saw happening. The teacher asked the pairs of children to take the ends of both material strips out of the dish of green water as soon as the green water reached the end of one of the strips.

The children were then asked to sit down and talk with one another (buddy-talk) about what they saw happening during the activity. This enabled them to say what they had noticed about the green water moving along the two strips of material and share this with their partner. Some children talked about one strip being better; others suggested the green water moved faster in one strip or that one strip had more green water. Some children seemed to move quickly to a decision about which material strip was better at soaking up water and the discussion with their partner enabled them to justify their decision with the evidence from the observations. Others began with their observation and their interaction with their peers and the teacher and teaching assistant paved the way to move from observation to consideration of evidence to a decision about the material strips.

This vignette highlights how inquiry activities support a creative approach to science. Craft (2002) refers to these types of classroom episodes as 'possibility thinking' because the learners are unconsciously considering the 'what if' during the flow of their active engagement. Such exploration within an inquiry activity allows the learners to consider what they can do with this information.

Through considering possibilities of the ideas in their heads, many of the children were able to reason and decide that the 'faster' and 'more water' strip would be a better material for the bear's mop. The teacher challenged the children who described one strip as 'better' asking them "what makes you think this?" making them reflect on what led them to their decision. Most of these children responded by pointing to or holding up their 'better' strip. They could reach the decision that one of the materials was better for making a mop but they found it more difficult to articulate why. The teacher helped them find the language and scaffolded opportunities for the children to explain their decision. The children were then given two fresh strips and asked to do their inquiry again to check they had given Paddington good advice for his mop material. The teacher and teaching assistant circulated asking questions of different pairs, checking on what children thought would happen, what their observations were indicating and probing how confident the children were in giving *Paddington* their advice.

In this vignette, the teacher was fostering children's creativity by valuing children's ideas and encouraging them to explore, share and check their ideas out. This enabled the children to become more confident in linking what they thought about the evidence they witnessed for themselves. These young scientists were encouraged to link evidence with their ideas and were being nurtured as meaning-makers and decision-makers; a central aspect of inquiry-based science.

Vignette 2: Bean Diary

This second vignette dips into life cycles, a project that a Year Three class (7-year-olds) were doing where each child had begun growing bean seedlings in jars the previous week. In this structured inquiry, the children checked their beans each day and were asked to write and draw in their Bean Diary any changes they could see as the beans germinated and started to grow. In this lesson, the children were asked to look back through their Bean Diary and to reflect on their entries and explain to other children on their table what changes had occurred to their beans over the week. Several children were asked to tell the class their summary of the first week's growth and the teacher selected some of the words they used and wrote these on the board.

The children were then provided with a pre-drawn table with column headings, providing space for them to enter their own data of the bean changes they noted over the week. The teacher then displayed the pre-drawn table on the whiteboard, pointing out the columns and explaining how to record their summary of weekly growth. The teacher explained that the children needed to summarise their evidence about the bean's growth each week and pointed out where on the table they needed to record their weekly summary. She also explained the table was a way of collecting their evidence together in a simple, yet clear way so that they could use this to tell others the story of their bean growth. Each child then took responsibility to record their own weekly summary of bean growth into their table of evidence.

Each week the teacher took the class back to their growing beans, their diary entries and the bean growth summary table. This stimulated a class discussion where the children both looked at the variation in ways of summarising evidence and the similarities and differences between how their bean was growing compared to others. The teacher began to introduce new language into this activity in weeks three and four, where she began to talk about pattern seeking and range, and also encouraging the children to compare their growing bean with others and with how their bean had grown over the previous few weeks.

One girl wrote in week 3: "My bean was last to grow a root but now is one of the best and biggest shoots".

Another girl wrote in week 4: "My bean has grown straight and tall and much faster than before. My bean is the nicest because it has tiny little leaves".

In this vignette, the teacher decided to focus on supporting the recording of observations over a sustained period of time in order to help the learners identify patterns in data. Because the children have their own individual bean, they form an emotional attachment with the seed as it grows; for example, many gave their beans names. This personalisation provided a motivational aspect and gave an authenticity to the activity of data gathering. From Monday to Friday, the children recorded details about the beans in their Bean Diary daily. They completed this task as they chose, with many drawing their bean, sometimes exaggerating any change and annotating, such as when the root started to develop. Many also wrote a sentence or two about how their bean had changed or how it was different to other children's beans. Sometimes children had actively sought help from the teacher with their diary and while the teacher discussed with them what they could observe that day and directed them towards noticing any differences from previous days, the children were encouraged to decide for themselves what they should note about their bean.

Giving the children responsibility for their bean growth and diary entry allowed them to use their imagination to draw together evidence and ideas about what they believed was happening as the bean grew. One boy wrote: "My bean seed looks a bit bigger today. It has been drinking up the water (in the jar)". Here we see this boy starting to make connections between his observations and making a claim about his evidence. Interestingly, few of the children noticed changes in the conditions in the jar nor mentioned anything about the water. A few children noted that the teaching assistant added water to the jars when the paper support for the beans became dry but did not connect this with what was happening to their bean.

The teacher then moves the focus from single daily observations to looking across several observations to build evidence of what is happening as the bean grows. Getting them to revisit and read their diary entries helped the children actively reflect on their observations and the changes that had taken place with their bean. Using ideas of what is similar and different helps the children understand and articulate change and how this relates to their conceptual understanding of growth. Using their imagination and possibility thinking as they considered their individual evidence from their 'bean story' alongside the stories of the others in the class, helped them notice patterns and themes leading to them making better sense of what has happened. This enables them to consider change over time and the reasons why things change and linking that with the present, allowing them to generalise to other related but different situations. Such lines of thinking provide a footing for also making connections with the future and predicting what may happen next.

In the Bean Diary and in the Racing Green Water vignette, the teacher plays a pivotal role in offering opportunities for creative development and providing scaffolding to encourage children to draw their ideas together to support science learning within these inquiry activities. They highlight ways into collecting and considering evidence for decision making within the inquiry process. While the activity is stimulated and mainly controlled by the teacher, it still fosters the emergence of student agency, allowing the learner freedom at various points to share and reflect on their own thinking and that of others. In the final vignette, for lower secondary students, we see these processes flourish as teachers more directly and explicitly pass control to their learners, while at the same time providing guidance towards a fruitful endpoint.

Vignette 3: Floating Fruit

This final vignette arose from the SAILS EU project as an aspect of the teacher development programme. The lesson was with a Year Eight class (12-year-olds) who were given a small orange and a beaker of water and asked what they might investigate with this apparatus. The teacher believed that his students may find this task difficult and that they would possibly only come up with slight variations around what might make the fruit sink or float. In fact, the learners discussed ideas in groups and seven questions emerged from the class:

1. What makes the fruit sink or float?
2. Can you make the floating fruit sink or the sinking fruit float?
3. Does floating change if you take off the skin? bake it? break it into piece?/squash it? put holes in it?
4. Why does a peeled satsuma always float the same way up?
5. Will it float differently in salt water? hot water? iced water?
6. Do all fruits float? … at the same height in the water?
7. Does changing the water depth alter how the fruit floats?

The teacher was somewhat surprised by the number and range of questions and some he had concerns about, worrying on safety grounds about the students baking an orange or using boiling water. The teacher also rejected question 4 since it was out of topic for where he hoped to take the learning. He also had some concern over questions 6 and 7 because his subject expertise informed him that the water depth did not affect how the fruit floated, plus the students only had access to oranges on the day. In the end, the teacher decided to allow questions 1, 2, 3, 5 and 7 and students (in small groups) could select which question they wanted to explore. Questions 1, 3, 5 and 7 were selected.

Each group had to come up with a reasonable method to investigate the question they had selected. They were encouraged to take some initial measurements and observations to check whether the data they were collecting was providing adequate and sufficient evidence to answer their inquiry question. Once they had checked their ideas and initial evidence with the teacher, each group proceeded to collect a set of data and analyse their results. Their findings and conclusions were shared with the whole class through 5-min group presentations in their next lesson. The teacher encouraged the class to look at some of the similarities and differences between each of the group's choices in working by asking questions such as:

This group collected more data—how did this help them in answering their inquiry question?
This group repeated some of its measurement—was that a wise move or not?
This group made its decision on three data points—was that enough evidence to answer their question?
How has this group's way of working differed from others answering the same question? Was it a better method? How would you judge that?

In this third vignette, the students' opportunity for decision making is factored into the teacher's planning from the outset, encouraging and enabling learner decision-making within all phases of the inquiry process. The stimulus of the orange and beaker of water instigates a range of 'possibility thinking' with students making connections with phenomena they have met in their everyday lives, such as 'bobbing for apples' and with ideas they had met previously in science classrooms such as floating and sinking. By pooling and discussing their ideas in groups, they were able to decide questions to investigate.

The students then move from their question to formulate ways of making measurements or observations to help them investigate whether the orange floats as they anticipate and the reasoning behind the phenomena. In this way, they identify what evidence is relevant to addressing their researchable question. They decide how to capture that evidence, how much data they might need and use these to analyse and draw conclusions.

The teacher probes for reasons and explanations in order to scaffold students' capabilities to critically review their process and their thinking. This approach challenges learners to consider how confident they are in their thinking and how their evidence supports or refutes what they claim. Such reflexivity encourages the learners to examine their beliefs, judgements and practices and go beyond the obvious. In doing this, learners can revisit their first ideas, to stand back and think creatively and, if necessary, reframe their initial thoughts and ideas and explore differently.

7.7 Discussion: Opportunities for Creative Thinking in Inquiry Classrooms

Our analysis of the three vignettes point to the pivotal role of the teacher in facilitating children's creative inquiry. In conclusion, we maintain that when teachers are helped to implement inquiry learning in science classrooms, children of different ages, gain opportunities to develop their creative thinking skills. In all three vignettes, the teacher plays a key role is offering engaging, authentic inquiry-based opportunities (Crawford, 2014). Creative thinking promotes diverse ideas, including deciding what would be relevant data, how to record data and engaging with what Crawford (2014) refers to as grappling with the evidence to draw conclusions. It is this thinking creatively and actively engaging with the processes of meaning-making that allows learners to explore novel information in new ways.

Despite reasonable agreement on the processes and aims of inquiry teaching, there remains considerable variability in the way that inquiry has been understood and operationalised within schools and reported in in the literature (Furtak et al., 2012; Jerrim et al., 2019). In many Inquiry-based science education studies, there has been an emphasis on either the types of activities learners engage in or the degree of guidance provided by teachers (Rönnebeck et al., 2016). This chapter represent a somewhat different view on inquiry in the science classroom. It centred on the children's creative thinking and the opportunities shaped by their teacher within the inquiry process, to use their imagination, consider possibilities and foster meaning-making. It took the view that inquiry-based science education centres on the children's creative thinking through opportunities shaped by their teacher, where learners begin with ideas, consider possibilities and share their thinking as they engage with activities.

The teacher enables children to use their imagination through careful planning, observation and responsivity, bringing structure to the inquiry activity. The first two vignettes are similar to what Tafoya et al. (1980) describe as structured inquiry, where the learners get the experience of investigating, yet the focus of learning is specifically on developing specific inquiry skills such as collecting data, organising data, making inferences and drawing conclusions from the evidence. In these cases, learners gain first-hand experience of working scientifically, focusing on gathering and evaluating evidence. Children are guided to make connections between things they notice in new situations and trawl through previous experiences to make connections that build and reshape ideas. Such an approach enables learners to engage in several iterations of creative thinking cycles within a structured inquiry activity, as children share their developing ideas with peers. While the locus of control still lies mainly with the teacher, there is space and encouragement for learner decision-making that is embedded into the learning process and recognised in the learning goals.

The final vignette is an example of a more open inquiry (Tafoya et al., 1980), where the locus of control resides with the learners more than the teacher. However, the teacher's role is far from passive as they must still be aware of learner intentions and actions and provide timely intervention to probe and challenge the learners' thinking processes and knowledge construction.

The three vignettes that we described and analysed in this chapter provide a small inlet into the large array of practices which teachers use to plan and implement inquiry activities that generate opportunities for science learning. Inquiry-based science activities draw on engaging scenarios to motivate learners to think creatively and actively engage with the processes of meaning-making. It encourages learners to focus on novel information in new ways, by responding imaginatively through exploration and discussion. This shapes experiences into evidence-collecting activities that informs their science meaning-making. In this way, children are able to take ideas that are new to them while moving in a direction that their teacher has steered for them; at the same time strengthening science processes that support such practices. The role of the teacher is pivotal in this journey in generating opportunities for 'possibility thinking' (Craft, 2011) within inquiry activities, with differing degrees of learner agency, and different learning foci. Such practices enable children to retain capacity, capability and enthusiasm for exploration and curiosity as they gain knowledge and confidence in science.

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Part II
Characteristics of Creative STEM Learning Environments

Chapter 8
Young Children's Creativity in the Context of STEM Learning Experiences

Christine D. Tippett and Roxana Yanez Gonzalez

8.1 Introduction

Young children's innate curiosity and disposition for exploration makes them naturally inclined to engage in science, technology, engineering, and mathematics (STEM) learning experiences. Participating in meaningful STEM experiences can positively impact young children's academic futures, providing a foundation of prior knowledge, experience, and habits of mind to tackle formal concepts introduced in later grades. In the past two decades, there has been an increasing interest in young children's learning in STEM and in the individual disciplines of science, technology, engineering and mathematics. Research on young children's creativity, however, is still quite limited, possibly due to definitions of creativity that focus on the value of innovations (Leggett, 2017). The relationship between STEM and creativity in the early years is an even more focussed, and thus more limited, area of research. In this chapter, we use the lens of creativity to reanalyse data we collected during a 2 year investigation of STEM in childcare settings. In particular, we examine aspects of children's creativity in STEM during play time while they engaged with peers and educators in a variety of indoor and outdoor settings at an urban childcare centre.

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8.2 Theoretical/Conceptual Background

Our approach to early childhood STEM education is shaped by two widely adopted theoretical and conceptual perspectives on early childhood education: constructivism and play-based learning. The first perspective, constructivism, has long been—and continues to be—highly influential in the field of early childhood education (Dietze, 2006). Vygotsky's (1978) ideas about the importance of play, active learning, socially mediated knowledge, and the role of a more knowledgeable other have had a profound effect on the field of early childhood education (Van Hoorn et al., 2011). Essential ideas that inform early childhood education across Canada (as well as globally) include the notion that all learners, even very young children, are active participants in constructing their own knowledge (Morrison, 2015). The perspective that constructivism includes "the idea that human beings learn through interactions with more competent 'others', who provide feedback to help new ways of thinking about the world" (Hesterman, 2018, p. 142) is reflected in the role of the early childhood educator as a provider of materials, support, and other experiences that enable children to acquire new competencies (Wortham, 2010). Relationships are crucial in early childhood and although the child should be at the center of the educational process, omitting the role of the educator would constitute an incomplete view (Malaguzzi, 1993). Thus, our research is in alignment with national and international constructivist perspectives on how young children learn.

The second perspective that informs our work is play-based learning, which is also in line with national and international approaches to early childhood education. Even though play can be a difficult concept to define because it comprises a wide range of activities, it can be described through key characteristics. Play is active, child-centred, process-oriented, and may involve an aspect of pretending (Henniger, 2018). Play has been recognised as sharing analogous characteristics with creativity (Saracho, 2002). Play is widely acknowledged as an essential vehicle for learning and for the development of social skills (Malaguzzi, 1993; Taylor & Boyer, 2020) and there is a global trend towards play-based learning in early childhood education (Bubikova-Moan et al., 2019; Nitecki & Wasmuth, 2017). Play can be a medium for academic learning because it can allow children to develop skills and to build on prior knowledge while interacting with others and with the environment (Pyle & Danniels, 2017). "The relationship between play and learning is complex, reciprocal, and multidimensional. The processes of play and learning stimulate one another in early childhood—re are dimensions of learning in play and dimensions of play in learning" (Hewes, 2006, p. 4). Malaguzzi (2016a) explained why a play-based learning approach is particularly appropriate in early childhood:

> [Children] want to play to test themselves and learn how to succeed in situations; make believe to create worlds and things that would be impossible otherwise. […] They imagine in order to invent, they explore in order to examine, they design and plan in order to construct, they socialise in order to ask for help and move on. (p. 239)

Play can include activities such as jumping in puddles, banging on pots and pans, building sandcastles, and telling stories, and these playful activities can support

STEM learning. More specifically, play can allow children to explore their surroundings, to develop cognitive skills, and to build spatial awareness (Barbre, 2017). Prescribed instruction following predetermined topics does not align well with play-based approaches (Moss, 2016). Instead, when adopting an emergent, play-based learning approach, educators observe children's interests, ask questions, and offer concrete and intentional learning experiences (Dietze & Kashin, 2019) and these interactions can be particularly fruitful in the context of STEM learning.

These constructivist, play-based perspectives inform our approach to STEM in early childhood. Although there is some ambiguity in the term STEM, we take the view that if educators purposefully acknowledge any two of the four disciplines in the context of a learning experience, then that learning experience can be considered STEM (Tippett & Milford, 2017). Although we view STEM as interdisciplinary in nature, we also consider each discipline separately in order to develop a finer grained understanding of the appropriateness of STEM in early childhood:

- Young children's curiosity and sense of wonder make them naturally prone to engage in simple science experiences (e.g., Eshach & Fried, 2005; National Science Teachers Association, 2014)
- Young children are surrounded by technology, whether we focus on ICT or include non-digital tools (e.g., Hartle, 2020)
- Young children naturally engage in engineering practices such as creating and manipulating objects (e.g., English, 2018: Lippard et al., 2019)
- Young children build a foundation for future learning of the highly abstract, but sequential topic of mathematics as they count, explore patterns, and discover spatial relationships, which stimulates creative thinking and reasoning (e.g., Clements & Sarama, 2020; Samara & Clements, 2009; Thiel & Perry, 2018)

Decisions about when and how to teach topics from individual disciplines or whether to integrate two or more disciplines need to include consideration of each discipline's appropriate learning trajectories (Early Childhood STEM Working Group, 2017). Furthermore, opportunities for very young children to engage in simple STEM experiences can be missed because educators may not be confident enough to take advantage of those opportunities.

Although conversations about STEM sometimes centre on economic outcomes, we focus on social and academic outcomes such as scientific literacy, whereby children develop "inquiry, problem-solving, and decision-making abilities, to become lifelong learners, and to maintain a sense of wonder about the world around them" (Council of Ministers of Education, Canada, 1997, para. 1). Because early learning environments can influence later academic success (e.g., Burger, 2010; Cortázar et al., 2020; Hadzigeorgiou, 2002), young children's positive STEM experiences can provide a foundation for elementary, secondary, and postsecondary achievement.

One way to foster positive STEM experiences could be to harness the creative affordances of STEM in the early years. Our views on creativity in early childhood more generally, and on creativity in early childhood STEM in particular, are influenced by Vygotsky (2004) who posited that creativity "is a normal and constant companion in childhood" (p. 38), which reflects the constructivist contexts within which we are working. Creativity is a complex socially mediated process in which artifacts, whether physical objects (e.g., toys, loose parts) or symbol systems (e.g., language), typically play an important role (Sawyer, 2006). Society typically values the products of creativity rather than creative potential, a viewpoint that minimises young children's "everyday forms of original thinking or problem solving" (Kupers et al., 2019, p. 104). However, Kaufman and Beghetto (2009) proposed a four-part trajectory model of creativity in which the starting point is mini-c creativity, and argued that even young children are capable of mini-c creativity. Mini-c is an active sociocultural process of building knowledge that captures the creativity inherent in transformative learning. The mini-c level of creativity helps broaden educators' conceptions so they can better nurture young children's learning.

To explore creativity in STEM, we use Murcia et al.'s (2020) 4P/A-E framework, which draws on Rhodes' (1961) 4P conceptualisation of creativity: interwoven strands of product, person, press, and process. These strands, which we refer to as aspects, were expanded into the 4P/A-E framework, which includes an aspect of place rather than press to more appropriately encompass the educational contexts that help or hinder creativity:

- Product includes the criteria that creative outcomes must be original and fit-for-purpose. For example, using an everyday item in a novel way to solve a particular problem.
- Person denotes the impetus behind the creative endeavour. For example, in early childhood the child can engaged by the educator's creativity, or the child can be demonstrating creative doing and thinking.
- Place is an enabling environment provided by the elements of resources, communication, and social emotional climate, and there are four specific indicators for each of these elements. For example, resources can include intentional provocations, stimulating materials, adequate materials for everyone, and time for creative exploration.
- Process is particularly complex component of creativity, with five elements—the A to E: agency, being curious, connecting, daring, and experimenting. There are six specific indicators for each of these five elements. For example, the element of being curious includes the indicators questioning, wondering, imagining, exploring, discovering, and engaging in "what if" thinking.

8.3 Method

In this chapter we take a particular perspective on early childhood STEM and its affordances for creativity. The data we present come from an ongoing exploratory mixed methods case study (Yin, 2014) focussing on early childhood educators and young children aged 1½–5 years old in the context of play-based STEM learning experiences. We reanalysed a dataset of STEM learning episodes collected during weekly observations and used the 4P/A-E framework as a lens to investigate creativity more fully. The 4P/A-E framework gave rise to the following questions guiding our reanalysis:

- What do children's creative STEM products look like? (Product)
- Who initiates children's creative STEM processes? (Person)
- How do environmental elements support children's creative STEM thinking? (Place)
- What are the characteristics of children's creative STEM processes? (Process)

8.3.1 Research Site and Participants

Our research site is a childcare centre located in the downtown core of Canada's fourth largest city. The non-profit, bilingual French/English centre began operation in 1982, is licensed by the Ontario Ministry of Education, and adheres to Ontario's Child Care and Early Years Act (2014). The early childhood educators at the childcare centre follow the pedagogical practices outlined in *How Does Learning Happen? Ontario's Pedagogy for the Early Years* (Ontario Ministry of Education, 2014), a document that emphasises play-based and child-directed learning, with a view of the child as competent and capable individuals who are rich in potential.

Our participants included all six educators at the center, five fulltime educators and one floater who replaces the fulltime educators during breaks. The five fulltime educators possess early childhood education diplomas (requiring two or more years of community college courses and at least three field placements) and all but one are registered with Ontario College of Early Childhood Educators. The exception is an educator whose diploma is from an out-of-province institution not recognised by the college. The floater educator has youth and childcare worker credentials. All six participating educators have extensive experience in early childhood education, with an average of 12 years working in this particular childcare centre alone.

The children who participated in our study were one group of toddlers aged 1½–2½ years old and one group of preschoolers aged 2½–5 years old. In the toddler group, we received consent from parents of all 10 children and in the preschool group, we received consent from parents of 17 of the 24 children. The toddler group—with two educators—remained together for all activities and routines during the day while the larger preschool group—with three educators remained together for most outdoor play, lunch, and nap time but separated into three groups with one educator per group during some indoor activities.

Our research partnership with the childcare centre began when we presented an introductory STEM workshop for the staff. We briefly described STEM and what it might look like for very young children. We then engaged the educators in a hands-on exploration of the STEM learning that can naturally take place when children play, using toys and materials available at the childcare centre. We discussed general strategies to support the children's learning and thinking. Following this orientation workshop, we visited the childcare centre weekly making 27 visits during the last 9 months of 2019. During the first 16 visits, we observed the toddler group and the preschool group, spending 45–55 min with each group. During the next 11 visits we observed the preschool group only, although which children were present varied, as the toddlers progressively transitioned to the preschool group.

8.3.2 Data Collection and Analysis

We collected data through observations and used an observation protocol that had a format similar to a running record (Martin, 2007) that was based on an instrument developed by Milford and Tippett (2015) and included information such as date, time, context, and notes on activities and behaviours being observed. In this protocol, we added sections on the materials used, the role of the educators, the observed STEM interests, and ideas to further the children's engagement with STEM. We also photographed activities and behaviours in order to document things that might be missed in the observational notes.

From the original data collected in the observation protocols we created an Excel spreadsheet and we included the photos and the notes to code every STEM-related episode contained in the data. Ultimately, we compiled a database of 27 observations and 143 episodes, where episodes were clearly bounded time periods during which one or more children engaged in activities and interactions that involved two or more of the STEM disciplines. Each episode was coded according to observation number, age group, and episode sequence within the observation. For example, 12TA would denote the first episode that occurred with toddlers during our 12th observation.

We conducted an initial analysis of the 143 STEM episodes in our dataset in order to identify episodes that qualified as creativity in STEM according to the 4P/A-E criterion of product. Episodes in which children demonstrated original thinking (in the mini-c sense) and created a product that was fit for purpose were deemed to be episodes of creativity in STEM. To illustrate the difference: a preschooler problem solving how to tow a wheelbarrow with his tricycle to create a trailer-type vehicle (16PA) would be an example of creativity in STEM (Fig. 8.1a), while a group of preschoolers making leaf rubbings with materials that the educator had prepared for them to explore the features of the leaves (20PC) would be an example of a STEM only episode (Fig. 8.1b). We were left with 52 creativity in STEM episodes—a high proportion considering creativity had not been our original focus for data collection.

We entered each of these 52 episodes of creativity in STEM into an Excel spreadsheet and coded according to the 4P/A-E framework, as shown in Fig. 8.2. For product, we coded all episodes, by definition, as original and fit for purpose and we also recorded the materials used and the function (purpose) of the product. For person, we first established if was an educator or child initiating the creative activity, and if it was a child we then looked more closely at creative doing and creative thinking. For place, in addition to identifying the presence of each of the three

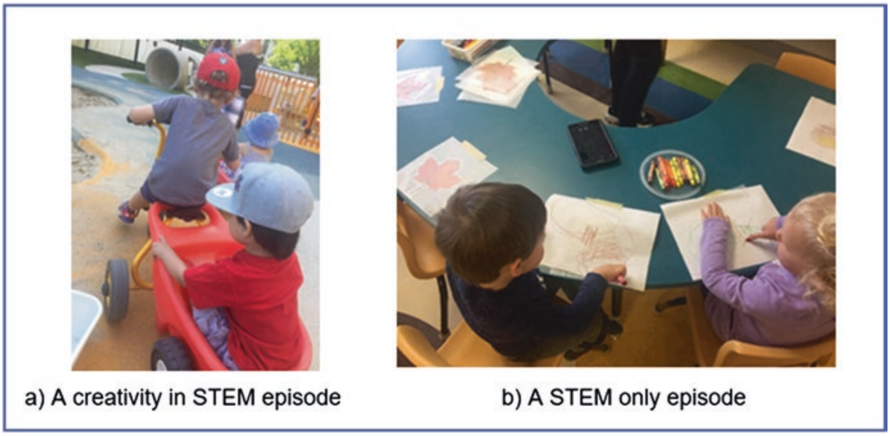

Fig. 8.1 Creativity in STEM versus STEM only episodes

	Product		Person			Place			Process				
Episode #	Original	Fit for Purpose	Child Engaged by Educator's Creativity	Child's Creative Doing	Child's Creative Thinking	Resources	Communication	Social Emotional Climate	Agency	Being Curious	Connecting	Daring	Experimenting
5PA	✓	✓		✓	✓	✓		✓	✓ACDE	✓D	✓AE	✓F	✓ACE
7PC	✓	✓		✓	✓	✓		✓	✓ACDEF	✓D	✓AF	✓BF	✓AEF
12TC	✓	✓		✓	✓	✓		✓	✓ACDEF	✓CD	✓ADE	✓F	✓ACE
23PD	✓	✓	✓	✓	✓	✓	✓	✓	✓ACDE		✓ADE	✓F	✓ADEF

Fig. 8.2 Spreadsheet showing coding for four episodes of creativity in STEM

elements of resources, communication, and social emotional climate we used a separate worksheet to note the indicators for each element in more detail. For example, under the resources indicator 'stimulating materials', we noted the range of materials that the educators made available to the children, while under the communication indicator 'open inquiry questions' we listed any specific questions that children were asked. For process, we coded each indicator for evidence of each element.

To ensure that our coding was consistent, both authors independently coded five randomly selected episodes for the aspects of person, place, and process. The aspect of product was used as the criterion for an episode being included in our creativity in STEM dataset and therefore did not require a reliability check. Thus, at the element level there were 55 coding instances to compare for rater agreement. We had nearly 93% agreement, with disagreements in only four of the 55 instances—two in communication, one in being curious, and one in connecting. These disagreements were discussed until we agreed on a final code for each instance. It is important to note that although we had high agreement at the element level, we had more disagreements at the indicator level. However, with no additional descriptors for the indicators, and with such high agreement at the element level, we decided not to focus on reliability of indicator coding at this early stage of field testing the framework.

8.4 Results

We present the results of our reanalysis of the creativity in STEM episodes according to the aspects, elements, and indicators outlined in the 4P/A-E framework. Where appropriate, we use provide an image, anecdote, or table to clarify our observations.

8.4.1 Product

Both elements of product were observed in all 52 episodes, because original and fit for purpose were our criterion for determining if a STEM episode was also an episode of creativity in STEM. Materials that we observed children playing with and making use of four or more times were boards, furniture, building blocks, sleds, and tricycles, in order of frequency from most often to least often. The purposes of the products that we observed four or more times included towing, constructing ramps, building, making circuits, and establishing personal space, again in order of frequency from most often to least often.

8.4.2 Person

In all 52 creativity in STEM episodes, there was evidence of the children's creative doing and creative thinking. In only three of the 52 episodes were the children engaged by an educator's creativity. These three episodes all arose from one single instance in which the educator modelled using a hula hoop as a skipping rope. The children later used hula hoops as rakes (Fig. 8.3a), as leaf reachers (Fig. 8.3b), and as hooks (Fig. 8.3c).

Fig. 8.3 Multiple ways to use a hula hoop

8.4.3 Place

Each of the three elements of place—resources, communication, and social emotional climate—were evident during all 52 episodes of creativity in STEM. Concerning resources, each of the four indicators was observed in every episode, because the educators provided the children with intentional provocations, placed stimulating and adequate materials for everyone, and followed a scheduled that gave children plenty of time to play (blocks of 1 h or more).

Concerning communication, the indicator 'intentional learning conversations' was only observed twice, both times when Roxana interacted with the children. We did not observe evidence of the indicator 'hearing and valuing children's ideas' although in one episode, an educator directed Roxana's attention to a group of children creating a 'water slide' with a wooden plank. In six of the 52 episodes, the educators asked 'open inquiry questions' and in two episodes it was Roxana asking those questions. None of the episodes provided evidence of the educators 'facilitating dialogic conversations'.

Concerning social emotional climate, a stress-free and pressure-free environment was observed in each of the 52 episodes. Educators responded to the children's needs, but allowed children to engage with materials without noticeable restrictions. Additionally, the educators were never observed demonstrating any kind of prescriptive or judgemental behaviours; children were allowed to explore freely and make mistakes. Only twice did we observe instances where children's activities were interrupted and, in both cases, the person who interrupted was a supply educator.

8.4.4 Process

In each of the 52 episodes of creativity in STEM, we observed all five of the elements for process, with the exception of being curious, which was observed in 35 episodes. Each element has six indicators, and the results of our coding for each process indicator are shown in Table 8.1. Example anecdotes for each of the elements, along with the indicators that we observed, are provided in Fig. 8.4 (agency), Fig. 8.5 (being curious), Fig. 8.6 (connecting), Fig. 8.7 (daring), and Fig. 8.8 (experimenting).

8.5 Discussion

Our reanalysis of previously collected data was guided by four questions that originated from the 4P/A-E framework. Thus, our discussion is structured according to the 4P/A-E framework.

Table 8.1 Process as observed in creativity in STEM episodes

Element and indicators	Observed episodes (n)
Agency	
a. Displaying self-determination	47
b. Finding relevance and personal meaning	3
c. Having a purpose	52
d. Acting with autonomy	42
e. Demonstrating personal choice and freedom	49
f. Choosing to adjust and be agile	14
Being curious	
a. Questioning	1
b. Wondering	1
c. Imagining	0
d. Explorin	35
e. Discovering	0
f. Engaging in "what if" thinking	1
Connecting	
a. Making connections	52
b. Seeing patterns in ideas	0
c. Reflecting on what is and what could be	1
d. Sharing with others	36
e. Combining ideas to form something new	43
F. Seeing different points of view	1
Daring	
a. Willing to be different	0
b. Persisting when things get difficult	18
c. Learning from failure (resilience)	0
D. Tolerating uncertainty	2
e. Challenging assumptions	0
f. Putting ideas into action	52
Experimenting	
a. Trying out new ideas	52
b. Playing with possibilities	1
c. Investigating	6
d. Tinkering and adapting ideas	25
e. Using materials differently	49
f. Solving problems	23

8.5.1 Product—What Do Children's Creative STEM Products Look Like?

For an episode to be included in our creativity dataset, there had to be an original product that was fit for purpose. Therefore all 52 episodes had evidence of product. According to our observational notes, the materials used to create the product were sometimes items that were intentionally provided by the educators as provocations (e.g., tricycles, building blocks) and other times were objects found in the environment (e.g., furniture, sticks). The most frequent intended purpose for the children's creative products included towing items (e.g., tricycles, sleds, and wheelbarrows),

A toddler took an adult by the hand, led her to the toy shed, and pointed to a wheelbarrow. He pulled the wheelbarrow backwards up a wooden ramp, then released the wheelbarrow and watched it slide down. In this episode, the element of agency stood out because the toddler initiated the exploration and conducted it entirely on his own despite being only two years old. (Indicators: displaying self-determination, having a purpose, acting with autonomy, demonstrating personal choice and freedom)

Fig. 8.4 The element of agency in an episode of creativity in STEM

Three preschoolers were playing with a bin of cars. Two of the children chose the smallest cars from the bin and used a slide as a racetrack for their little cars. As they observed the different cars roll down the slide over and over again, they were curious about which car would be the fastest. They yelled, "Mine is the fastest!" and "No, mine is the real fastest!". The third child continued to play off to one side while still observing the races. (Indicators: exploring)

Fig. 8.5 The element of being curious in an episode of creativity in STEM

After several attempts to place their balancing boards inside separate tires, two preschoolers joined forces, suspending their boards across the tires. They created a little path that they walked across and bounced up and down on, over and over again. Later, the preschoolers rearranged the boards and created a bridge between the tires using one of the balancing boards. More preschoolers joined the explorations, which lasted for more than 30 minutes. (Indicators: persisting when things get difficult, putting ideas into action)

Fig. 8.6 The element of connecting in an episode of creativity in STEM

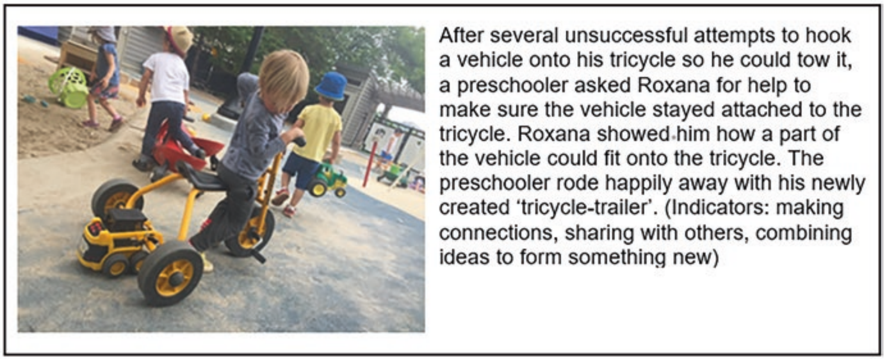

Fig. 8.7 The element of daring in an episode of creativity in STEM

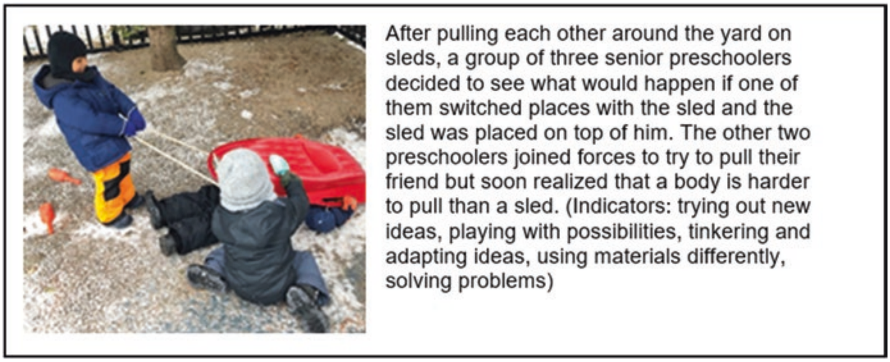

Fig. 8.8 The element of experimenting in an episode of creativity in STEM

which we found somewhat surprising, given the limited literature on young children and towing, as compared to the substantial literature on young children and ramps (e.g., Harlan & Rivkin, 2012; Lange et al., 2019; Moomaw, 2013).

8.5.2 Person—Who Initiates Children's Creative STEM Processes?

In 49 out 52 episodes the children were the ones who initiated the creative doing and the creative thinking. Only three episodes were (or appeared to be) triggered by the educator's creativity. These findings are consistent with the literature, which describes young children as possessing an innate creative confidence and being naturally adventurous and brimming with ideas (e.g., Lange et al., 2019; Robinson, 2011). However, even though the educators did not explicitly generate the episodes, they did create an environment rich in materials, time and opportunities for play, which are all essential elements for creative processes to occur (Leggett, 2017). Reunamo et al. (2014) pointed out that if creativity is flowing, then the educator does not need to interfere. The role of the educator is to provide a fruitful context for creativity to flourish.

8.5.3 Place—How Do Environmental Elements Support Children's Creative STEM Thinking?

Context is encompassed by the aspect of place in our analytical lens, which includes the three environmental elements of resources, communication, and social emotional climate. With regards to resources, in every episode of creativity in STEM, the educators selected stimulating and open-ended materials and placed them intentionally in the children's indoor and outdoor environments. The intentionality of the educators in providing appropriate resources in the environment was evident in our observational data, because the materials were different each time, tailored to the weather conditions, and appropriate for the number of children. For example, on a warm and sunny day, the educators placed several water bins and water toys around the yard; the following week, on a similarly summery day, the educators brought out the water bins and large quantities of ice cubes for the children to explore. In addition, the children were consistently given long uninterrupted blocks of time for play. Time is an essential resource in the nurturing of creative thinking because as Malaguzzi (2016b) said, "children have their own times, which are subjective and objective, but they are extraordinarily important times, and if you respect them then the children repay you with creations and learning that leave you amazed" (p. 412).

With regards to communication, we observed very few educator-initiated verbal interactions in the 52 creativity in STEM episodes, which was unexpected because in our larger dataset of STEM episodes, the educators engaged with the children in many conversations. This obvious lack of verbal communication in most creative episodes led us to question whether educators need to stop talking and take a step back in order to allow children's creative thinking to emerge. Silence can be a form of communication, although not captured in the 4P/A-E framework. In fact, Ollin (2008) has described the "complex skills of 'silent pedagogy' where the teacher makes conscious decisions to abstain from intervention based on continuous sensitive readings of the learning environment" (p. 265).

With regards to social emotional climate, our analysis of the data revealed an overall positive social emotional climate because the educators created a stress free, pressure free environment by remaining consistently attentive and responsive to the children's needs. This accepting and open social emotional climate was also free from judgement and prescription with children being allowed to take risks and make mistakes. Bazhydai and Westermann (2020) note that only in play is creativity manifested, when freedom from constraints can lead to novel actions and outcomes. We observed only two exceptions when the climate was slightly disrupted; in both cases by substitute educators due to safety concerns arising from a lack of knowledge of the children and their limits.

8.5.4 Process—What Are the Characteristics of Children's Creative STEM Processes?

The aspect of process has five elements in the 4P/A-E framework: agency, being curious, connecting, daring, and experimenting, each of which contain six indicators. Together, the elements and indicators provide a picture of the characteristics of children's' creativity during STEM. We discuss each element in turn below, making inferences about the presence, absence, and/or combination of indicators that we observed and suggesting explanations for those observations.

8.5.5 Agency

The element of process that we observed most frequently was agency, with each of the six indicators evident in most episodes and 39 out of 52 having the same four indicators: displaying self-determination, having a purpose, acting with autonomy, and demonstrating personal choice and freedom. These findings are perhaps not surprising because the educators take a play-based and constructivist pedagogical approach that positions the children as protagonists in their own learning (Ontario Ministry of Education, 2014). A play-based approach has been noted as contributing factor in the development of children's agency (e.g., Sirkko et al., 2019). Additionally, the educators created a context to support the children's agency by providing the elements of an enabling environment.

8.5.6 Being Curious

Despite the important role of curiosity in creativity, being curious was the element of process that we observed least frequently. This lack of evidence is likely due more to our data collection methods than to the children not being curious. Many of the indicators for being curious such as imagining and wondering would only be revealed through intentional interaction with the children (i.e., asking children questions about the thinking behind their actions) rather than through observations of the actions themselves. For example, the indicator what if thinking is only observable if a child says, "what if", which only happened in one episode. Our lack of evidence as gathered through observations does not mean children were not engaging in what if thinking.

8.5.7 Connecting

Although we observed the element of connecting in every episode only three of the indicators were observed frequently and in fact the indicators making connections, sharing with others, and combining ideas to form something new were usually observed in conjunction with each other appearing together in 34 out of 52 episodes. The other three indicators may not have been developmentally appropriate; for example, seeing patterns in ideas would be challenging for children in preschool who are just learning to make simple patterns with concrete objects (e.g., apple, banana, apple, banana), while seeing different points of view is a social emotional ability that preschoolers are just developing (Best Start Expert Panel on Early Learning, 2007).

8.5.8 Daring

Similarly, we observed evidence of the element of daring in all episodes, but we only observed one indicator, putting ideas into action across all episodes. We did observe the indicator persisting when things get difficult in 18 episodes. These results may be associated with the participating educators' knowledge of the benefits of risky play and their willingness to let the children test their own limits in an environment that minimised hazards (Brussoni et al., 2012). We think that risky play should be better reflected in the element of daring particularly because several of our unobserved indicators would only be evident over the long term (e.g., willing to be different, learning from failure).

8.5.9 Experimenting

Another element of process that we observed in all 52 creativity in STEM episodes was experimenting. Two indicators, trying out new ideas and using materials differently, were observed together in 49 of the 52 episodes. The important role of materials in supporting creativity is highlighted by these results and suggests the importance of educators' intentional and thoughtful use of provocations to surprise, spark discussion, and stimulate curiosity and imagination (Strong-Wilson & Ellis, 2007). The indicator playing with possibilities was only observed once, likely because it is another indicator that would be more easily identified through conversations with the children.

8.6 Implications

We share three implications from the results of our reanalysis: the importance of multiple provocations, the key role of the educator, and possible revisions of the 4P/A-E framework. Our results suggest that if educators purposefully introduce STEM provocations in a play-based environment, children will engage with those materials in ways that suggest creativity. It is important that young children are provided with multiple opportunities for meaningful interactions in their environment. Educators should consider introducing provocations that highlight the affordances of materials such as water, ramps, loose parts, plants, and wheels for promoting children's creativity, while providing STEM learning opportunities.

The importance of the role of the educator in setting up an environment in which young children's creativity can flourish cannot be overstated. Environments that are rich in materials and provide numerous opportunities for creative thinking, such as the contexts documented in our reanalysis, can support the development of creativity that might not otherwise occur. Similarly, educators need to be adept at supporting problem-finding and solving opportunities that may not arise naturally (Tegano et al., 1989) and our results suggest that indeed there is a difference between educators who are adept and educators who are not, indicating the need for professional development. The role of the educators also includes a capacity to read and react to the environment to decide when and how to interact with the children, and how to create a social emotional climate conducive to creativity.

Although our use of the 4P/A-E framework indicates that the framework in general is appropriate for analysing episodes of creativity within young children's STEM learning experiences, it also reveals some areas that could be improved as field testing continues. We found it challenging to find evidence for some of the indicators, which could be addressed by developing exemplars. The framework should not be considered as a stand-alone approach to analysis and should instead be supplemented with interviews of the educators and children being observed. Using only the framework led to a somewhat fragmented view of creativity, underplaying the potential richness of how creativity might manifest in STEM episodes. Our attempts to code for individual indicators for the elements of process, in particular, suggest that these indicators might be reconceptualised as examples rather than as specifics that need to be coded. Additionally, we noted the absence of pride and satisfaction, which is an area of social emotional development explicitly addressed in our province's early childhood pedagogical documents. Similarly, flow, which is the state of being fully focused and immersed in the creative process (Nakamura & Csikszentmihalyi, 2002) is also absent from the framework, although not from our observations.

8.7 Limitations

Our reanalysis has three main limitations: setting, data collection methods, and the analytical framework. First, we conducted our research at a single high quality, well funded centre with a low staff turnover, so our research site cannot be said to be representative of a typical childcare setting. Additionally, our findings might only be transferable to other formal early learning settings and not to less structured environments such as a group of children playing in a park. Second, we collected data through observations only and therefore we missed opportunities to examine the children's thinking processes in more depth (e.g., through interviews). Because our observations were limited to once per week for a short period of time, we can only report on these snapshots, so if a behaviour had been modeled previously, we would not know. Third, the analytical framework had not yet been widely field tested and we had to make our own interpretations of the indicators. Addressing these limitations in future research would be fairly straightforward and would be useful to advance the study of creativity in early childhood STEM.

8.8 Concluding Remarks

If we acknowledge that creativity and play are important aspects of early years education, showing that creativity occurs spontaneously during play-based STEM learning experiences helps to demonstrate that incorporating STEM in early years education is appropriate. The 4P/A-E framework has enabled us to identify the diverse ways in which young children can be creative in the context of STEM. Our preliminary findings lead us to posit that STEM can be a nurturing context rather than a limiting context for creativity. The results we share here may help researchers and practitioners to move from an intuitive understanding of creativity to a deeper and better-informed perspective of its aspects, elements, and indicators. Even though we highlight creativity in STEM, a more comprehensive understanding of creativity will support efforts to nurture creativity in other contexts. Our work shows that young children, even toddlers, are capable of engaging in complex creative thinking processes during STEM learning experiences.

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Chapter 9
‘Creatively’ Using Pre-School Children’s Natural Creativity as a Lever in STEM Learning Through Playfulness

Chrystalla Papademetri-Kachrimani and Loucas T. Louca

9.1 Introduction

In this chapter, we narrate two stories of a group of 18 five-through-seven-year-old children, participating in a STEM afternoon club, in which they were provided with meaningful opportunities for learning through dynamic interactions between ideas, objects, peers and adults. Our purpose in this chapter is to identify ways to build on children’s innate qualities of curiosity, creativity, attention and persistence (Hall et al., 2014) through play and playful learning. Towards this, we have adopted a framework underpinning internationally recognised Early Childhood Education (ECE) approaches (e.g., Reggio Emilia (RE) approach, Free Play approaches) and their Constucti-vism/onist roots. The presentation of our findings builds on the intersection between the learning culture constructed in this STEM programme and these ECE approaches.

Throughout the chapter, the idea of creativity is built on the element of tolerance of uncertainty and willingness to experiment, a quality attributed by the literature on cognitive and human development to creative people (Haberlandt, 1997; Louw, 1998). This element of creativity is highlighted by contemporary views of learning which build on the connection between creativity, learning and play. The tolerance to uncertainty and the willingness to experiment, which removes any negative connotation associated with failure and making mistakes, is highlighted within the stories narrated both in the quality of the adult as the designer and the wise leader of the activities, and the quality of the children as architects of their own learning.

In the two sections that follow we discuss how the needs of twenty-first century life have highlighted the necessity for connecting learning across disciplines in

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STEM with creativity. We then extend the discussion to include play, and discuss the way play-based learning is grounded within contemporary theories such as complexity and constructionism.

9.2 STEM Education and the Needs of the Twenty-First Century

The need for developing the creative capabilities needed to thrive in a rapidly changing world is reinforced by a growing body of research in STEM education. Since the beginning of the1990s, when it made its first appearance, STEM education continues to raise more questions than there are answers (English, 2016; Li et al., 2019b), has dealt with a lot of scepticism and critique (Li et al., 2019a), is defined in as many different ways as there are authors (Martín-Páez et al., 2019) and is often loosely defined and open to different interpretations (Li, 2018; Li et al., 2019a). Even though STEM education can be implemented and viewed in a variety of ways (English, 2016), it builds on the epistemological connection that exists between the four disciplines (Science, Technology, Engineering, Mathematics) in a manner that invests in a workforce capable of seeking understanding of how the world works and applying this understanding to improve social, economic and environmental conditions (Li, 2014; Martín-Páez et al., 2019). Additionally, STEM education promotes "team and community work, cross-disciplinary collaboration, and long-term dedication" (Li et al., 2019a). STEM education also builds on the intersection arising from different, separate and distinct domains and paradigms (e.g., modelling-based learning, investigative-based learning, problem solving, Papert's constructionism, play as an approach of ECE, complexity theory). A difficult task at hand is to decide where to start from, in order to define and describe it. Below, we build on previous similar attempts (Papademetri-Kachrimani, 2015; Papademetri & Louca, 2020) pinpointing that play might be considered as a main theme in defining this intersection. In addition, the "kindergarten-style learning is exactly what is needed to help people of all ages develop the creative capabilities needed to thrive in today's rapidly changing society" (Resnick & Robinson, 2017, p. 7).

9.3 Complexity Theory, Constructionism and Play

In proposing complexity as a theory of education, Davis and Sumara (2000) criticised their experiences as teachers in the 1980s in regards to completing yearly plans based on 'orderly, sequential, grid-like structures' concluding that this kind of planning is "easy to make, commonsensical, familiar, reassuring" (p. 822) and builds on the "pre-specification of learning outcomes and the articulation of comprehensive lesson plans" (p. 830). They acknowledge that this practice can eclipse the richness, diversity and complexity embodied in any moment of learning engagement. This reminds us of the argument against the fragmentation of knowledge which as a pedagogical practice builds on an effort to make learning easy but eventually deprives knowledge of personal meaning (Papert, 1998). "Learning, from Piaget's constructivism and Papert's constructionism perspective, is always highly connected with play" (Papademetri-Kachrimani, 2015, p. 370). Within a constructionism perspective, play is conceived "as an attitude and an approach for engaging with the world", associated with "taking risks, trying new things, and testing boundaries, tinkering, experimenting and exploring; aspects central to the creative learning process" (Resnick, 2014, p. 18). However, many of the characteristics attributed to play (e.g., freedom, spontaneity, exuberance, fun, ownership) are difficult for some teachers to handle since these "do not sit happily or naturally within a context geared to prescriptive programmers, long-term planning or summative testing" (Abbott, 1994, p. 77).

Papademetri-Kachrimani and Louca (2020) demonstrated that young children find meaning in activities in which they are doing mathematics and science as they are exposed to new ideas, abstract concepts, riddles, and problems; leading, as play does, to "hard fun-hard learning" (Papert, 1998). The stories narrated and analysed in the above study (as in the case of the stories narrated in this chapter), involved activities, which were initiated by the adult, but, nevertheless, shared characteristics of play.

It is apparent that Constructionism (as constructivism did) underlies the importance of play. However, what does Constructionism add to constructivism?

> It is now a quarter of a century since the idea of constructionism was launched by Seymour Papert – the n-word rather than the v-word, constructivism […]. While the latter idea captured nicely the psychological substrate on which all learning (irrespective of teaching) is built, the n-word sought to develop a theory of pedagogy that could foster learning. […] Constructionism symbolised a way of thinking about learning, a metaphor for the ways that human beings come to learn most effectively (Noss & Clayson, 2015, p. 285).

In underlining the constructionism roots of this paper, we would like to build on Papert's conviction "that diving into the unknown, at the cost of experiencing a momentary sense of loss, is a crucial part of learning." (Ackermann, 2004, p. 23). Similarly, Ackermann (2015) states that mindfulness and playfulness are both 'integral to human creativity and their combined role is to keep us alert, in it for surprises, and willing to look at things twice and, each time, as if for the first time!'

To draw connections among play, learning and creativity, we view young children as experts in creative learning and that kindergarten is an invention of an educational approach "that is ideally suited to the needs of the twenty-first century" (Resnick & Robinson, 2017, p. 7), that it is also ideally suited to the way children naturally learn. Thus, our argument is built on the view that the kindergarten way of learning is based on the natural and spontaneous way learning takes place from the day a child is born. Who is more expert than children in constantly learning, in dealing with the unexpected, in creating, and in playing? The answer is apparent to anyone that had the opportunity to observe children naturally learning (Papademetri-Kachrimani, 2007; Papademetri-Kachrimani, 2012). As Gopnik et al. (1999) state "what we see in a crib, is not a picture of helplessness but the 'greatest mind that has ever existed, the most powerful learning machine in the universe'". (p. 1)

9.4 Methods: Narrative Inquiry

The ability to identify the relationship between the epistemological foundations of research, and the methods employing in conducting research, is critical in order for research to be truly meaningful (Darlaston-Jones, 2007). In this study we employ narrative inquiry and autoethnography to address our aims as these share the same epistemological roots as constructionism and complexity theory. Whereas other forms of human inquiry aim to reduce uncertainty, narrative inquiry embraces multiple meanings, expanding the notion of possibility (Thomas, 2012). As in the case of the act of learning, narrative inquiry requires personal engagement and shares the property of complexity and diversity which may make it troublesome for researchers to handle. Narrative is a way of knowing by experience and originates from an interest in studying and making sense of experience, against the tendency for its fragmentation (Thomas, 2012).

In this study we use our individual stories as educator-researchers to share our experience of a culture of creative learning and play. "Narrative is a particular feature of a given cultural mileu" (Atkinson & Delamont, 2005). Since narratives are representations of human experience, in narrative research the researcher usually uses these representations to make meaning of the lives and experiences of others. Using autoethnography allows us to examine our own pedagogical practices as our "lived evocative experiences, an approach which can be an appropriate tool for research and teaching for transformative education" (Belbase et al., 2008, p. 86).

Additionally, in the case of this study, where the researcher and the narrator are the same person, the idea "that narratives have already undergone a form of analysis in the telling process" is reinforced, and the concern that "ownership of data and representation emerge as specific areas of contention in the narrative analysis debate" (Thomas, 2012, p. 213) is eliminated.

We describe the stories in this study as representations of our interpretation and analysis of that experience. We highlight the parts of the narration which pinpoint the analysis and interpretation aspect of how the experience was lived. The findings and discussion of this study evolves around the intersection we identified between (a) internationally recognised ECE approaches (e.g., RE approach, Free Play approaches) and their Constucti-vism/onist roots and (b) the learning culture constructed in this STEM programme. In the following discussion we explore emerging themes. The first is related to ways the adults in the study identified their role within the learning process. The second is related to the ways the learning stories share the same characteristics as play and therefore build on the children's curiosity and innate capability to learn.

The first story, which is described in most detail, provides evidence of both these themes. The second story adds on another important aspect, namely the ways in which the design of the activities allowed for the children to build on their innate ability to invent creative, alternative ways to explain, express, communicate and represent their understandings in STEM disciplines. This aspect reinforces the idea that "visual and graphic languages provide ways of exploring and expressing understandings of the world that are easily available to most preschoolers" (Katz, 1998, p. 35).

9.5 Participants, Context and Disciplinarity

The two stories we narrate in this chapter concern a group of 18 five to seven year-old children attending a weekly after-school STEM club. Children's prior experience in similar clubs ranged between 1 and 4 years. The STEM programme was carried out by both authors who had the responsibility of the iterative design and implementation of the activities. All implementations were videotaped with the written consent of the children's parents. Additional sources of data included the children's artefacts and representations, and the authors' reflective notes (from the design, the implementation and the reflection process itself).

Within the dynamic environment of the afternoon club, STEM education can be promoted naturally and spontaneously or/and through adult-initiated structured activities. In this sense, learning is constructed through a meaningful, balanced and negotiated interplay between various types of activities such as child-led/initiated, adult-led/initiated, and free play/structured play (Fisher, 2013; Moyles, 2010, 2012). Within this setting, STEM activities could be implemented in a variety of ways in a complementary manner. Our learning approach builts on a broad perspective of STEM education where the various forms of discipline integration co-exist in dynamic and meaningful ways. English (2016, p. 2) proposed that STEM can be approached in a disciplinary manner, as "concepts and skills are learned separately in each discipline", or in a multidisciplinary manner, as "concepts and skills are learned separately in each discipline but with a common theme", or in an interdisciplinary manner, as "closely linked concepts and skills are learned from two or more disciplines with the aim of deepening knowledge and skills" or in a transdisciplinary manner, as "knowledge and skills are learned from two or more disciplines are applied to real-world problems and projects thus helping to shape the learning experience". The stories analysed for the purposes of this chapter consist of examples of STEM adult-initiated, structured activities implemented in a disciplinary manner negotiating mathematics and science concepts respectively.

9.6 The First Narration: 'Playing with the Square Root'

The first story describes a sequence of activities (3×1 h sessions) facilitated by the first author.

The first session begun with the adult telling the children that as she was about to leave her house for their STEM club, her 9-year-old daughter asked her if she knew what a certain calculator button did and she concluded "It's a good thing that I was in a hurry because I have no idea what this button does".

The adult was about to ask the children for help. However, the children's curiosity and optimism caught her up, since one of the children suggested that if shown him the button, he could help her. The adult showed the children the button ($\sqrt{}$). After declaring ignorance, one child spontaneously said "press it". The adult pressed the button in anticipation reflecting the children's emotions. But nothing happened. "Maybe it's broken", "Maybe you didn't press it correctly", "Try again" were some of the children's responses. The adult tried again but again nothing happened. The adult asked the children whether they should press something else as well and the children suggested pressing a number.

From the numbers suggested by the children the adult chose number 50. The children directed her to press the right numbers (5, 0) and then the mysterious button. There are no words to describe the children's surprise when number 7.071067811865475 appeared. The children started reading the numbers one by one and a child noticed that there was a dot after the first number. One child said: "Maybe it's a mistake. Try again". So she tried number 50 again (after demonstrating the cancel button) but the same number appeared. The adult suggested trying a new number and she tried number 1000. The resulting number was still a long series of numerical digits, but now the dot was after the second number. "Maybe it's because the number is bigger" one child suggested. "Mm, that's a good point!", the adult replied and tried out numbers 2000 and 20 to check out the child's hypothesis.

"I still don't understand what this button does" the adult said and added "I'll try another number". She tried number '9'. Based on the results of the previous trials, the children were surprised when this time a single number ('3') appeared. One child screamed: "You did something wrong." So the adult tried 9 again but the result was the same. Now the children really looked puzzled.

At that point, the adult had a suggestion. "Why don't I give each of you a handout with all the numbers from 1 to 100 and a calculator, so that you can try out different numbers to see what happens?" After a short discussion about how the children should 'work' (trying out the numbers in the first column and writing the result on the second-result column as illustrated in Fig. 9.1) the children started working excited about the idea of 'playing' with calculators.

For the next 40 min the children were immersed. Each child was left free to try any numbers. Every time the children tried a number they would show their amazement and enjoyment in different ways (e.g., facial reactions, gestures, yells, showing each other what they found). Each time a child would find a number without a dot (integer) they would shout it out to the rest of the class. And then, most of the children would try that number out and reply "Me too". As if it was a common mission to find all the numbers that resulted an integer. Except one girl who, in opposition to the rest of the children, reacted in disappointment every time she would try a number that resulted in an integer. The only support provided by the adult was

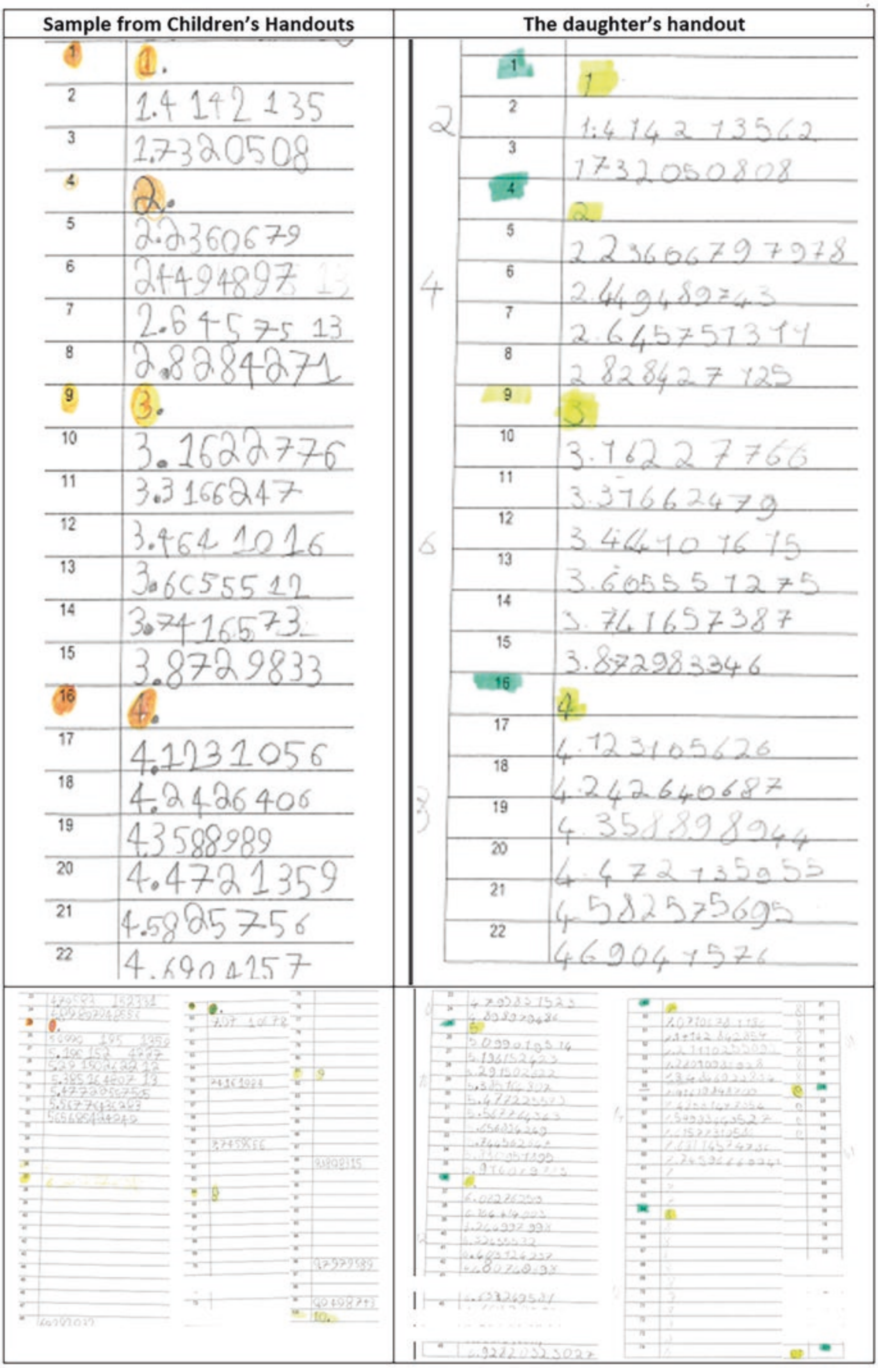

Fig. 9.1 Completed square root handouts

sharing with the group their reactions, reminding them about the cancel button and being careful when copying numbers on their handout.

At the end of the session, children were rather disappointed that they had to stop. The following week, when the children came to the session, they found their handouts and calculators waiting for them. They spontaneously spotted their own handout and started 'playing' with the calculator. When all the children arrived in the room the adult gathered them in a circle with their handouts in hand. After the children shared what they have found thus far, the adult guided their attention to the numbers which resulted an integer. She gave them highlighters and asked them to mark these numbers (see Fig. 9.1) and then encouraged them to compare their highlighted numbers with the child next to them. In cases of dispute the children tried the numbers out and corrected their handouts.

At some point one boy shouted in excitement showing highlighted numbers in the result column of his handout: "The numbers we highlighted are in order". After explaining what he meant and the rest of the children confirmed this was the case with their handouts, they all realised that they now knew which numbers were missing and by asking each other or trying out on the calculator they tried to find the missing numbers that should be highlighted.

At some point the adult interrupted the children and explained that when she returned home last time she told her daughter what had happened and her daughter asked her for a handout and tried to complete it. The adult showed the children the actual handout completed by her daughter and asked them about the numbers marked on the left hand side of the handout (see Fig. 9.1). The children carefully observed the handout and tried to figure out what these numbers meant. This resulted in two important observations: (i) a number was skipped each time (2,4,6,8, ...), (ii) the numbers were connected with the numbers of rows between the highlighted numbers. These observations led the children to conclude that they could 'guess' where the next number to be highlighted could be found. Therefore, if one child had highlighted up to number 6 he had to skip 12 rows in order to write number 7. The children would double-check this with the use of the calculator. By following this procedure all the children managed to highlight all the right rows on their handouts (Fig. 9.1).

At the beginning of the third session the adult projected a photo from something another group of children did (Fig. 9.2b, a sequence of squares) and asked them to reproduce what they saw in the photo on the magnetic board with square magnets. She then looked at what was constructed by the children (a representation of the children's constructions and the numbers which they wrote for each square is illustrated in Fig. 9.2a) and declared that the numbers reminded her of what they had done last time while giving each child his/her handout from the previous session (Fig. 9.2c). The children realised that the set of numbers highlighted on their handouts were the same set of numbers for each square they constructed. The adult waited to see if the children would spontaneously say something interesting.

A boy, made an unexpected remark: "I see the first square in the middle of the third square and the second square in the middle of the fourth square (as illustrated in 9.2a)". Since this was totally unexpected the adult had to decide whether she

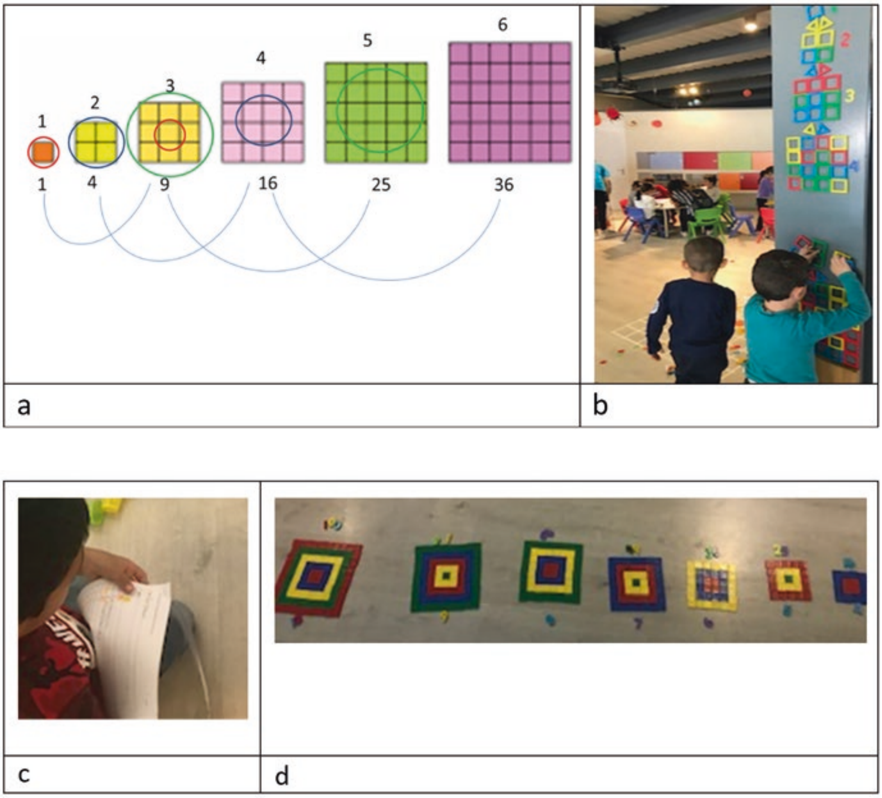

Fig. 9.2 Connecting the results from the square root handouts with squares constructed with tiles

should build on this remark or let it fade. She found it so interesting that she decided to build on it. She asked the children if they could build the squares again by using the coloured tiles they had the opportunity to play with many times in the past. She asked them if they could use the colours of the tiles (the set included tiles in 4 different colours) to show this observation. The children collaborated as a group and after approximately 15 min ended up with the squares in Figure 9.2d.

When the children finished, the following discussion took place:

Adult: How many tiles will you need to make one more square?
Child: Open the calculator …. Press 11, then the ‘and’ button, then eleven again, then the ‘and’ button and do this 11 times.
Adult: Ok. You have to count so that we make sure that I will do this 11 times…. (Number 121 appeared on the output display)
Child: We will need 121 tiles
Adult: What will happen if I write 121 on the calculator and then press the mystery button?
Child: Number 11 will appear.

Even though all of the children were following this dialogue with great attention the answers were given by the same child.

The elements of surprise and uncertainty that were vivid throughout the narration of the first story underpin the main lenses through which we view the subject of creativity in this chapter. As we indicated in the introduction, the subject of creativity is built on the element of tolerance of uncertainty and willingness to experiment, which deprives any negative connotation from failure, and making mistakes, a quality attributed to creative people. Within this narration these qualities are identified both in the adult and the children. The children fearlessly and confidently 'jumped' into the journey of discovering what the mysterious button does, ready to face unexpected situations and willing to experiment even when things did not turn out as expected. Similarly, the adult was willing to face the children's unexpected reactions and observations and lead them through routes that were not preplanned but were 'forced' by the children.

9.7 The Second Narration: 'Investigating How a Compound Dissolves in Water'

The second story took place during the investigation of how a compound dissolves in water, and had a duration of 3 × 1 h session facilitated by the second author. For the purpose of this study, the description concentrates on the second and third session which, as discussed later, adds an important aspect to the findings and discussion of the chapter. More details of the sequence of the activities can be found in Louca (2020).

The first session was focused on investigating how different substances behave in water in an attempt to operationally define the phenomenon: some substances dissolve in water (e.g., instant coffee, salt, sugar), while others do not (e.g., small rocks, beans, soil). The children worked in groups, played with water and various substances, and made drawings of their observations. They then had to decide how to group their findings; either by using the translucence of the mixture or the ability to remove the substance from the mixture with bare hands. Children, working in groups of six, were left free to identify their own criterion for their grouping, and then subsequently they shared their ideas for groupings during a whole group conversation. Two groups used the first criterion and one group the second. The whole group discussion focused on the similarities and differences between the two groupings. This conversation led to the construction of the concept of substances dissolving in water, by identifying the characteristics of the phenomenon.

In the second session, children observed and collected data from the phenomenon through a different experiment: The children placed a drop of food colouring at the bottom of a clear glass of water. Every 2 min, children recorded what they observed. Children's drawings were then displayed in sequence (Fig. 9.3) and discussed, focussing on the changes in the water. The children spontaneously started

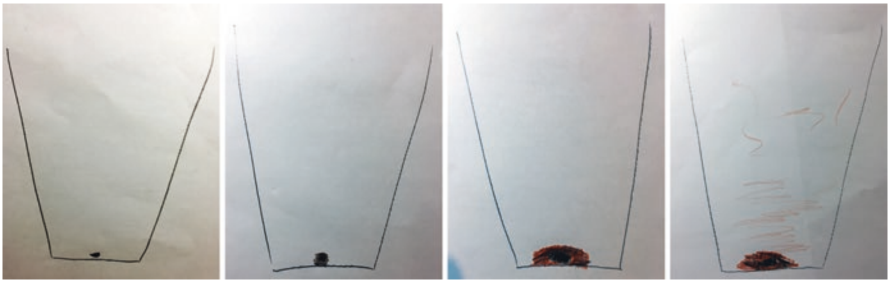

Fig. 9.3 Example of data collected in sequence about a substance dissolving in water

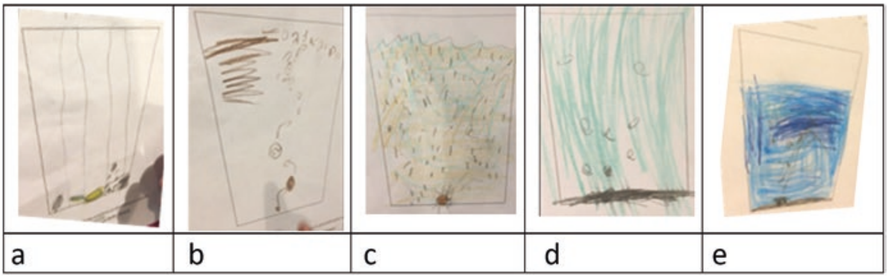

Fig. 9.4 Examples of representations developed by the children

posing questions to be investigated such as “What happens in the water?”. This was reinforced by the adult: “Suppose that you are in the water. What would you see happening?” Children then worked on drawings that would answer these questions. In the third session children presented their 18 drawings that were representations of dissolving. While reflecting on the drawings, the children were encouraged to discuss their differences and similarities.

The following discussion focusses on the five different types of representation used by the 18 children for the dissolving phenomenon. These drawings captured diverse possibilities for explaining the phenomenon and underpinned the creative ability of the children to represent, express and communicate their understandings. One representation (Fig. 9.4a; five children) described how a substance in the water becomes bigger and bigger and bigger, gets old, ‘dies’ and bursts into small ‘pieces’ (aka molecules), which are then spread in the water. As the children suggested, in the second representation (Fig. 9.4b; three children), the substance, like animals, grew up to become bigger, and bigger and bigger, and then it got old, it died, and broke up into small pieces which then swam around in the water turning the water brownish. A third representation (Fig. 9.4c; two children) suggested that the substance, like animals, grew up to become older, gave birth to babies (new substances) that they grew older and then they gave birth to their children and so on. A fourth representation (Fig. 9.4d; two children) suggested that the substance in the water infects (like an infectious disease) the water ‘pieces’ (aka molecules) around it (thus water molecules around it turn brown), which in turn infected the water molecules around them, resulting in all the water eventually becoming brown. Lastly, a fifth representation suggested that the coloured molecules got 'stuck' on water molecules, which carried them around in the water (Fig. 9.4e; six children).

In analysing the children's representations, five different representation types were used for explaining the observed phenomenon. Their attempts to explain what they observed varied, but all had the following in common. Firstly, the children looked for relevant experiences they had to develop analogies with the phenomenon under study. The children were creative in their representations and these provided a rich context for a science discussion that followed, both on the epistemological and the content level of the phenomenon under study. Children had to invent ways to make interpretations about how the phenomenon took place. It appeared that the variation amongst the different ideas provided by the children, provoked further thinking and scaffolded the development of new ideas that could possibly explain the phenomenon under study. In designing the experience, the ideas that emerged from the children could not be pre-planned, however, they were a crucial aspect of the conceptual development achieved during the activity.

9.8 Discussion

Building on the narrations of the two stories, in the following sections we elaborate how the analysis of key words and phrases allowed us to sketch the role of the adult as the designer of the learning culture. We then explore the interconnection between this learning culture and children's playful involvement in the activities. The discussion illuminates the intersection identified between internationally recognised ECE approaches (e.g., RE approach, Free Play approaches) and their Constucti-vism/onist roots and the learning culture constructed in this STEM programme.

9.8.1 The Adult as a Designer

The narration suggests that the role of the adult was crucial to the learning that took place; mostly because of the adult's willingness to keep the process open to all possibilities. This orientation differentiated the adult's role and showed how they were designing rather than planning. Planning has a linear nature (criticised by Complexity Theory), whereas design is a dynamic, evolving, cooperative, interactive and open-ended process; as stated by scholars having a Constructionism perspective, such as Martinez & Stager (2013, p. 70).

> if we focus on a handful of powerful ideas and create experiences where students naturally need to stretch their understanding, students learn more. The role of the teacher is to create and facilitate these powerful, productive contexts for learning. One simple way to do this is to make your teaching mantra 'Less Us, More Them' (LUMT). …To start making your

> classroom more student-centered, demonstrate a concept and then ask students to do something. […] LUMT may result in […] pursuing paths that may lead to unanticipated results […which are …] natural and worthwhile.

For example, in the first story, the mysterious calculator button was introduced to the children and then the children were left free to 'play' in order to investigate what this button does. Martinez & Stager (2013, p. 72) pinpoint that Constructionism should not be misunderstood as being against any direct instruction. "Being shown how to use a tool or shown a useful bit of information is fine. […] Instruction is useful for learning things […] when little benefit would be gained by investigating it yourself". This is similar to demonstrating to children the cancel button on the calculator (first narration), rather than allowing them to discover it themselves. It is the adult's role to decide when instruction is useful.

Martinez and Stager (2013) also assign the following roles to the adult in a constructionist classroom: (a) Ethnographer (identifying children's prior knowledge), (b) Documentarian (collecting evidence of children's learning as it happens), (c) Studio manager (Making resources available) and (d) Wise leader (Guiding children towards big ideas smoothly). These roles are also present in the RE Approach. The connection of Constructionism and the RE Approach was also identified by Stager (2012) since he considers it "the most outstanding implementation of constructionism" and Resnick (2007) who connects his constructionist approach to creative thinking with the RE approach. Resnick (2007, p. 5) indicates that the most impressive part of the RE approach "is the way they encourage children to reflect on what they are doing". In the second story we identified four of the main ingredients which Resnick assigns to the cycle of creative thinking: imagining (by interpreting what happened in the stories/analogies), creating (in drawing their interpretations), reflecting (in talking and comparing their interpretations) and sharing (through group discussion).

In light of the aforementioned references to the RE approach we abridge the four roles of the adult listed by Martinez and Stager (2013) to the following three.

1. *Documentarian*: In both stories the adults documented the children's thoughts and ideas in order to 'plan' for the next step. In the second story the adult analysed the children's drawings which is the essence of documentation, a realisation which allows us to connect our stories with another important aspect of the RE approach. In the RE schools, it is recognised that children have the need to communicate from the day that they are born and thus have a hundred languages in which they creatively express (Edwards et al., 2011). The inability of children often to express their ideas in words makes them inventive in using other ways to express and communicate (Papademetri, 2007). Drawing, which was the way the children represented their ideas in the second story, is one of the main languages the RE approach invests in to support children's learning (Clemens & Gleim, 2014; Edwards et al., 2011).
2. *Studio Manager*: One of the main ideas of the RE approach is the realisation of the environment as the third educator (along with the teacher and the child) (Wharton & Kinney, 2015). For example, in the first story, besides using materials

she ‘planned’ to use, the adult introduced other tools (e.g., coloured tiles) to allow the children to build on their own ideas and observations.

3. *Wise Leader:* As a wise leader the adult needs to guide children’s inquiry towards big ideas without coercion. Leading children to big ideas leads to hard learning-hard fun (Papert, 1998) and playful learning as opposed to the type of education which Resnick (2004), defines as ‘edutainment’. In both stories the children negotiated their understandings about powerful scientific phenomena (story two-how a compound dissolves in water) and mathematical ideas (story one-the square root and its connection to squares and square numbers) under the wise leadership of the adult.

These adult roles differentiate ‘planning for teaching’ from ‘designing for learning’. In planning, adults plan in advance what they will implement specifying a linear route through a number of activities that lead directly to prespecified outcomes. Alternatively, in designing, as identified in the two narrations, the planning is an ongoing process where adults create dynamic environments, introduce the children to powerful ideas and then allow them to take the lead while wisely leading them to build on their own ideas by using the powerful tool of documentation. In this process dealing with the unexpected and also creating moments of uncertainty and surprise play a crucial role and keeps the discovery mode alive.

9.8.2 Learning as Play

While there is a number of debates regarding the description of research on, and the definition of play as a human act and its relationship to learning, there is a consensus for the strong relationship between play and creativity (Waller & Davis, Waller & Davis, 2014; Goodliff et al., 2017; Proyer et al., 2019; Bateson et al., 2013).). The *Lego Foundation* research (Zosh et al., 2017; Lui et al., 2017; Parker & Thomsen, 2019; Whitebread et al., 2017) has concluded that learning through play is (a) joyful, (b) meaningful, (c) actively engaging, (d) iterative and (e) socially interactive. Additionally, we would like to refer to another set of properties recognised in play and play-based learning as documented by the stories we narrated. We suggest that play is (i) challenging, adventurous, risky and thus … rewarding; (ii) unpredictable, surprising and open to all possibilities’ (iii) immersive; (iv) spontaneous (not scripted); and has a sense of ownership and freedom (Papademetri-Kachrimani & Louca, 2020). We consider these added properties as the ‘seasoning’ that enhance the flavour of the play learning experience.

All of these added properties are important to be highlighted in a distinct manner, but are also highly connected with the previous characteristics as these are identified by the *Lego Foundation*. For example, play is joyful because it is challenging, adventurous, risky, full of surprises and open to all possibilities. Similarly, the sense of ownership and freedom engaged in play is what makes learning meaningful.

In the stories narrated, it is possible to distinguish both the main 'ingredients' as well as the 'seasoning' in the learning culture. In the first narration, we followed the children in an active, hands-on and engaging thinking journey where they were socially negotiating and constructing their understandings of the square root. This experience was meaningful and enjoyable and it involved iterative cycles of experimentation and testing of new ideas, sometimes initiated by the adult (e.g. suggesting experimentation with calculators or indicating the connection between the results of this experimentation and the construction of a sequence of squares) or the children (e.g the child's observation that he sees each square in the centre of a following square).

By further interrogating the narrations, we assert that the experiences were fun for the children because they were challenging, unpredictable and full of surprises. For example, the children's conviction that the mysterious calculator button led to a long series of numerical digits with a dot after the first and second digit, which was a surprise in the first place, collapsed when the adult tried out number nine. The children were given time to immersively experiment with the calculator and the freedom to make their own observations, which contributed to their engagement with the experience and sense of ownership. Even though the activity was adult initiated it was not strictly scripted and thus open to the children's creative thinking and proposing of possibilities. Furthermore, in the second story the children were creatively inventing ways to interpret the phenomenon under study and express or represent their interpretations which led to a variety of ideas that were not pre-planned.

Even though these two narrated stories cannot be labelled as play in the authentic manner in which free play is defined, and they describe structured activities initiated by the adult, we assert that they share the same characteristics and support children's learning and creativity in similar ways as play and thus build on a sense of playfulness.

9.9 Concluding Remarks: The Adult's Willingness

In conclusion, we would like to highlight the 'angle' from which the adult seems to be looking at the children and their perspective of the learning process. Firstly, it was apparent from both stories that the adult was willing to deal with the unexpected and viewed learning as a dive into the unknown. They were open to the many possibilities offered by the children and provided a dynamic fabric to the learning experience. Even though this willingness to explore and openness to possibilities is not something normally seen in classrooms around the globe, the idea is not new. Lawrence Stenhouse, one of the most influential figures in education and advocator of the teacher research movement in the 1970s (Fordham, 2016), argued that successful education needed to allow for a student's behavior to be unpredictable (Elliot, 1995).

In the narration stories the adults' willingness to deal with the unexpected is connected to a more general willingness to learn with, and also from the children. Learning is an active, child centred experience; so from this perspective, the educators' role is to guide and prompt rather than instruct and tell. As stated by Seymour Papert, quoted by Martinez & Stager (2013, p. 69):

> I think it's an exaggeration, but there's a lot of truth in saying that when you go to school, the trauma is that you must stop learning and you must now accept being taught.

As children move through the education system, they may stop thinking and spent a lot of their time trying to guess or understand what the teacher wants. In contrast, the stories narrated in this chapter, showed adults who were willing to listen and explore children's ideas, thus leaving room for the children to observe, think, create and construct personal meaning within the learning experience. This observation connects strongly with what the RE approach calls a pedagogy of listening, democracy, dialogue and negotiation which demands processes of documentation and design (Dahlberg, 2012; Forman & Fyfe, 1998; Rinaldi, 2011).

This idea of willingness is built on the image of the children not only as capable and innate learners, but also as active participants and shapers of their worlds. This is the essence of creativity as it intersects with constructivism and children's STEM education. Thus, what we could call a Pedagogy of Willingness leads to the need to see young children with new eyes (Clemens & Gleim, 2014).

In summary, we described our journey of seeking ways for using pre-school children's natural creativity as a lever for STEM learning. Underpinning this journey, was a perspective of creativity that included a tolerance of uncertainty and a willingness to experiment. Connections between creativity with play and playfulness were apparent in the two narration stories shared, both in the ways the adults conceived their roles and thus built on the children's ideas and the ways the children themselves creatively participated in the activities.

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Chapter 10
Characteristics of Learning Environments and Teachers' Support for Children's Creative STEM Enquiry in Japan

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10.1 Introduction

In recent years, interest in science, technology, engineering, and mathematics (STEM) in pre-school, primary, and secondary education has increased in Japan. As a result of this academic trend, the *Japan Society for STEM Education* was established in 2017. In addition, other science education-based academic associations have increased their amount of related research on the basis of competitive research grants, such as *Grants-in-Aid for Scientific Research* as supported by the *Japan Society for the Promotion of Science*. Moreover, an increasing number of books and toys oriented towards STEM for pre-schoolers and early elementary students are now displayed at bookstores and toy stores. However, some of them merely focus on a single STEM discipline, such as counting, resulting in fewer opportunities for children to be creative. It is expected that STEM enquiries in multiple STEM disciplines would provide learning opportunities for children when they try to combine different ideas to solve a problem and make something new.

The purpose of this chapter is to discuss important elements of STEM enquiries that can foster creativity (hereafter called creative STEM enquiries) from the perspectives of both environments and teachers' support by using a curriculum analysis, meta-analysis, and practice record analysis.

This study presents Japan's case for creative STEM enquiries, which emphasises comprehensive instruction under its curriculum. A report on how creative STEM

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enquiries in early childhood are being taught under this kind of curriculum could be useful for countries with similar curricular characteristics.

10.2 Background

To provide context for creative STEM enquiries in early childhood education in Japan, we discuss the major characteristics of both the curriculum and STEM enquiries, as well as situations wherein creativity has been interpreted. These situations will be used as markers of creativity in this chapter.

Historically, comprehensive instruction has been emphasised in early childhood education in Japan. Based on children's interests and curiosities, instruction is provided through children's play and activities, which are not directly related to set disciplines. Although the *National Curriculum Standards for Kindergarten* (i.e. the national pre-school curriculum; hereafter called the National Curriculum) stipulate five content domains, such as 'health', 'human relationships', 'environment', 'language', and 'expression', these domains should be treated holistically. For example, the *National Curriculum Standards for Kindergarten* explains that the learning of the curriculum's content is "delivered in a comprehensive manner through the specific activities which are developed in relation to the children's learning environment" (Ministry of Education, Culture, Sports, Science and Technology (MEXT), 2017, p. 11). That is, teachers must bear in mind that comprehensive instruction should be used for activities. This approach is a major curricular characteristic of early childhood education in Japan.

In the context of Japanese primary and secondary schools, STEM learning aims to solve complex issues in contemporary society by utilising multiple concepts and ways of thinking that originate from each of the STEM disciplines (Matsubara, 2020) rather than using a single discipline. STEM enquiries can be understood as the use of multiple perspectives or ways of thinking; namely scientific enquiry, engineering processes, and mathematical thinking (Matsubara, 2020; Otani, 2020). While each discipline-based way of thinking is important, the engineering process is focused on in this study's analysis. This is because engineering involves the extraction of an optimal solution via trial and error for a specific purpose, and is more closely related to creativity than other ways of thinking.

The definition of creativity varies, to some extent, depending on the academic field. In this study, we refer to Takahasi Makoto's general definition of creation from the *Japan Creativity Society*. Takahashi issued a questionnaire to members of the Society that asked "What is creation?" in 1983, and received definitions from 83 members. After referring to these definitions, he came up with the following: "Creation is to solve problems when people put together and integrate different kinds of information and produce a new value at the society or individual levels" (see http://www.japancreativity.jp/definition.html; translated by the authors). Regarding early childhood, children can 'solve' problems through their activities, which naturally involve play at the ECEC centres. Most children typically try to solve a problem by using creativity during early childhood. Generally, the level of creativity that can be seen in the ECEC centre setting is quite basic. Thus, in relation to creativity, children's actions that we see are expected to be simpler and the utterances we hear are expected be shorter and more limited in meaning. Considering Makoto's definition and adaptation to children's activities in the ECEC centre setting, we assume that creativity can be cultivated when we witness children's actions and/or utterances regarding the following:

1. Trying to solve a problem individually or with a group, often using different types of information.
2. Producing new things or ideas.

In the following sections, we use situations (1) and (2) as markers of creativity to determine whether or not activities that children are involved in can be regarded as activities fostering creativity. It is important to note that teachers can provide the right environment and support for such situations through STEM enquiries. In particular, engineering, which deals with trials and errors, goes well with creativity.

10.3 Elements of Creative STEM Enquiries and National Curriculum for Kindergartens

This section conducts a brief curriculum analysis to identify important elements of both environments and teachers' support that are thought to help creative STEM enquiries in early childhood education in Japan. In the curriculum analysis, our focus was on creativity and the ways of thinking about STEM enquiries, particularly those related to engineering processes. The interpretation of creativity and the major characteristics of the curriculum and STEM enquiries, as discussed above, were utilised as lenses to view descriptions of the curriculum. Regarding the procedure, a qualitative analysis was conducted to identify important elements of both environments and teachers' support that are thought to enhance creativity or STEM enquiries in descriptions of the curriculum. Two experts in STEM education and the curriculum, and one expert in early childhood education participated in the analysis. Reference was made to statements from the National Curriculum provided by the *Ministry of Education, Culture, Sports, Science and Technology* (MEXT).

10.3.1 Creativity in the Curriculum

The National Curriculum uses the term 'creativity' only once and describes it as "developing rich feelings and the ability to express oneself, and enhancing creativity by expressing experiences and thoughts in their own words" (MEXT, 2017, p. 17). This is intended to explain the meaning of the 'expression' domain, which is one of the five domains defined in the National Curriculum. The 'expression' domain's content uses the term 'creative' to signify "[children] being familiar with various materials and making use of them creatively in play" (MEXT, 2017, p. 17). The Ministry guidelines on the National Curriculum explain that this kind of experience during play is the source of creative activities (MEXT, 2018). From these descriptions, we can see that the curriculum emphasises the importance of an environment that contains various materials alongside the teachers' support to allow children to make use of these materials during play. The National Curriculum also stipulates that the seeds of creative thinking should be cultivated during early childhood (MEXT, 2017). The guidelines further state the importance of expanding children's interests through experiencing various surrounding things, and that they should keep thinking and trying, even when these things do not work well (MEXT, 2018). From these descriptions, we can see that the curriculum emphasises the importance of an environment that attracts both the children's interests and the teachers' support so as to allow the children to continue to try. For example, teachers can support children by providing enough space and time for them to keep trying when they are involved in an environment that is relevant to their interests.

Regarding environments and teachers' support, we have seen that, with a focus on creativity, the curriculum emphasises:

- Environments that contain various materials as well as teachers' support to allow children to make use of these materials during play.
- Importance of environments that attract children's interests.
- Teachers' support that allows children to continue to try.

These points will be used to organise the important elements of the creative STEM enquiries later in this chapter.

10.3.2 STEM Enquiries in the National Curriculum

STEM enquiries are not commonly understood in the field of early childhood education in Japan. One reason could be that the concept of STEM education is a relatively new idea for teachers in this field in Japan. A more important underlying reason could be that comprehensive instruction is valued, as previously explained. Many practitioners and researchers would disagree with the idea that activities in ECEC centres focus on specific disciplines such as science, arithmetic, and languages. However, while they are not explicitly described, some ways of thinking that are related to STEM enquiries can be found in the National Curriculum. They are often embedded as parts of comprehensive instruction since content is not separately described as specific disciplines.

The latest National Curriculum has incorporated perspectives and ways of thinking within pre-school education. These include becoming aware of one's environment and its significance as well as ways of engaging with it, exploring it in a trial fashion, and thinking about it (MEXT, 2017). These kinds of thought processes in early childhood education demonstrate correspondence with the seeds of engineering processes—namely, 'thinking by means of trial and error'. We can also see that the curriculum emphasises the importance of teachers' support, which allows children to explore and think by trial and error when focusing on the way of thinking shown. In addition, the descriptions of 'becoming aware of one's environment' and 'engaging with it' (one's environment) show how the curriculum emphasises the importance of the environment that children engage in as a learning content that should be relevant to both their interests and the real world.

Regarding environments and teachers' support, we have seen that, with a focus on STEM enquiries, the curriculum emphasises that:

- The environment in which children engage in as a learning content should be relevant to their interests and the real world.
- Teachers' support allows children to explore and think using trial and error.

Table 10.1 summarises the two perspectives with a focus on creativity and STEM enquiries.

This chapter uses the points emphasised by the curriculum—the various environments that are relevant to children's interests and the support for children's trial and error during play—to explore both environments and teachers' support, which are thought to help with creative STEM enquiries in early childhood education in the context of Japanese ECEC centres.

These two important elements of creative STEM enquiries will be used in the next section of the meta-analysis to review the studies that have dealt with STEM and early childhood education.

10.4 Learning Environments and Teachers' Support for Creativity in STEM

We conducted a meta-analysis of the existing studies to see how they dealt with the two aforementioned elements and explored whether they contributed to fostering creativity. One thing to note here is that the reviewed studies were not necessarily

Table 10.1 Environment and teachers' support for creative stem enquiries extracted from the national curriculum

	Environment	Teachers' support
Creativity	The environment should have various materials and teachers' support to allow children to make use of material during play. The importance of the environment attracts children's interests.	Teachers' support allows children to continue to try.
STEM enquiries	The environment that children engage in as a learning content should be relevant to both their interests and the real world.	Teachers' support allows children to explore and think by trial and error.

those that were intentionally prepared to show the relationship between the environment and/or teachers' support and creativity. To determine whether creativity is cultivated, rather than directly searching for the term 'creativity', we inferred from descriptions in the literature when we found information about children's actions and/or utterances regarding the following:

- Trying a problem individually or with a group, often using different types of information.
- Producing new things or ideas.

The analysis was conducted using the following academic journals: 1) those that cover STEM education fields in Japan; namely, *The Journal of Science Education in Japan* and *The Journal of Research in Science Education*; and 2) those that deal with pre-school education, namely *Research on Early Childhood Care and Education in Japan*, *The Journal of the International Association of Early Childhood Education*, *The Japanese Journal of Infant Care and Early Childhood Education*, and *The Japanese Journal of Historical Studies of Early Childhood Education and Care*. The analysis period was from 1989, the year of the first major revision of the National Curriculum for early childhood education, to 2019. This was because the 1989 revision was the first time that pre-schools were released from a kind of preparatory education for elementary school, which was a format that existed to a certain extent within childcare and similar facilities. The aim of the major revision was to launch independent, autonomous pre-school education. The core of the revision was the 'comprehensive instruction through play and the daily life of pre-school children' at childcare facilities and so on. While minor curriculum changes have occurred approximately every ten years since then, the 1989 revision entailed a transformation of the fundamental principles of ECEC in Japan.

A search was made for titles and subtitles in the aforementioned journals, as follows. In the journals that cover STEM education fields, the keywords were 'pre-school', 'pre-schooler' or 'child', 'kindergarten', 'day-care' or 'childcare', and 'young child'; 11 related articles were extracted from these journals. In the journals that deal with pre-school education, 43 articles that included keywords related to the STEM domain were extracted. Next, the contents of the extracted papers were reviewed, and a selection was made of those that included statements related to 'learning environment' and 'support provided by ECEC teachers' (i.e. day-care centre teachers, kindergarten teachers, etc.) within Japanese pre-school education. Thus, 25 papers were selected for analysis. There were two out of the 25 papers that included some ideas regarding the fostering of creativity, and one of them describing the 'various environments relevant to children's interests and the real world' and the other describing the 'support for children's trials and errors during play' were identified in the curriculum analysis. Each of them was given additional information provided by another paper out of the 25 papers They were summarised into two case studies: the playground environment and origami (paper folding), as shown below. Only ten out of the 25 papers mentioned one of the two important elements without describing creativity.

10.4.1 Various Environments and Trial and Error During Play for Creativity

10.4.1.1 Playground Environment

Tajiri and Takashi (2005) questionnaire survey showed that there was a relationship between the natural environment that surrounded a facility (e.g. trees to climb, trees that produced fruit or nuts) and activities involving production play and related natural phenomena. The production play here produces a new activity related to creativity. Their results showed that the various natural environments that attracted children's interest and intentional environments, such as biotopes, were effective in fostering creativity. In addition, Inoue & Takashi (2006) identified that less than ten per cent of the playground had areas such as biotopes or composting piles where natural diversity and the natural cycle could be readily displayed to children. The facilities were faced with the issue of finding ways to improve its environment in order to engage with nature as a daily sustained activity.

10.4.1.2 Origami (Paper Folding)

Origami is a traditional play activity in Japanese homes and is a typical activity at ECEC centres. Children use trial and error during origami play while teaching each other how to fold with friends and teachers, and they imitate how to fold from early childhood education-related books. In his research on origami, Fukui (2003a) stated that as children fold paper, they experience changes in shapes and dimensions (e.g. from two to three dimensions) while exploring activities that are similar to trial and error. Accordingly, children appear to set their own goals and experiment with new styles and developments during play. Fukui (2003a) proposed the need for motivation within a childcare education setting to encourage creativity. Fukui (2003b) also found that early childhood education-related books on play involving origami stressed the importance of teachers helping children to gain perspective on shapes and their construction based on an understanding of children's physical abilities and their technical and mental development.

The first case study shows that various natural environments that attract children's interests and intentional environments are effective in fostering creativity. The second case shows that when children fold paper (origami), their activities could include the use of trial and error with new goals or styles during play. Furthermore, the Fukui (2003b) study proposed the need for motivation within the childcare education setting to encourage creativity.

From the two case studies, it can be interpreted that various environments that are relevant to children's interests, as well as support for children's trial and error during play, can contribute to fostering creativity.

10.4.2 Teachers' Provision of Intentional Environments and the Use of Trial and Error

10.4.2.1 Relevant Environments to Children's Interests and the Real World

It is known that nurseries and childcare facilities with biotopes or compost piles have important educational effects including the fostering of a scientific mind, raising awareness of the importance of nature, and improving mental health and motivation (Osawa, 2006). A study on sandbox facilities discovered that a variety of play activities were performed in accordance with the component amounts of clay and silt in the sand (Takei, 2012). In a study on the relationships between facility equipment and natural materials, it was demonstrated that the characteristics of natural materials and equipment defined children's expressive acts as they played with water, sand, earth, snow, ice, and so on (Ishikura, 2012). Another study reported how the construction of a wooden deck at a facility enabled children to circulate among multiple spaces, and led to specific changes in the way that they played (Kawabe, 2006). From these studies, it can be interpreted that teachers' provision of intentional environments, such as biotopes and sandboxes, are effective for stimulating interest.

Hosaka et al. (2009) focused on activities that showed the development from the cultivation of cotton and indigo plants used for the dyeing process, which is a familiar activity in Japanese traditional lifestyles, and noted the positive use of a variety of sensory experiences. Kubo (1996) focused on the Japanese game of *Sugoroku* (a variation of 'Parcheesi'), and summarised that it aided the development of concepts regarding numbers and probability, and cultivated social skills and other such elements of educational significance. Takahashi and Kiuchi (2000) conducted a survey of illustrated children's books. They found an extremely large number of books that could give children a 'virtual' experience of interacting with nature. As such, these studies reveal how various environments are relevant to the real world.

10.4.2.2 Support for Children's Trial and Error During Play

As a study related to the support for children's trial and error, Saito (1999) focused on the importance of providing sites for children's spatial representation and expression styles. Another study examined the careful preparation of sites to stimulate thoughts and viewpoints that could serve as a basis for novel awareness (Yuzawa & Torimitsu, 2004). Minowa (2006) clarified differences in teacher intervention regarding 'hill-building', where teachers gave three- and four-year-old children specific instructions on the task, while no such instruction was provided to five-year-olds. Here, it was thought that since 'co-operative learning' could be seen among the five-year-olds, the teachers' support became harder to manifest. These studies show the importance of preparing situations for children to use trial and error.

This section shows how the two important elements of creativity have been dealt with among the existing studies and explores whether they actually contributed to fostering creativity. It can be summarised teacher's provision of various environments, as well as children's trial and error can contribute to fostering creativity.

10.5 Analysis of the Practice Record

This section presents a practice record that includes an activity that fostered children's creativity. As previously discussed, this chapter takes the position that creativity can be cultivated when we see descriptions of children's actions and/or utterances regarding two things: trying a problem individually or with a group, and producing a new thing or idea. The following practice record demonstrates that children make new things. Using the actual practice at the ECEC centre, the purpose of this section is to provide a real example of how teachers can prepare various environments that are relevant to both children's interests and the real world, and how teachers can support children's trial and error during play.

The practice record of 'pretend train play', conducted by teacher Komatsu Hukuzou and five-year-old children at Wako Kindergarten, is presented below. This practice record concerned the activity of making a train that the children could ride. After a holiday, the children came up with some ideas during a classroom discussion and shared experiences of their holiday travels, where they had the opportunity to ride various kinds of vehicles. Although this practice record is from 1975 and is relatively old, it has often been used as a good example of a holistic project activity that demonstrates pretend play (Asai, 2012; Kato, 2008; Shishido, 2008). It is reasonable to use this practice record because the activity allowed the children to engage in making something new. It is also widely recognised as a practice record that includes comprehensive instruction: a major curricular characteristic in early childhood education in Japan.

10.5.1 Practice Record at Wako Kindergarten (Komatsu, 1975)

The children asked, "How can we make a train that we can actually ride?" They started their creation through a group discussion. They came up with the idea of making trains out of cardboard and apple crates, but when they made them and got on them, the cardboard train immediately broke. The train made from the apple crate had door rollers and ran very well inside the pre-school, but when it was put out in the yard, the door rollers dug into the ground and would not move.

The children then devised an improvement plan: "Let's use something bigger, like a tricycle wheel". The teacher then went to a local waste collection company to get a tricycle and pram that had been thrown out. The next day, the children watched the teacher remove the wheels from the items. The wheels were handed over to the children, who managed to install and complete the train without the teacher's help.

The children enjoyed riding and playing with the train for a while, but their interest in playing started to seek a more realistic form, and expanded into them wanting 'to make a train that four or five people could ride together'.

Therefore, the teacher prepared three planks of wood of approximately 2 m × 30 cm. In order to make a carriage larger than the apple crate, the planks of wood had to be cut and put together. Thus, the teacher first disassembled a paper box and showed it to the children, who then realised that they needed five planks of wood, and they had several discussions about what shape they should cut the planks into. In addition, the teacher taught them how to cut the wood with a saw, and in four days, the larger train that they had longed for was complete. The story ends when the wheels were attached to complete a large, slender train. Then, using the completed large train and three other single-seater trains that had already been completed and developed into a large-scale 'pretend train play' that used the entire yard (Komatsu, 1975).

10.5.2 The Teacher's Provision of an Environment and Support for Creativity

The children initially made trains using cardboard and apple crates, which had some limitations, and then made better trains by utilising bigger wheels from abandoned items. Eventually, they completed a three-seater train that met their needs for play, thus demonstrating their creativity. This could have occurred in the environment that the teacher had intentionally prepared and supported.

The teacher had prepared some environments that were relevant to the children's interests and the real world in both the early part and the development part of the activity. As can be seen from the beginning of the practice record, the train started from the children's interest. Most probably, their holiday experiences of riding vehicles helped to grow their interest in making something that they could ride. The teacher then intentionally utilised their real experiences during the holidays, which worked well. Furthermore, when the children wanted "something bigger, like a tricycle wheel", the teacher prepared the junk tricycle and pram which they could use for the wheels. One important point to be noted here is that the preparation of the environment was conducted quickly enough before the children's interest or desire diminished. The children went through much trial and error during play while riding and making the train. Their first train made from cardboard broke when they got on it, while the apple crate train got stuck out in the yard, although it worked very well inside the pre-school. They solved the problem by utilising bigger wheels, but the train's capacity was not sufficient until they had crafted the three-seater train. In those scenes, the teacher provided support for the children's trial and error during play in good time. When the children wanted bigger wheels, the teacher not only prepared the used tricycle and pram but also provided support by removing the wheels. When they wanted to make a bigger train, the teacher showed them a basic configuration by disassembling a paper box. In addition, the teacher told them how to cut wood with a saw. One important point to be noted here is that the teacher did not teach them how to make a box but waited until the children had realised by themselves that they needed five planks of wood.

This practice record is regarded as a problem-solving project. Ohta and Asai (2012) stated that this was because the children had their own purpose and continued their creative activities due to their earnest desire and authentic interest about their own play (Ohta & Asai, 2012, p. 152).

The practice record displays how the teacher could prepare various environments that was relevant to the children's interest and the real world and shows how the teachers could support the children's trial and error during play, which lead to creative activities.

10.6 Discussion and Conclusion

This chapter discussed important elements of STEM enquiries that can foster creativity from two perspectives: environments and teachers' support. These perspectives involve various environments that are relevant to children's interests and the real world and teachers' support for children's trial and error during play, which are points that were found to be emphasised by the curriculum. These perspectives are thought to help creative STEM enquiries in early childhood education in the context of Japanese ECEC centres. The meta-analysis determined whether these points contributed to fostering creativity, and two case studies showed that various environments that were relevant to children's interests or support for children's trial and error during play could contribute to fostering their creativity. It found that some studies have stated that the intentional environments that teachers provide are effective in stimulating interest, while other studies have focused on the various environments that are relevant to the real world and seemingly implied their importance in early childhood education. The importance of preparing situations for children to use trial and error has also been addressed by several studies.

The analysis of the practice record displays a real example of how teachers can use the two perspectives successfully. One important point to be noted here is that in the practice record, the preparation of the environment had been done quickly before the children's interest or desire diminished. Therefore, providing an environment in a timely manner will increase children's chances of being creative. Another point is that the teacher waited until the children realised by themselves that they needed five planks of wood when they wanted to make a new type of train. This reminds us that the teacher's strategy of waiting for the children is very important when it comes to STEM enquiries for creativity. The teacher who implemented the practice record's activity reflected upon the practice and wrote that, "As a ECEC teacher, I needed to secure ample time and environments that enable children to repeat their trials and errors, in order to make the activities educational play not mere play, which does not sustain children's interests". (Komatsu, 1975, p. 72). Conducting STEM enquiry activities, especially when making things using trial and error, is time-consuming. However, securing ample time for children's trial and error during play is something we need to remember if we want to make children's STEM activities more creative.

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Chapter 11
Bush Kinders in Australia: A Creative Place for Outdoor STEM Learning

Coral Campbell and Chris Speldewinde

11.1 Introduction

Influenced by European and UK forest schools, Australian bush kinder programmes, are aiding in developing new approaches to early childhood education. Bush kinders take children outdoors, away from the regular indoor kindergarten premises and allow them to focus on the learning opportunities provided by nature. As these play-based sites of learning have grown (Christiansen et al., 2018), many educators have adopted 'nature pedagogy,' an approach to teaching in natural or 'wild' settings (Warden, 2015). The interaction with nature and the outdoors that bush kinders afford are beneficial for children, leading to improvements in long-term health, wellbeing and development (Elliott & Chancellor, 2014, p. 45). Bush kinders' heavy grounding in the growing field of nature pedagogy (Warden, 2015) provides opportunities to observe how "an exploration of the natural methods and practice of working with nature… sit within a set of values" (Warden, 2015, p. 35).

Many of the learning opportunities bush kinders provide fall into holistic learning and can incorporate STEM, the arts, humanities and literacy experiences for Australian early years' learners. Our research initially set out to understand how STEM learning occurs in the bush kinder yet we quickly became aware of how play offers opportunities for creativity. The children's play exhibited creativity for example the children exhibited as they learnt about the world around them from the perspectives of science, technology, engineering and mathematics. It is evident that

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creativity in children can be fostered from the early years via early childhood education (Craft, 2002; Kemple & Nissenberg, 2000) particularly as creativity facilitates children's whole development, a primary goal of early childhood education (Lowenfeld & Brittain, 1975).

Creativity, as defined in this chapter is influenced by Sternberg and Lubert (1995) who view creativity as being an ability to produce work that is both novel that is, work that is original, unexpected, imaginative and work that is appropriate that is, useful, adaptive and concerning task constraints. Creativity though, as Murcia et al. (2020) note, is complex. In this chapter, we focus on creativity generated through children's STEM experiences as the outdoor environment of the bush kinder provides strong opportunities in these areas.

This research sought to explore and gain insights into science teaching and learning in bush kinders. Through ethnography, we were able to observe and participate in the events such as those described later in this chapter, that were occurring around us. Through our ethnographic observations of science and more broadly STEM teaching and learning in bush kinders, we were able to identify a range of themes that included gender, place, pedagogy and creativity. Our experience of watching teachers and children's' creativity during bush kinder sessions drew us to posit two key themes to this chapter. Firstly, we explore how bush kinder environments provide multiple opportunities for children to develop their creativity that then enables solving of STEM problems. Then, we provide insights into how the environment enables children's creativity to develop, using current theories related to creative play. We address these two themes derived by applying research data from an ethnographic study. It takes in the voices of teachers through formal and informal interviews and observations of teaching and children's learning.

11.2 Understanding Creativity in Early Years Education

Creativity as an area of study is not new, with its origins dating back to the nineteenth century (Dovemark & Beach, 2014). Csikszentmihalyi's (1996) claim is that the term 'creative' originally meant "to bring into existence something genuinely new that is valued enough to be added to culture". Sternberg and Lubert (1995) define creativity as the ability to produce work that is both novel (original, unexpected, imaginative) and appropriate (useful, adaptive concerning task constraints). Creativity is now spoken about in terms of imagination, initiative and the unconventional (Dovemark & Beach, 2014, p. 99). Vygotsky's (2004, p. 7) notion that "any human act that gives rise to something new is referred to as a creative act" is influential as it is important not to dismiss any activity in the myriad of events which can be observed during fieldwork in an early years setting. Children's imagination is an important conduit to their creative output in real world situations. Vygotsky (2004, p. 13) confirms the importance of this connection between imagination and reality because, as he points out, "everything the imagination *creates* (emphasis added) is always based on elements taken from reality". The examples we provide later in this chapter, through teacher and our observations, allow us to see the child's imaginings for uses of what nature provides in spaces like bush kinders. These imaginings become an outlet of creativity, particularly when it comes to children building an understanding of the natural world and their own place in it.

Cropley (2014, p. 7) comments that creativity is not limited to a select few and is far from a fixed, inborn trait. Taking away toys, dolls, sporting equipment and electronic gadgets, such as what we observed in the bush kinders, compels children to use what is available to them to play (Christiansen et al., 2018). What is available in the bush kinder are aspects of the natural environment—rocks, gumnuts, parts of trees, and other material—often called "loose parts" (Elliott & Chancellor, 2014; Nicholson, 1971) and more permanent natural structures such as trees, rivulets and hillsides. The context of the bush kinder allows children to conduct investigations that scaffold children's learning and provides affordances to facilitate learning (Campbell & Speldewinde, 2020). Importantly for creativity, children can explore nature and its phenomena (Abdullah Mirzaie et al., 2009, p. 83) such as events associated with changing seasons, e.g. birds nesting, deciduous trees losing leaves, snow, that is both fun and interesting. The bush kinder takes the child away from the more structured approach of a formal kindergarten setting.

Kierwa and Veselack's (2016) investigation of how creativity occurs in outdoor classrooms provides an important background to this study as it confirms how children problem solve and construct using the materials nature provides. They view creativity as being important in maximising human potential, a sense of well-being and making a positive change to society. They provide a list of necessary elements required to support the creativity of early years' learners. There needs to be an array of natural materials; the capacity for children to 'think for themselves', problem solve, dream; have the capacity to move about freely and; have adults who support the children's efforts (Kierwa & Veselack, 2016 p. 89). Bush kinders are often places with minimal design, other than what nature provides.

The Torrance test remains as one of the favoured measures of testing for creativity. Torrance's test involves eight verbal and figural activities with written and oral responses that measure different creative abilities (Cramond et al., 2005, p. 283). Torrance's original test sought to measure four different factors of creativity when children undertook a task: (a) fluency—the number of relevant responses to the task; (b) flexibility—the number of different categories or shifts in responses to the task; (c) originality—the number of unusual yet relevant ideas as determined by statistical infrequency; and (d) elaboration—the number of details used to extend a response to the task (Torrance, 1966, 1974, 1990). Torrance (1969 as cited in Abullah Mirzaie et al., 2009, p. 82) viewed creativity as using a process of problem-sensing, then looking for solutions, hypothesising, testing and evaluating. In testing creativity in outdoor settings we devised our own tool (Fig. 10.1). In addition, the framework that Murcia et al. (2020) developed, the 'A' to 'E' of Creativity, which draws together product, person, place and process to understand how children can be creative, was used in our analysis.

11.3 Understanding Bush Kinders: Influences on Children's Creativity

Outdoor environments have been found to be influential on symbolic play, more so than indoor environments due to natural materials and spaciousness (Shin & Frost, 1995). Natural environments provide "a richness and level of complexity that is impossible to duplicate" (Stephens, 2007 as cited in Ernst, 2014, p. 97). Bohling, Saarela and Miller (2010), in their study of outdoor learning spaces, argued that designed outdoor spaces allow children to have choice with what they play with. Bush kinders are a unique site of learning in the context of Australian early years learning. Those responsible for kindergarten provision view the bush kinder environment as one response to the Australian Government's policy directive that four year old children are required to be provided with 15 hours of 'quality' preschool per week (Campbell & Speldewinde, 2019; Elliott & Chancellor, 2014). From the existing literature and our own research, it is clear that the uniqueness of this context is captured by understanding that no bush kinder is identical to any other in its appearance, size, or affordances and opportunities for learning (Campbell & Speldewinde, 2019; Christiansen et al., 2018). Bush kinder environments are also unique in Australian context of early years education in as much as they occur in a multitude of different locations ranging from open paddocks, wooded parklands and beaches, each providing specific yet wide ranging opportunities for learning and creativity to develop.

Outdoor play and physical activity had been neglected in the latter decades of the twentieth century despite the affordances that outdoor environments provide children and adolescents for learning (Fjortoft 2004; Campbell & Speldewinde, 2019). Additionally, digital technologies have promoted more sedentary play types for all ages of children. Drawing on principles from the forest school approach and with impetus from the *Australian Early Years Learning Framework* (DEEWR, 2009), Bush Kinders have gained prominence as a reaction to the reduced interaction with nature and outdoor play opportunities.

Bush kinders provide an interesting example to apply to principles of creativity. Two recent frameworks, the *PISA Framework of Creative Thinking* (OECD, 2019) and the *A To E Creativity Framework* (Murcia et al., 2020) can be considered. The PISA framework has the following components: Generation of Diverse ideas, The Generation of Creative Ideas and the Evaluate and Improve ideas. These seem very similar to the Torrance factors of Flexibility and Fluency, Originality, and Elaboration (in that order). The *A To E Creativity Framework* (Murcia et al., 2020) provides the opportunity to consider the relationships between creative outcomes (product), the child who is doing the thinking (person), the resources, environment and communication occurring (place) and the creative thinking occurring (process). The analysis to come later in this chapter will integrate these process related concepts with those of Torrance to show how children's creativity is developed and demonstrated through their bush kinder experiences.

11.4 Observing Creativity in Play

We undertook a study across 2015–2017, and in 2020 with four bush kinder sites in the Sandy Shore Shire (pseudonym) of south-eastern Australia and were interested in understanding how creativity was understood and interpreted by the qualified teachers. All bush kinder field sites observed in this research had a lead teacher and teaching assistants. The teachers involved in this study were all very experienced, with many years of regular kindergarten classroom experience; however, their experience in bush kinder sites was limited to only a few years. Groups consisted of between twenty and twenty-five children. We applied ethnography to this study (Malinowski, 2014; Tashakkori & Teddlie, 1998, 2010), becoming participant observers, taking field notes both during and reflexively after our visits to the field and conducting individual teacher interviews over several periods, regularly returning to the field over a number of years. Originating in the discipline of anthropology, ethnography acts as a collection of research methods that provide 'holistic accounts' of institutional socio-cultural contexts and practices (Siraj-Blatchford, 2010, p. 271). If children's experiences are to be understood then a need exists for 'more ethnographic research, which can paint in the fine-grained reality of educational processes within early childhood settings' (Siraj-Blatchford et al., 2001, p. 194). Ethnographic research involving children is helpful to understand evolving group memberships and dynamics (Corsaro & Molinari, 2000). In our research we were limited in how we could incorporate the children's 'voice.' We could not interview the children as we were restricted by ethics to only observe the children and collect interview data from educators and children's parents of their child's bush kinder experience.

Having initially visited the bush kinders in 2015–2016 with the intent of understanding science and STEM learning and teacher pedagogy, we returned in 2017 and 2020 with a more directed focus on creativity. In 2017, we spent many weeks observing children's play and noting children's experiences that we would classify as demonstrating the Torrance factors of fluency, flexibility, elaboration or originality. For this, we devised an observation protocol, where we collected photographs as evidence of children's creativity and noted details on the protocol. Following this, we wanted to know how the teachers viewed creativity in their approaches to STEM teaching and what it meant for the children to be creative in the bush kinder, so reviewed our earlier information on teacher pedagogy. We extended our study by further observing teachers' pedagogy in relation to creative moments, but also by explicitly asked them for their interpretations of creativity and creative play.

11.5 Bush Kinder Environments: Providing Strong Opportunities for Children's STEM Creativity

This section applies two sources of ethnographic data to allow for an understanding of the examples of creative STEM behaviour witnessed in the bush kinder and the teachers' beliefs surrounding what creativity means in bush kinders. The first of these sources allows the reader to understand how we analysed the data using a protocol template. The raw data, a collection of anecdotes and observational notes, interview transcripts, video and audio data, were documented in a template according to the following flow chart. Then we provide examples from interview with teachers how show how teachers interpret creativity in bush kinders.

With the Observation Template to organise the raw data (Fig. 11.1) and ethnography as our research methodology that included observation, listening and video capture as tools for recording creative play, we recorded over 80 instances of creative play across 26 different bush kinder sessions. We searched for the four components of the Torrance Test (fluency, flexibility, originality and elaboration) evident in children's play in activities such as construction, problem solving, and re-purposing of material and that we could categorise our raw data according to these components. Our observations included taking photographs and using the observation template that involved us at times sitting at a distance and on others being close to the activity occurring. We considered the influence of the teachers on this creative play and what the teachers' beliefs were regarding how they were influencing creativity. As children utilised the materials available to them: fallen logs, trees, loose

Creativity factors

In the table below, describe an activity which illustrates the appropriate factor Site.................................. Date.......................

fluency: the ability to produce a large number of ideas	*flexibility*: the ability to produce a large variety of ideas
elaboration: the ability to develop, embellish, or fill out an idea	*originality*: the ability to produce ideas that are unusual, statistically infrequent, not banal or obvious

Fig. 11.1 Observation template

material, wooded and open spaces to initiate and conduct play, we began to observe the teachers through the lens of pedagogical approaches and the teachers' own involvement themselves in this play.

11.6 Observing Creative Play Experiences

Developing the observation protocol was rhizomatic (Delueze & Guttari, 2004) in that it produced 'a simplistic account of very complex and multifaceted phenomena' (Strom & Martin, 2017, p. 26). It attended to, in a rhizomatic fashion, map connections and disconnections of instances of creativity between and across STEM pathways. We agreed upon the Torrance Test factors as a way to understand what we were witnessing in children's play and how the children's STEM learning was occurring. We examined many phenomena, as per the examples outlined in Fig. 11.1, that had occurred in isolation over time with the intent of showing how these STEM events were demonstrating the children's creativity. Having taken dozens of photographs and pages of notes during and after the visits to the bush kinders, we set to analysing the data. From this earlier data analysis came a table (Fig. 11.2) that would allow incidences to be categorised. One 'row' from the table is provided here as a way of the reader understanding the way we came to understand the opportunities that were arising in the bush kinder. The table columns were devoted each bush kinder and rows to visits.

Within each row, the creativity events were listed then categorised according to their fluency (the children's ability to produce a large number of STEM related ideas); flexibility (the ability to produce a large variety of STEM related ideas); elaboration (the ability to develop, embellish or fill out an idea) and; originality (the ability to produce ideas that are unusual, statistically infrequent, not banal or obvious).

Whitesands Bush kinder **Shark beach, 9am-12pm**	**Chatlock bush kinder** **8.30-10:00am or 10.30-11.30am**	**Wicklesham bush kinder** **10.30am-Noon or 9:00 am-10:00am**	**Sunrise Bush Kinder Group A** **8:45am -12:45pm**	**Jan Juc Bush Kinder Group B** **8:45am -12:45pm**
22 March 1. SCI -rock collection (colour, size), also CR – increased in size over an hour, (EL/FL) 2. CR – sand drawing, started with house, added to drawing. (EL/OR) 3. CR – sand drawing, use of directional arrows to lead to new drawing. (EL/OR) 4. CR – sand drawing body outline (not done at kinder previously). Students collectively added faces and body parts, seaweed for hair. (OR/EL)	**23 March** 1. CR – tree climbing. Unsticking oneself – (EL) 2. CR – mixing mud. Dry, so mixed water from drink bottles. (OR / EL) 3. CR- mixing mud, flattening so can draw on . (EL) 4. CR – using a tree branch as a tool to pull down another branch to reach gum nuts. (OR) 5. SCI – Gum nuts are animal (grub) homes – discovered when children opened them.	**23 March** 1. CR- Preparing an animal home. Over time, the home is added to with grass and seedpods. (EL) 2. SCI – children collecting millipedes, create 'home' for them. 3. CR – building dens, forts from material – problem solving. (EL) 4. CR – making choc cake with choc icing and selling them using grass as the money. (EL)	**1 March** 1. CR- A small group began to run around making fire engine siren type noises. (OR) 2. CR- Two boys found a long broken branch about 3 meters long and carried it around. Once it was back on the ground they tried to walk on it and the teacher mentioned 'balance'. Teacher said ' while your balancing the stick can go on the ground.' (EL)	**2 March** 1. CR- children running around pretending to be dinosaurs, making roaring noises. (FL) 2. CR- Cubby house construction. (EL) 3. CR- sticks hitting against other sticks of the cubby frame and listening to the different tones and noises. Teacher asks 'why do you think it is making different sounds?' as the children hits the sticks together. (EL/OR) 4. SCI/CR Bullants as part of the space –how far do they walk, where do they go, look at what they are carrying. (FL/EL)

Fig. 11.2 Aggregated data on creativity events

11.6.1 Vignette – Sand Drawings/Body

The three teachers and twenty children walked to the nearby beach (approximately 500 meters away) and after a short toilet and drink break, were given the freedom to use the environment for play. Two girls drew an outline of a body—bigger than themselves. The initial drawing (Fig. 11.3) was quite simple, but over time, and with time away from the drawing, the children returned three of four times to extend the drawing (Fig. 11.4). They added beach material to create facial features and sea-weed for hair. The children were evidencing and depicting science awareness of body parts and features. In terms of creativity, the children were elaborating on an initial idea—so this example was recorded as EL for elaboration. Due to the large variety of ideas they had for filling in the body features, it was also tagged as FX—flexible. Discussion with the kinder teacher indicated that the children had not undertaken similar tasks as part of their kinder learning, so the experience was also tentatively suggested as an original idea the girls had.

Fig. 11.3 Sand drawing: beginning

Fig. 11.4 Sand drawing: developing

11.6.2 *Vignette – Solving a Perplexing Problem*

When Sandy (pseudonym) arrived at bush kinder, she went to her favourite place to play. However, there was a small piece of torn animal skin and fur in her special place. She did not want it there! She did not want to pick it up with her hands either! After a few seconds looking at the fur, she left. I thought that she was going somewhere else to play but after a few minutes, she returned with two sticks from trees which she attempted to use as levers to lift the fur (Fig. 11.5). Her initial efforts did not work. One stick was too long and didn't allow her to manipulate it properly. She stopped for a few minutes and thought about her problem. She disappeared again and returned with two sticks of approximately equal length and tried again (Fig. 11.6). This time she successfully picked up the piece of fur and walked it about 20 metres away, to place into a bushy area. She returned to play in her own special place. This experience demonstrated an awareness of levers in science, properties of materials (rigidity of sticks), maths (equal lengths) and problem-solving. In terms of creativity, this was categorised as Sandy demonstrating an original idea.

When we classified our observations of the approximately hundred and twenty children across the bush kinder sites, we found that the creativity factor demonstrated the most was that of elaboration where children were able to embellish or develop an idea. Children demonstrated many original ideas—ideas that were unusual or at least unusual to them. Children's ability to produces a large number of ideas (fluency) or a large variety of different ideas (flexibility) was much lower.

Fig. 11.5 Sticks as levers

Fig. 11.6 Sticks as levers

11.6.3 What the Teachers Said About Creativity

In particular, place and person are of interest to us as bush kinder are places where toys and activities are removed from play in a bush kinder space and the children's learning and play is determined solely by what is available in the natural surroundings and the children's own imagination and creativity. As seasonal changes alter the environment, the opportunities for young children to observe and play within their surroundings also change. At the outset of building an understanding of how creativity was occurring in bush kinders, we sought to understand how the teachers defined creativity. Teachers were asked the question: "How would you describe 'Creativity' in bush kinders?" As we gathered the responses, we then sought to categorise the responses according to the Torrance test. Then as we spend more time at bush kinder, we began to frame our conversations with the Torrance test in mind. We wanted to know how the teachers viewed each of the four Test elements as sought responses in both interviews and during informal conversations. It was apparent that bush kinder teachers had distinct ideas about what was available in bush kinders to allow children to use creativity in their exploration of STEM concepts. To begin with we wanted to understand what creativity meant to bush kinder teachers:

> To me I'd say imaginative play, imaginative play…
>
> …the ability to actually be engaged the whole time they're out there without sitting.
>
> …to me means finding all those amazing, natural, loose parts…
>
> I think creativity is really prompting the kind of science…(Lucy)

We came to understand from these teacher comments that creativity had several meanings—engagement in the space by the children, the children's discoveries in nature and, confirming Vygotsky's (2004) notion, the children's use of their imagination in how they interacted with the bush kinder space. Our study began with a science learning focus, so we also sought to understand the connections teachers were making between creativity in bush kinders and science learning, one teacher remarked that:

> I think they're also creative in how they find out about their world; they know what to do how to look. They know to actually even look for things, rather than ignore them. (Allie)

With this in mind, we analysed how teachers viewed creativity in terms of fluency, flexibility, elaboration and originality.

11.6.3.1 Fluency

When it came to children creatively using the bush kinder space, the teachers were able to point to STEM play and learning that we could categorise according to their ability to produce a large number of ideas. Example such as, how children could purpose a large fallen log or use a group of feathers found on the ground showed that children can apply their imagination and develop different ideas to a resource nature has provided. Ideas that involved STEM learning which included balancing on large logs much like that of a seesaw but minutes later that same log became a rocket or airplane as different children transition in and out of one space in the bush kinder. At the next session, a week later, the log became an icecream shop. Often the same materials would be repurposed. As one teacher identified with the influx of birds at the bush kinder that:

> We've got an enormous number of feathers this year, we've got corellas everywhere and they're dropping white feathers everywhere. So we've had little hairdressing salons where the children have been using feathers in children hair and making Indian headdresses. (Amanda)

What becomes apparent is that nature's characteristics of the bush kinder and the resources available allow children to become fluent in the ideas that develop.

11.6.3.2 Flexibility

Teachers, when asked about children's ability to produce a variety of ideas, could identify flexibility as apparent in bush kinders. In one instance, a teacher saw that there were "no boundaries (unless there is a safety concern)" (Allie). The children were able to experiment and flexibility would allow for children to "pose questions and encourage different ideas. To listen and to accept all ideas and explore them"(Amanda). For example, over the duration of the research, we often observed creativity through children's cubby or play houses being imagined and constructed spontaneously. These play houses came in a variety of locations within the bush kinder space and used a variety of materials. At times, simply being under the canopy of a large tree was a play house. At other times, teams of children would cooperate to gather materials and then erect structures using fallen tree limbs and sticks and leaves. An adjacent fence became the permanent structure for yet another playhouse. The notion of a dwelling for play was one that produced a variety of ideas in the location and materials which were applied. On occasions, flexibility could be viewed as children would often roll on the ground. At times on the ground and at other times one teacher alerted us to their discussion with children:

> where they were starting from [rolling down the hill], some were starting at the midpoint of the hill whereas others where starting at the top. (Mary)

This discussion stimulated conversation between teacher and children about the physical science of force. It created a variety of ideas, again demonstrating flexibility in creativity, about the direction the children rolled, the topography of the land (was it flat or sloping?), how their body shape influenced rolling (did being curled up in a ball or stretching out influence their rolling?), and the surfaces on the hill (the amount of vegetation and avoiding small trees when rolling downwards).

11.6.3.3 Originality

Because much of bush kinder's activity involves only what nature provides and few artificial or fabricated materials, children are often left to repurpose only what is available in a bush kinder space. Children's engagement with nature and developing STEM understandings requires ideas that appear unusual or not obvious. The teachers were regularly surprised by the way children would develop ideas to problem solve. Play was open-ended, which enhanced opportunities for creativity (Cropley, 2014) and one teacher noted that "…original ideas are in abundance" (Allie).

This does mean that children become attuned to their environment. Originality was regularly required to overcome the obstacles nature puts in place such as how to climb a large tree. One teacher, indicating how originality was applied, noted that the children were:

> …looking at where they put their feet and find out the best way to get to the highest point of the tree. (Samantha)

Being able to negotiate their way up a tree led to the children coming up with novel way to climb, supporting each other and ensuring they did not fall down from high branches. The teachers themselves, initially reluctant to let children climb due to being risk-averse, eventually realised that not allowing children to climb was in fact stifling their creativity and STEM learning.

> We came to realise that we needed to allow the children to climb so they could learn to be safe. They had to be creative in how they climbed to ensure they were safe. (Mary)

Imaginary play begins to incorporate elements of STEM including mathematics that was initially not obvious and demonstrated the originality of the ideas being produced as maths began to interact with fairies and dinosaurs:

> There was a lot of maths in there with sizes and shapes like fairy rings and things like that. Just the different layers of it, and even to fairies. There was fairies came up in it as well, 'oh that's a good fairy house'. (Samantha)

> Or .. if you think of an example of Jack.. last year they'd always make a dinosaur nest every Bush Kinder session. So they'd have to build the tower that contained the nest, they'd have to find something that would be the egg. (Allie)

11.6.3.4 Elaboration

Bush kinders foster children's ability to take an idea and embellish it or develop. Children become attuned to changes in the environment around them that are instantaneous and seasonal. Being able to take ideas prevalent in STEM is an important element of developing creativity. As one teacher noted, bush kinders force children to:

> Ask 'why?' They explore the change in seasons. [They explore and want to understand] dirt changing into mud. (Samantha)

Returning to children's rolling down a hill, a teacher indicated that:

> In the Bush Kinder, we talk about ways the children roll down the hill and how some are going faster than others. (Allie)

The educators at times will scaffold play if deemed to be appropriate. Ideas are embellished when facts are sought to identify found bugs, insects, spiders and birds. Educators will support:

> filling out an idea if seen as needed to extend children's ideas and play. (Samantha)

A further example is that with the children, teachers will:

> Explore what we can see e.g. mud drying up. Where does the water go? (Amanda)

11.7 The Environment as an Enabler of Children Creativity and Creative Play

Simon Nicholson (1971, p. 30) in his paper *How NOT to Cheat Children – The Theory of Loose Parts* commented that "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." He suggested was that materials that can be moved around, designed and redesigned, and tinkered with—provide more opportunities for creative engagement than static materials and environments. Basically, the more materials there are the more children can interact with them, and each other. The environment of the bush kinder, whether it be bush, beach or open grasslands, is instrumental in enhancing children's creative play. The open-ness of the studied environments allowed for multiple interpretations of the materials on the sites and an almost immeasurable number of ways these materials could be used. For example, sand could be collected, piled, shaped, drawn on, added to, decorated, covered up and re-purposed (Fig. 11.7). A large tree limb could be a horse, a plane, a seat (Fig 11.8), a boundary, part of a cubby (Fig 11.9), a balance beam (Fig. 11.10)—unbounded by notion of 'treeness'.

11.8 Rethinking Creativity Using Different Frameworks

Sometimes it can be limiting to analyse information from one perspective, so we looked back at our data with new lenses. One of these was the application of the *A to E of Creativity Framework* (Murcia et al., 2020), the other was looking at the new PISA 'Creative Thinking Framework'. Due to its similarity to the Torrance creativity factors, and the fact that it is designed for older children, we chose not to use the PISA Framework and we limited our re-visioning only using the *A to E of Creativity Framework*

Fig. 11.7 Sand drawing

Fig. 11.8 Tree limb as a train

Fig. 11.9 Constructing a cubby house

Fig. 11.10 Tree limb as a balance beam

11.8.1 Children's Creative Play Experiences

In reviewing our 80 examples of children creative play experiences, we found that they did indeed fall into the two categories suggested by Murcia et al. (2020). Children's play was either original (aligned with Torrance's factor of 'original') or 'fit-for-purpose' where children were deliberately and intentionally engage in play that had imaginative or creative features (aligning with many instances of flexibility, fluency and elaboration). In the instances we recorded, most were related to children's creative doing or creative thinking.

11.8.2 Teachers' Pedagogy Related to Creativity

Research in pre-school classrooms has shown that teachers can adopt strategies for fostering creativity (Abdullah Mirzaie et al., 2009; Beetlestone, 1998). These strategies then become reliant on the teacher's proficiency in fostering the creativity, leading to a need for creativity training or discipline focussed training for example science-based training. There were some instances of teachers engaging children in creativity. In many cases, this exhibited itself in the scaffolding provided to the children through suggestions and questions to enhance their curiosity or promote further child exploration. Much of the teacher's pedagogy was enabled by the bush kinder setting and this linked into the 'place' notion in the *A to E Creativity Framework*

11.8.3 The Environment as an Enabler of Creativity

Both the children's creative ideas and the teacher's scaffolding of the creative play relied on the environment of the bush kinder. The bush kinder is an open environment with many materials which allow re-interpretation. There are no external materials brought into the bush kinder, so there are no pre-existing expectations of children's play. In considering the *A to E Creativity Framework,* aspects such as the resources (stimulating and adequate for all) link to children's enhancement of creative play. Teachers' and children's communications were open, with a valuing of children's ideas and learning conversations with others. The environment was non-prescriptive, with no gendered expectations or judgements made. For all children, bush kinder appeared to be value-free.

11.9 Concluding Comments

Our research initially set out to understand how children's interactions with teachers was influencing creative play and whether teachers were aware of creativity when it came to their planning and programming of children's learning in bush kinders. To assess creativity, we applied the key creativity components used in the Torrance Test for Creativity to our data (Torrance, 1966), leading to us developing a template of four creativity components by which individual creativity could be observed: fluency, flexibility, elaboration and originality.

We observed multiple examples of children displaying different creativity factors during play and interrogated how the teachers were viewing this. Our study highlighted that although teachers did not know the theoretical aspects of creativity, they recognised when children were demonstrating creativity. Often teachers linked creativity with imagination and this is a valid connection. According to Robinson (2011) imagination is considered the source of creativity where creativity involves putting your imagination to work. Teachers demonstrated a capacity to move into play to scaffold a creative instance as well as raise questions which might prompt further play. The extensive time spent in bush kinders observing play, through the lens of creativity, highlighted that bush kinders in Australia are a creative place for outdoor STEM learning.

Moving forward, as bush kinders continue to grow and flourish, opportunities will develop to further explore how children's creativity is fostered in and by the natural environment. Our research emphasised STEM teaching and learning but other learning domains can be explored. The Arts, Social Sciences such as Geography and Indigenous studies, and literacy all have their place in fostering children's creativity. The environment has already proven to be an enabler for children's creativity. Bush kinders provide an exciting challenge to educators as each site is different, no bush kinder is the same. The result of this is that each bush kinder comes with its own opportunities for teaching and challenges for teachers to develop their teaching to suit each site. There is no 'one size fits all' approach to bush kinder, what can be said is that bush kinders are a place for creative outdoor STEM learning.

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Part III
Creative Approaches to Teaching STEM

Chapter 12
Exploring an Engineering Design Process and Young Children's Creativity

Karen Murcia and Chloe Oblak

12.1 Introduction

There has been growing recognition of the importance of early childhood education for establishing foundation STEM (Science, Technology, Engineering and Mathematics) competencies and self-efficacy (Kermani & Aldemir, 2015; Murcia et al., 2018). Developing positive learning dispositions in the early years may well address the lack of interest in STEM subjects reported amongst adolescents and the decline in creativity of young children (Chapman & Vivian, 2016). In response to this challenge we conducted practitioner research that investigated how 3 and 4-year-old children attending an Australian Early Years Centre's Kindergarten, responded to the intentional inclusion of an engineering design process into integrated STEM activities. Our approach to this study was based on the assertion that engaging young children with playful learning through meaningful inquiry projects, could build confidence, and critical twenty-first century learning skills such as creativity, problem solving and communication (Murcia et al., 2020b; Howitt et al., 2011; Katz, 2010). Quality early learning experiences could potentially contribute to improving longer term STEM engagement.

The design experiment conducted in our study was based on constructivist and constructionist learning theories. We recognised that children's learning involves the sharing, negotiating and constructing of socially informed knowledge and as a teacher,

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we act as a guide rather than an instructor (Pritchard & Woollard, 2010). The learning environment explored in our study was set up to provoke children's interest and support them to actively construct their own knowledge. The teacher, who was positioned as a practitioner researcher, used an engineering process for guiding children's construction and engagement with collaborative problem-solving experiences. The teacher's role in the design experiment was to ask questions, and provoke thinking in order to support children's development of understanding. Our vision for STEM integration in the learning environment was informed by Kelley and Knowles (2016, p. 3) who explained integration as "the approach to teaching the STEM content of two or more STEM domains, bound by STEM practices within an authentic context for the purpose of connecting these subjects to enhance student learning". In addition, we also drew from authors Linder et al. (2016) and their proposed fundamental elements to quality integrated STEM learning in early childhood education. These were, pose a problem for children to solve or set a challenge, focus on processes (problem solving, critical thinking, experimentation, proof and reasoning) as children experience a STEM task and provide meaningful learning experiences where children make connections between STEM content fields and the world around them.

In this chapter we describe and analyse two learning experiences; child instigated free play building a train and a teacher guided design process experience, where children constructed a boat to transport their doll named Sally. We share the checklist of creativity indicators developed for this study that was aligned to the three stages of the design process; ideation, creation and, reflection and evaluation. This checklist was used to monitor and later analyse descriptive learning stories for indicators of children's creativity. In the discussion, we compare the occurrence of indicators of creativity across the two different types of learning experiences and consider how the design process impacted on children's development of creativity capabilities.

12.2 The E in STEM: An Engineering Design Process

STEM has become an integral part of the early childhood curriculum with science, technology and mathematics already being established learning areas in the Australian curriculum. With increasing awareness of the integrated nature of STEM education, we are also seeing engineering design processes applied through these three learning areas (Bagiati & Evangelou, 2016; Lippard et al., 2017). Researchers Kennedy and Odell (2014, p. 254) also recognised the integrated nature of learning and reported that "students have to apply the science and mathematics knowledge they learn to an engineering problem and utilise technology in finding a solution." Engineering can be defined as the practical application of scientific knowledge to solve everyday problems, whereas the engineering design process involves young children engaging in the practices of the engineering field through solving engineering problems (DiFrancesca et al., 2014). Introducing STEM projects that integrate an engineering design process have been found to impact on young children's development of a positive 'engineering identity' and build an understanding of a design process (Lottero-Perdue et al., 2016; Pantoya et al., 2015).

There is limited research identifying effective early childhood engineering pedagogies but the field is slowly growing. Researchers Lippard et al., (Lippard et al., 2017) conducted a review of published engineering research involving 3–5-year-old children. They found that engineering thinking in children was promoted through engineering education, when informed by constructivist learning theory. They also stressed the importance of intentionality and ensuring sufficient materials are provided for children to use as they create. Further to this, Murcia et al. (2020a) reported an inquiry approach to children's construction activities where teachers' open-ended questioning encouraged the participating 3 and 4-year-old children to engage in higher order thinking and creative problem-solving. These researchers reported seven stages to the design process intentionally introduced by educators into the children's learning environment (asking, imagining, creating, trying-out, improving, reflecting and reasoning). These researchers reported that the aligned nature of the teachers' inquiry questioning with a stage of the design process, provoked the children to engage and progress through to reflecting and evaluating their product and process for completing engineering design and construction tasks.

12.3 Creativity and an Engineering Design Process

Implementing engineering design processes in early childhood settings can help to foster children's creativity (Pantoya et al., 2015). Yet there has been a trend with creative experiences in early childhood classrooms where children produce identical products and lessons are adult-directed with the intention of teaching techniques instead of developing creativity in young children (Yates & Twig, 2017). This adult-directed practice may well be contributing to a decline in young children's creativity (Sternberg, 2007) as it is counter to Joy Paul Guilford's (1950) assertion that all people show varying levels of creative behaviour through inventing, designing, contriving, composing and planning. The *Torrance Tests of Creative Thinking* were informed by Guilford's seminal work and these tests are commonly used worldwide as a method for measuring children's creativity. Torrance (1977) also emphasised the importance of problem solving, creative thinking, and decision making above recall and reproduction and believes that through manipulative, exploratory and experimental activities, young children can begin to develop creative thinking.

Enablers of creative thinking in the learning environment are clearly strongly interconnected (Murcia et al., 2020b). However, it is also proposed that creative thinking is also influenced by the child's own internal enablers or resources such as "domain specific knowledge and experience, openness to new ideas and experiences, willingness to work with others and build upon others ideas, willingness to persist towards one's goals in the face of difficulty and beliefs about one's own ability to be creative and task motivation" (OECD, 2019, p. 11). These internal enablers or social and emotional capabilities are a focus of early years education (DEEWR, 2009) and could be intentionally focused on by educators during children's construction tasks and experiences with a design process.

Our rationale for exploring the impact of an engineering design process on children's creativity was further supported by Sternberg (2007) who established the notion of creativity as a habit. He proposed that creativity is not an innate characteristic, but an attitude towards life with individuals improvising and showing flexibility when problem solving. He proposed 12 keys for developing the creative habit in children, one of which is the inclusion of integrated learning with examples of mathematics, science and social studies. Therefore, we argue, that by integrating an engineering design process with STEM into early learning curriculum, children's creative experiences can become habits and a way of thinking.

12.4 Our Learning Design Experiment

Our research aim was to explore how introducing an engineering design process into young children's STEM inquiry projects could impact on their development of creativity capabilities.

12.4.1 Context and Participants

The research was conducted in a Western Australian Early Years Center locate in the metropolitan area of the state's capital, Perth. The Centre offers long day care for children aged zero to five. There are two kindergarten classrooms running in the Centre with a maximum of 26 children between the ages of 3 and 5 years in each. The kindergarten rooms are always staffed with a ratio of at least one educator to every 10 children. Our study's practitioner researcher was also the team leader in one of the kindergarten rooms. Parents and guardians of all children in her kindergarten room were invited to participate in the research. Then, from the children who had gained signed permission, a diverse group of six children (three boys and three girls) was chosen.

12.4.2 Action Research and the Design Experiment

Action research principles framed the study which was conducted in partnership with a practitioner researcher. The research programme was carried out by the practitioner (Teacher) in their kindergarten room. Using action research methods allowed us to focus on practical issues that arose in the educational setting, acting to make a change or improve practice and then collecting data as evidence of the impact of implemented actions (Creswell, 2008; Tomal, 2010). Action research is mostly conducted by teachers in their own setting with the aim to improve issues in the classroom or community as well as their own practice. As a process of inquiry, action research is cyclical in nature and allows for reflective practice (Creswell, 2008). Together with the practitioner researcher we planned a learning design experiment. She then implemented the planned actions, made observations and critically reflected on the focus children's learning and creativity. Repeated, yet evolving cycles of action were conducted and the learnings from a design experiment informed the planning of the next.

The first stage of action included observing children's self-instigated constructions and reflecting on these experiences through the project's creativity checklist. During this 2-week period, the practitioner-researcher aimed to use an inquiry questioning approach as she interacted with the children. She aimed for her questioning to be open and encouraging of the children's ideas and problem-solving actions. During the second stage of action, a scenario was presented to the children which generated a design challenge. The intentional provocation and resources introduced into the learning environment prompted the focus group of children participating in the study to apply science and mathematics concepts as they engineered solutions to problems. As part of the practitioner-researchers planning, inquiry questions were prepared which aimed to support and facilitate children's thinking and actions at each stage of the design process. The timeline of the second stage of action was kept open as it depended on how long the children took to complete the process and how far they went in developing their designs, creations and modifications resulting from testing.

12.4.3 Indicators of Creativity

During the children's learning experiences, an observational checklist was kept on hand and used to record observed indicators of creativity. The checklist was based on the three stages of design; ideation, creation and reflection and evaluation. The indicators were drawn from Guilford (1950) and Torrance's (1977) framings of creativity. Children's overarching social and emotional capabilities were also viewed as interconnected with children's creativity, so indicators were included in the checklist. These indicators were informed by the *Framework for the Assessment of Creative Thinking in PISA 2021* (OECD, 2019).

Ideation (I)

1. Asks questions
2. Challenges ideas and or assumptions
3. Proposes multiple ideas for design.
4. Considers critically a range of ideas
5. Makes connections between things that are not usually connected
6. Proposes and gives reasons for a possible solution
7. Imagines multiple uses for an object

Creation (C)

1. Establishes a purpose for their actions
2. Draws together two ideas or objects to create something new
3. Uses an object in a way other than its intended use
4. Tries out new arrangements or approaches
5. Modifies initial design
6. Generates a solution to solve a problem

Reflection & Evaluation (RE)

1. Reflects critically during the creating process
2. Reflects critically on idea and process for solving problem or constructing the product
3. Evaluates the product for its originality, effectiveness and being fit for purpose

Overarching Social and Emotional Capabilities (SE)

1. Resilience: staying with the task even when struggling and learning from previous errors.
2. Determination: intrinsically motivated to solve a problem or complete a task
3. Collaboration: Playing and learning collaboratively with peers
4. Uniqueness: Being prepared to be different
5. Openness: Being receptive to novel ideas, imagination & fantasy

12.4.4 Data Collection

Any indicators of creativity demonstrated by the focus children were recorded and dated on the prepared checklist. The children's demonstration of creativity indicators during the first stage of action were then compared with the data collected from the second stage of action to see impact of the intentional introduction of the engineering design process.

In addition, for triangulation purposes and to ensure rich and objective data, a voice recorder was used to captured dialogue and photographs were taken of children during the observed learning experiences. Further qualitative data was collected in the form of 'learning stories' which are written by educators' as critical and analytical accounts of children's experiences. Learning stories were a part of the daily practice at this Early Years Centre, as they provided evidence of children's learning and development. The practitioner-researcher also kept a reflective journal through-out the action research project which informed collaborative reflections, synthesising and analysis of the data for indicators of creativity.

12.5 Learning Stories

Critical learning episodes were identified in the cycle one and two data sets and are presented in the following two learning stories. These stories of children's learning experiences, illustrate the creativity observed during construction tasks. The first, titled "Constructing a choo-choo train" was a child-initiated play experience. The teacher observed and provided assistance as requested by the children. This learning story illustrates the design process naturally used by children. The second learning story, titled "A boat for Sally" illustrates how the teacher intentionally implemented an engineering design process and guided the children's play. Analysis of key episodes identified indicators of children's development and demonstration of creativity.

12.5.1 Cycle 1 Learning Story: Constructing a Choo-Choo Train

12.5.1.1 Introduction

Sarah and Ava were playing together with the *Mobilo* construction pieces on the mat. I asked what they were making. Sarah replied, "Something that moves on the ground. It's a train." In the *Mobilo* basket Sarah found some *Mobilo* people heads which, with Ava, they tried to link and connect. With help, they succeeded and Sarah says, "I've got a choo-choo train." Cycle 1 was a 20-min experience (Fig. 12.1 and Table 12.1).

The children's goal was clear throughout the whole activity; however, Sarah did change the initial 'design' from not connecting to having it connected as her train

Fig. 12.1 Imagining "It's just pretend"

Table 12.1 Cycle 1

Stage	Design and construction activity	Indicators of creativity (IC)
Asking	While observing the children play, I asked, "Are they all little trains or is it one big train." Sarah says "It's one big train" and starts to put them into a line like they're the carriages. "How will you make it move all together as one train?" Sarah replied. "Nothing. They drive by themselves. It's just pretend." She then says, "You know how I make it move by itself? By pushing!" Sarah then pushes the trains from the back but the train doesn't stay together and starts to come apart. Sarah says, "It's broken the train." I asked, "How are you going to fix it?" She places it back together and tries again but it keeps breaking.	Sarah could have used the typical and standard magnetic trains and tracks but instead she wanted to use the *Mobilo* to make a train and use the people as the passengers. She made connections between objects and considered their use in different ways. (I5, I7).
Imagining	I ask, "How can you make it so it doesn't keep breaking?"	The girls didn't consider possibilities or plan but rather started immediately building.
Creating	Ava says, "You can use those things." And shows us the connecting plugs. They try to attach the plugs but it's quite hard for them and Sarah says, "We're using our muscles but it won't work." Ava manages to connect them so Sarah continues to add people to new 'carriages' while Ava connects them on.	Ava and Sarah collaborated and helped each other to connect pieces for the shared goal of making a connected train (SE3). They created a solution and started to connect pieces for making their train that carried people (C6).
Trying out	I ask them how many pieces they can connect on the current plug being used and if it's better to use the plug that connects 2 or 3 pieces. Ava says 3 and Sarah says 2. Ava changes her mind and says, "Maybe 2 will work better." They try it out. Together the girls say, "That works." Ava says, "We need the number 2 one." The train now has 4 'carriages.' Ava moves the train but it keeps breaking. Ava says, "I need help, no one's helping me."	Both Ava and Sarah were trying out new arrangements, and changing their initial ideas (C4). Ava switched from using the plug with 3 connection points to the 2-point connector (C5).
Improving	I ask her what's happening. Ava says, "it keeps breaking". I ask her why it keeps breaking and she replied "it's too big." (referring to the length of the train). Sarah goes and gets a longer piece of *Mobilo*. I ask her what she's got. She says a "long train." Ava then says, "I'm not doing it, I'm going to play in the home corner." She moves away from the play but Sarah continues. She manages to connect the *Mobilo* pieces together that she couldn't do before.	Sarah showed determination and resilience, continuing to try even when her train kept breaking (SE1 & 2). By using trial and error, Sarah realised it was easier for her to connect the *Mobilo* pieces first and then add the people heads on later (C5). It wasn't Ava's initial idea to make the train and it appeared she wasn't as invested in making it work. When the train kept breaking, Ava went to play elsewhere.

(continued)

Table 12.1 (continued)

Stage	Design and construction activity	Indicators of creativity (IC)
Reflecting & Reasoning	Sarah says, "It's connected. I made it connected!" "I made my train!" she says.	Sarah evaluated her actions and stated that she had successfully connected the pieces (RE2). By putting the pieces together, she had achieved her goal and constructed a people carrying train that could be pushed and moved (RE3).

kept breaking when she would move it from the back. In the end the train design was original, effective and fit for purpose of carrying people.

12.5.2 Cycle 2 Learning Story: A Boat for Sally

12.5.2.1 Introduction

I introduced Sally the doll to the children and asked how she could get across the water trough which, we imagined to be a river. Sarah said, "could go around." I elaborated the story saying it was a very big and long river so it would be a huge walk and take too much time to go around. Ava was excited and said, "she could go on a boat." Cycle 2 went over two sessions, the first being 40 min and the second being 20 min (Figs. 12.2, 12.3 and Table 12.2).

Fig. 12.2 Creating a boat for Sally

Fig. 12.3 Improving "Sally's boat floats"

Table 12.2 Cycle 2

Stage	Design and construction activity	Indicators of creativity (IC)
Asking	I showed the children images of different types of boats on the *iPad*. Ava talked about how she had been on one of the boats I showed them. We looked at how boats move and that some needed oars and others have sails. Sarah said while pointing "they are flags that make the boat pretty." I told her they were called sails and made the boat move. I asked what pushes the boat along and she replied, "the wind and it blows big and the boat goes and floats." We then looked at pictures of boats with engines.	Sarah was making a connection between something that wasn't usually connected when saying that the sails on the boat were flags (I5). She used her imagination and shared how the sails looked like decorative flags (SE5).
Imagining	Sarah decided to make her boat like the ferry type boat, counting 4 windows and including this feature in her picture (design plan). Ava decided to make hers a paddle boat with 2 oars and included this feature in her picture. "What materials could we use to make the boats?" Ava said wood and Sarah said paper. I asked if the paper could go in the water. Ava said, "No it will rip." Sarah then said, "I know, bricks!" I asked if the bricks would float on the water or sink to the bottom and Ava said they would be "Too heavy and sink."	Sarah proposed multiple ideas for creating her boat by suggesting paper and bricks as possible construction materials (I3). Ava critically considered Sarah's ideas saying that paper could rip and the bricks could sink (I4). Sarah and Ava were collaborating, listening and to each other's ideas and talking about possibilities (SE3).

(continued)

Table 12.2 (continued)

Stage	Design and construction activity	Indicators of creativity (IC)
Creating	We went inside and looked at the different materials I had collected. The children collected a number of plastic containers of different sizes, some straws, pop sticks, string, sticky tape and masking tape. We discussed size and making sure Sally would fit and used the measuring tape to measure how long Sally was. Sarah read the tape measure as "20" and "9." I told them that Sally is 29 cm tall. We then measured how wide Sally was. At first Sarah said 33 and Ava repeated 33. When I told them it was one of those "tricky teen numbers" they paused to think and Sarah then said "13!" the children both said they need to measure how long their containers were. "Too short," Ava said about one container. They then used trial and error, using Sally the doll to see if she would fit in the containers (Fig. 12.2). Ava used two of the slurpy straws to make oars for her boat, sticking them on with sticky tape. Her boat that she made looked like her original design. Sarah decided to make her windows using masking tape on the container and drawing on them. She decided she wanted to change her design and add a sail, which after some trial and error and help from Ava, she ultimately made out of felt wrapped around a pop stick.	Both Sarah and Ava used the materials in ways other than their intended use (C3). Sarah used a plastic container to make the base of the boat, a stick and felt as the sail and made windows for decoration using masking tape. Ava also used a plastic container as the base of the boat and slurpy spoon straws as oars. Ava was also able to generate a solution to solve the problem Sarah faced making her sail (C6) Both Sarah and Ava had a purpose for their actions, measuring to see if Sally would fit into the containers (C1). They were using the materials to match their boat designs and using objects in ways other than their intended use. Ava used slurpy straws as they were the same shape as oars and Sarah used masking tape for adding on windows (C3). Sarah and Ava tried out new arrangements, first by measuring the containers, then using trial and error by placing Sally into different containers to see if she would fit (C4). They reflected while constructing, imagined different uses for materials (I7), made decisions and solved the problem of Sally not fitting into certain containers (RE1 & 2).
Trying out	We filled up the trough and tested the boats out in the water. Sally tipped backwards into the water. Ava said, "Oh no, her head!" "What's wrong with her head," I asked. "Her head keeps falling down," said Ava. We tried a few times but she kept falling in (Fig. 12.3). "Did it work Ava?" "No," she said. Sarah had her turn and Sally also fell out of her sail boat. "What do you think we need to do?" I asked. "I think we need to make it bigger," said Sarah.	Sarah and Ava tested their boats and evaluated whether they were effective and fit for purpose (RE3). They were both resilient when their initial construction didn't work and continued to seek solutions (SE1). Sarah was determined to make a boat that floats (SE2). She generated a solution to the problem of Sally tipping over into the water, and identified that they needed to make bigger boats (C6).

(continued)

Table 12.2 (continued)

Stage	Design and construction activity	Indicators of creativity (IC)
Improving	"What do we need to do to make Sally float?" "We need a bigger one," said Sarah. "Make it heavy," said Ava. "What would happen if you made it heavy?" I asked. Both children said, "Float." Sarah then said, "If it's too heavy it will sink," She then asked me if one of the containers was heavy. I asked her what she thought. "Heavy," she said. We compared the other container to Sarah's original boat by hefting and decided it was heavier. After looking at all the containers and talking with the children about their varied design options, I asked, "Are the containers too small or are they the right fit to make a boat for Sally". Ava said, "Too small." "What would happen if we made a big boat for Sally?" "Yeah!" said Ava. "A cruise ship," said Adam who was watching Sarah and Ava making their boats. Sarah said, "Let's put our boats together to make a bigger boat." Ava suggested putting oars on like on her original boat.	Sarah reflected critically about Ava's idea to make the boat heavier and recognised that an alternate idea was needed (I4, RE2). Sarah explored weight by hefting and then proposed an alternative idea which was to make the boat bigger (I6). Sarah and Ava collaborated, shared ideas and jointly considered their options (SE3). Together they tried a new approach and put their boats together to make one large boat (C4). The children joined their boats together, hence modifying their initial design (C5). They gave reasons for making one big boat and proposed the action as a solution to the problem of the original boats sinking (C6). The children are motivated to make Sally's boat float (SE2). They stayed with the task and learned from previous mistakes (SE1). By collaborating, they drew ideas together (C2), learned from one another and their shared effort was successful (SE3).
Reflecting & Reasoning	Sarah lay Sally with her head at the top of the boat but she tipped back into the water again. Sarah turned Sally around in the container and with excitement from the group, she said "Sally's boat floats." I asked, "Sarah and Ava, did you make your boat like your original design?" "No," they both said. I asked, "How is it different to your original design?" "Because we attach it and its very big," said Ava. I then asked why their original design didn't work. "Because it wasn't big enough," said Ava. "Did it work after you made the changes and made it bigger?" "Yeah," they both said.	Sarah and Ava evaluated whether their new boat floated and if it was different to their original designs (RE3). Ava was able to explain how it was different and why the first design didn't work (RE2).

Designing, creating and then testing a boat for Sally was an extended learning experience that ran over 2 days. Both children were open to novel ideas and were drawn into and contributing to the imaginary scenario of crossing a large river by boat. They were highly engaged and showed determination during the initial ideation phase, and also while creating and trying out their boats. The first part of the experience ran for over 40 min and had to be put on hold due to other demands from the day's programme.

Sarah and Ava both showed resiliency when the boats they initially created didn't carry Sally and float. After having initially running out of time, they were keen to return to the task another day and again worked collaboratively to solve the challenge. The positive energy and excitement surrounding the task drew other children to the testing of the re-designed boats.

12.6 Creative Engineers: Impact of the Design Process

The children were naturally 'engineers' as when freely playing, they were observed using their imagination, generating ideas, creating, trying out and improving their constructions as needed. However, this case study suggests that intentional teaching strategies, guided by a design process did enhance opportunities for children's development and demonstration of indicators of creativity.

12.6.1 Children's Demonstration of Creativity Indicators

The frequency of children's creativity indicators observed in Cycle 1 and Cycle 2 learning experiences is presented in Table 12.3. It was evident in Cycle 2, when the Teacher intentionally introduced the design process and an inquiry questioning strategy that the children were not only engaged for a longer period of time, but importantly they were also demonstrating more indicators of creativity.

It is evident in this summary of indicators of creativity that the children were demonstrating higher order thinking throughout Cycle 2, as there were more incidences of them reflecting on their activity and evaluating the relative success of their constructions. This would suggest that the use of open-ended inquiry questions aligned intentionally to each stage of the engineering design process not only extended the time children stayed engaged with the experience but also their level of thinking.

During Cycle 1, the practitioner-researcher observed the children and what they were creating, only asking a few questions to understand what they were doing and why. With the inclusion of the engineering design process and aligned inquiry questioning in Cycle 2 she became more confident and asked questions to intentionally promote the children's thinking and learning. Throughout the learning experience she avoided telling the children what to do, and encouraged them to take the lead in

Table 12.3 Children's demonstration of creativity indicators

	Cycle 1: Train		Cycle 2: Boat	
Indicator	Sarah	Ava	Sarah	Ava
Ideation (I)				
1				
2				
3			1	1
4			1	
5	1		1	
6		1	1	1
7	1		1	1
Creation (C)				
1	1	1	1	1
2			1	1
3			2	2
4	1	1	3	2
5	1		2	1
6	2		2	2
Reflection & Evaluation (RE)				
1			2	
2			2	1
3	2		2	2
Overarching social and emotional capabilities (SE)				
1	1		2	2
2	1		3	3
3	1	1	4	4
4				
5			1	

what they designed and created by using questions such as "What will happen if.." "Do you think it would work that way?" or "Could you try another way?" She also allowed the children to take their time with their designs and creations. When time ran out, she saved their constructions as 'work-in-progress' which encouraged the children to return in the following days.

By intentionally incorporating a design process, she planned and followed the activity stages of *Asking, Imagining, Creating, Trying Out, Improving, Reflecting and Reasoning* (EiE, 2016). This changed her practice significantly at the beginning and the end of the learning journey. Firstly, she created an imaginary scenario that established the problem of building a boat to carry Sally 'across the river'. Then she seeded the children's thinking and encouraged them to share ideas by exploring and discussing photographs of different types of boats. These ideas were then incorporated into the children's design drawings and planning for how they would make their boats. Importantly, like practices observed by Lippard et al., (2017) a range of suitable construction materials and tools were made available for all the children and this contributed to their motivation to construct (Fig. 12.4).

Fig. 12.4 Design and construction resources

The teacher avoided doing the creative thinking for the children or telling the children what to do. Alternatively, she encouraged children to test ideas, try out constructions and to reflect on what didn't work and why. Similar to constructivist pedagogy discussed by Pritchard and Woollard (2010), the teacher was guiding or coaching children for learning rather than instructing. At the end of the learning experience, the children were observed debriefing their activity amongst themselves and with their teacher who asked "Did you make the boat like your original design?" As well as, "What did you change? How come?" Then reflecting on the process, she asked, "Why didn't the first design work? Why did it work after you made the changes?" This reflection on both the boat produced and the steps the children had taken to make the boat, was another significant shift in practice from Cycle 1 to Cycle 2 and evidence of further development in the teacher's pedagogical knowledge.

Complementing the design process and inquiry questioning approach implemented in Cycle 2, was the ongoing priority given to children's agency and the maintenance of an emotionally safe learning environment. Our practitioner-researcher had worked with the children all year, and developed secure and trusting relationships where they were encouraged to try out ideas without fear of making mistakes. She used positive language such as, "that's okay we can try again," and asked the children questions such as, "how will that work?" and then giving them the opportunity to correct themselves rather than having an adult complete task for them. The children were encouraged to play and learn collaboratively, and to be resilient and learn from errors as they tested designs and worked to solve the challenge.

In conclusion, the intentional inclusion of an engineering design process was found to increase children's demonstration of creative thinking and actions. The children stayed engaged with the design challenge for a much longer period of time and they were participating in extended learning conversations with their teacher. The children were observed sharing their ideas, and investigations. When prompted they reflected and evaluated the suitability of their constructions as a solution to the problem established by their teacher in the design challenge. However, we recognise that the generalisability of these findings is limited due to the specific context and nature of the case from which they emerge. We recommend further research be conducted to test the rigour of the Indicators of Creativity checklist and the impact of teachers' pedagogy on children's development of creativity through STEM experiences.

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Chapter 13
From Slavery to Scientist: Dramatising a Historical Story to Creatively Engage Learners in Resolving STEM Problems

Debra McGregor, Sarah Frodsham, and Clarysly Deller

13.1 Introduction

This chapter describes how a sequence of drama activities informed by the life and work of George Washington Carver (GWC) were adopted to engage children in Science, Technology, Engineering and Mathematics (STEM) inquiry activities. Although research into the ways that historical story can be brought to life to extend affordances for pupils has been demonstrated by others (McGregor & Precious, 2015; Swanson, 2016; McGregor et al., 2019), this chapter focusses specifically on the story of GWC, an American born into slavery, who worked with local farmers to improve their agricultural practices and develop a wide range of products from plants, including dyes and adhesives. Adopting a socio-cultural lens highlights how this project: (i) included the exploration of the context in which the scientist was working; (ii) adopted a framing of an imagined, figured world (Rainio, 2008) constructed through the application of a series of drama conventions (summarised in Table 13.1), and finally; iii, suggested how inquiry practices (Table 13.2) could be used to solve a STEM problem. The intervention also demonstrated how the nature of science can be better understood by pupils given opportunities to be immersed in an imagined historical context and work-in-role as a scientist within that conjured kind of setting (Table 13.3).

The features of an intervention highlighted in this chapter demonstrate the sequential use of a series of different drama conventions to immerse a group of

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Table 13.1 Summary of the GWC dramatised activities and pupil activity in relation to the applied drama convention

Sequencing, and description, of GWC drama activities	Drama convention	Pupil activity
Activity 1: GWC introducing himself, through the reminiscening of an old man, reading what it says on his tombstone and talking about his life as an agricultural scientist, who discovered how to grow particular plants in rotation to increase yield.	Listening to a monologue (Fig. 13.2)	Observing and listening to the reflective story being told by their teacher (the Teacher working in Role or TiR)
Activity 2: Discussing the uses of different plant materials, so that nothing was wasted from a crop.	Hot seating (Fig. 13.4)	Questioning the TiR as an 'expert' about GWC, his work and the historical context in which he lived.
Activity 3: Highlighting the tenacity, determination, insight, application of knowledge, empathy with farmers plight and other attributes that GWC demonstrated in the way he conducted his life and work.	Tableau (Fig. 13.3)	Depicting the various characteristics of GWC's life, work and scientific discoveries. Acting as reflectors of GWCs life and work. Depicting GWC's ability to draw, applying his detailed observation skills, study of plants and the structure of soil (Fig. 13.6)
Activity 4: Enacting processes related to development of crop rotation that GWC proposed: i. the impact of depletion of nutrients in soil ii. Replenishing nitrogenous content of soil	Modelling: Representing changing nitrogenous content of soil (Fig. 13.5i, ii)	Exploring the growth of plants over time, responding to sustained (remain healthy) or depleted (gradually wither and die) soil nutrients (Fig. 13.5i) Exploring the growing of peanut plants when the nitrogen levels in soil are increased (Fig. 13.5ii)
Activity 5: Inquiring in-role as GWC	Pupil working in role (WiR) as GWC (Fig. 13.6);	Responding as a scientist and applying a scientific method. E.g. i. Repeated trials: Growing radishes three times in the same soil. ii. Inferring: Discussing, deliberating and exploring ways plant parts might be used to create or make something new and creative.

Adapted from McGregor and Precious (2015)

Table 13.2 Indications of pupils creative thinking and scientific inquiry practices (adapted from Osborne, 2014) while engaged in different dramatic conventions

Indications of pupils' creative thinking & scientific inquiry practices	Affordances offered within the dramatised activities	Quotations from pupils, and or their teacher, demonstrating their taking-up of the afforded opportunity
Asking questions	Having listened to the monologue, pupils inquired by asking questions of the teacher in role (TiR) as GWC (Fig. 13.2)	"Some people seem to think that the history of it is kind of pointless [...] if you can figure out what their thought-process was maybe you could do something similar. Or at least if you can't do something similar you can kind of better understand where it comes from. I guess it just helps you to see from their perspective." Joe: Pupil reflection
Constructing explanations	Pupils were thinking creatively and proposing explanations from observations about what happens to plants when nutrients are depleted.	"We modelled being trees and put counters on the floor to represent water, nutrients and light. Each tree had to get what it needed to grow healthily, those that didn't ended up withering and dying." Chloe: Interview
Engaging in argument from evidence	Pupils were considering observations, and thinking like scientists about different forms of evidence.	"I really like that [..] the creativeness [….] it was really interesting, I think it gets you in the right frame of mind actually creating stuff is I guess that's what science actually is." Joe: Interview
Planning and carrying out investigations	Pupils were positioned as scientists as they planned conducted and reviewed outcomes of experiments.	"It was lovely that it was practical and hands-on. I know better how to plan my experiments in class now." Phoebe: Interview
Analysing and interpreting data	Pupils reflected and inferred as they reviewed outcomes of the repeated trials (x3) of radish seeds grown in the same soil (Fig. 13.6i, ii, iii).	"I guess if you understand where the original scientists happened upon it, I guess it helps you recreate that he saw what they went through and then if you do a similar technique, you kind of figure out what it's like. If you don't know how they found out there's no way that you're going to. Maybe the way they came across it is the best way to learn it." Joe: Interview
Using mathematical and computational thinking	Pupils dialogically exchanged ideas, tested their methods and developed creative solutions, positioning themselves as scientists.	"The children discussed their ideas about how they worked as scientists testing their own theories." Teacher: Reflective field notes

(continued)

Table 13.2 (continued)

Indications of pupils' creative thinking & scientific inquiry practices	Affordances offered within the dramatised activities	Quotations from pupils, and or their teacher, demonstrating their taking-up of the afforded opportunity
Obtaining, evaluating and communicating information	Pupils communicated how they investigated and found solutions when they explained what they did to the teacher and their peers.	"It's great to find out about things I do not understand and using drama helps me learn better in science." Madison: Interview

Table 13.3 Teacher's reflections: The impact of the intervention on pupils' creative STEM-inquiry processes

Inquiry ideas and evidence	"Generating ideas by using drama techniques, such as the stories of scientists via dramatic monologues does stimulate great ideas in learners. It helps them to *stand in the shoes* of scientists, understand their difficulties and unique ways of working, thus helping them to assume a role of [a historical] scientist themselves. Looking at evidence from the past, modelling ideas with their bodies (such as the uptake/replenishment of nitrogen in soil by cotton/peanuts) and learning about scientific endeavour, sites their own learning in realistic scientific contexts. They find this engaging and enjoyable and it provokes much discussion and dialogue as they construct their own ideas and ways of working based on a historical figure".
Planning an experiment	"Pupils have described understanding how a scientist studied and worked themselves, is key in their approach to designing an experiment. With the GWC story, the fact that he came up with 300+ uses for a peanut inspired the children to *think outside the box*. If he could develop so many uses for one product, they too could do that. Discursive approaches helped the children to not only discuss, but also develop new approaches to planning their experiments modelling their ways of working on their perceptions of his scientific process and making sense of seemingly complex processes into their own more simple ones".
Obtaining and presenting evidence	"The children had to *sell* their uses for their product, as GWC pioneered, taking a mobile classroom (on a *Jessop wagon*) to bring his ideas to farmers. Children enjoyed this engaging way of presenting their results and evidence to others. They engaged in good questioning of each other in the process".
Considering evidence and evaluating	"Evaluating their learning from these immersive tasks, children wrote very enriched learning comments in their science books".

pupils, aged 10–11 years, in thinking about a scientific story within an historical context. In responding to their inquiry questions, the pupils drew on aspects of the scientist's life [GWC] and considered how he resolved the challenges faced during his life in the deep south of America, where poor farmers struggled to increase their annual yield of cotton (and other crops).

The activities were carried out in science lessons with a view to the pupils understanding more about plant growth. They were able to familiarise themselves with GWC's life and his work in early twentieth century America. Specifically, he explored ways that different plants (or their parts including the peanut) might be mashed, ground, dissolved, sieved, mixed and heated to make different products including ink, paints, pastes, adhesives etc. He also recognised how impoverished soils impacted negatively on the agricultural yield of crops and that leguminous peanut plants, that restored nitrogenous content to the soil, were invaluable in crop rotation.

The *Action Research* (AR) design (summarised in Fig. 13.1) included examining the impact of the various drama conventions. A mixed methods approach, was adopted, to collect impact data (including field notes, photo-documentation, interviews and reflective questionnaires). This approach enabled us to address the question 'How can a dramatised inquiry, informed by George Washington Carver's historical story, support pupils' STEM learning?' Scrutiny of the evidence, from the data collected, suggested that by providing dramatised activities that explained and justified an authentic problem, learning became more meaningful for the pupils. They naturalistically used their ingenuity and creativity as they empathised with being a scientist or technologist in their inquiries. The conclusion of the chapter offers generalised principles for dramatising STEM learning that draws on other scientists' and technologists' stories to promote inquiry practices.

13.2 Theorising the Nature of Creativity

The nature of creativity and the ways it is defined are still contestable today. Over 70 years ago, during a keynote speech, at the *American Psychological Association*, Guilford (1950) highlighted the need to clarify the educative nature of creativity. More recently concerns around clarifying what such an entity might look like across the disciplines identified how an artist, inventor or craftsman might recognise and cultivate creativity differently (Glăveanu, 2018). Over the past few decades though, because of the juxtaposed way that teachers of English, the Arts or Sciences might understand and interpret creativity, it is not always clear 'what' it is or indeed how to 'best' support it (Kampylis et al., 2009). This is especially challenging when considering the multitude of definitions of creativity that are presented for teachers to consider. Welch (1980) cited in Isaken (1987, p. 9), reviewed 22 descriptions of creativity, whilst Rhodes (1961) reported over 56. He went on to say that, whilst numerous, these definitions were not "mutually exclusive" because: "…they overlap and intertwine. When analysed, as through a prism, the content of the definitions form four strands. Each strand has a unique identity academically, but only in unity do the four strands operate functionally" (*ibid*, p. 307).

The four strands interacting 'in unity' were labelled by Rhodes (1961) as "the four P's of creativity". They were:

1. 'the person'—the "personality, intellect, temperament, physique, traits, habits, attitudes, self-concept, value systems, defense mechanisms, and behaviour" (*ibid*, p. 307)

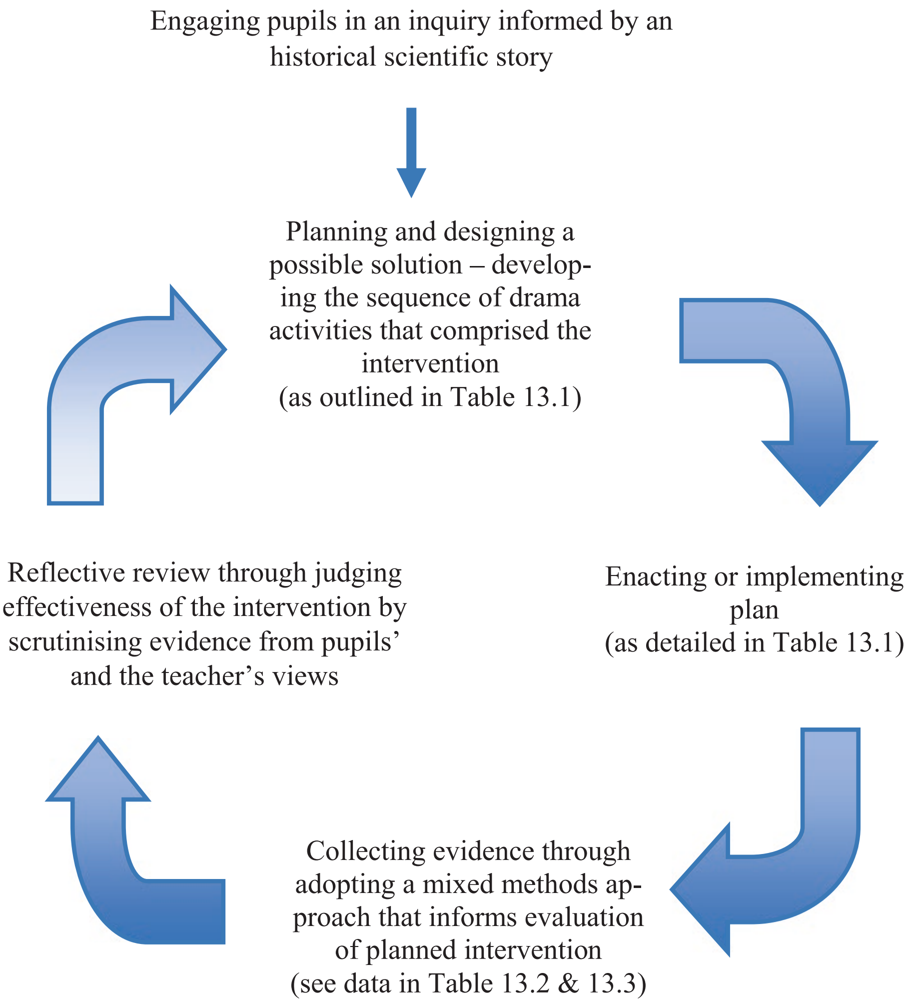


Fig. 13.1 Outline of the action research approach described in this chapter (adapted from McGregor and Cartwright (2011, p. 244)

2. 'the process'—which "…applies to motivation, perception, learning, thinking, and communicating" (ibid, p. 308),
3. 'the product'—which is when "… a thought [an idea]…has been communicated to other people in the form of words, paint, clay, metal, stone, fabric, or other material" (*ibid*, p. 309) and
4. 'the press'—which constitutes "…the relationship between human beings and their environment" (*ibid*, p. 308) because "no-one can perceive a person living or operating in a vacuum" (*ibid*, p. 305).

However, as Isaken (1987) pointed out, this perspective of creativity, which appeared to incorporate all human beings regardless of age, or their perceived ability, retained a definition, but it was so general it was not directly useful to apply in educational settings. More recently the four Ps have been revisited by Murcia et al. (2020) in the development of their *A to E Framework*. Glăveanu (2013, p. 69) also reconsidered the four P's and proposed an alternate framework, the "5A's, actor, action, artefact, audience and affordances". He argued that the 5A's better embraced a socio-cultural approach, which offered a more comprehensive perspective of creativity. This more ecological approach to creativity is acknowledged in this chapter through recognition of the ways various affordances are embraced within the approach that adopts drama conventions to frame and develop children's immersion in an historical context and subsequent engagement in inquiry.

The increasing educational interest in creativity arguably emanates from the *Programme for International Student Assessment* (PISA) announcing its planned inclusion in the 2021 tests (OECD, 2021). Although it has been suggested that international testing of creativity will produce a narrow vision of creative skills (Guror, 2016), there has long been a concern in the United Kingdom that creativity is supported in school classrooms. In 1999 the then Secretary of State for Culture, Media and Sport, invited Sir Ken Robinson to form the *National Advisory Committee on Cultural and Creative Education* (NACCCE). This committee attempted to define creativity for both primary and secondary education. NACCCE (1999, p. 30) defined creativity as, "… [an i]maginative activity fashioned so as to produce outcomes that are both original and of value". They clarified *teaching creatively* (TC) as that where "…teachers using imaginative approaches" could make "learning more interesting, exciting and effective" (NACCCE, 1999, p. 102) and *teaching for creativity* (T4C) designed to promote learner creativity was a form of teaching "…intended to develop young people's own creative thinking or behaviour" (*ibid*, p. 103). These two perspectives, evidenced in the project reported on in this chapter, also clearly relate to Murcia et al.'s (2020) view and Glăveanu's (2020) 5A's framework.

Organisations, such as the *Office for Standards in Education* (Ofsted) in England, which ensures that providers of education, training and care services maintain high standards for pupils through regulatory inspections, have more recently promoted elements of creative practice. They indicated how teachers "…encouraging pupils to question and challenge, make connections and see relationships, speculate, keep options open while pursuing a line of enquiry, and reflect critically on ideas, actions and results" could support more creativity in inquiry (Ofsted, 2010, pp. 5–6). Whilst these qualities have been associated with that of a scientist, as suggested by McGregor and Precious (2015), simply acknowledging these features in policy documents (Department for Education, 2013) is not enough to promote scientific creativity in England's classrooms (McGregor & Frodsham, 2019). Teachers also need clarity to realise how to extend affordances (Glăveanu, 2020) and develop pedagogic strategies that actively encourage their pupils to *act* as scientists; engage in scientific actions; produce relevant scientific artefacts and in so doing respond to the ways that material, visual and cognitive opportunities to be creative are offered to them.

Glăveanu (2011) also identified interactional features, that were dialogic and symbolic in nature, and promoted creative collaboration. In such creative environments, pupils engaged with others in collective endeavours that supported sense making and the construction of understanding. Rainio (2008) extends this and describes how teachers develop a classroom into an imagined, figured world, where material artefacts and particular kinds of tasks enable learners, of any age, to take-up different roles; giving them a better appreciation of cultural influences shaping how they come to know things. McGregor et al. (2019) adopted these notions to illustrate how drama provides the opportunity to gradually re-position pupils to become ‘scientists-in-role’ so that they could verbally and actionally make decisions and solve scientific problems through inquiry. The creative teacher in this project generated an imagined world in the science classroom that related to GWC’s social, historical and cultural context, and offered opportunities for pupils to engage in imaginative thinking and creative problem solving.

13.3 The Creative Use of Drama Conventions to Promote Inquiry

Engaging in solving scientific problems, provides pupils with opportunities to practise and apply inquiry skills (Osborne, 2014). The framing of the dramatic inquiry in the GWC project offered opportunities for children to practise being agentive, to think and work scientifically, consider and argue about meanings and relevancy of data. McGregor et al. (2019) illustrated how the pedagogical methodology of introducing an ‘as if’ context offered an approach that overcame many issues previously recognised as barriers to learning through inquiry (Minner et al., 2010; Harlen, 2011). Immersing the pupils into an historical context, providing an open question for inquiry, and providing materials associated with the imagined world, enabled the pupils to actively respond, engage and credibly solve an authentic issue. The resolution of an open inquiry is not pre-determined, hence, alongside developing scientific literacy (Taber, 2011), it contributes to understanding the creative element within the nature of science (Lederman et al., 2013). Arguably, by ‘setting-up’ situations in which pupils could think and behave with purpose, teachers provide opportunities for pupils to work as scientists-in-role (e.g., describing observations, clarifying thinking, justify claims, and clearly and persuasively using evidence) which, builds an understanding of the nature of the work carried out by scientists.

Just as McGregor and Precious (2015), Swanson (2016), Stagg (2020) and McGregor et al. (2019) indicated, this approach suggests a third kind of location in the ‘as-if’ dramatised (or re-configured) world, that can extend affordances for pupils to actively participate with thinking, making-decisions and taking action; thus experiencing inquiry processes. This extends Craft’s (2001) notion of possibility thinking. Key features of the experiences described by these authors included different ways of positioning the pupils in a figured world context. For example:

- Immerse themselves in the context of an 'as-if' figured world (Rainio, 2008).
- Enable participation in activities related to the scientist's historical and scientific context.
- Engage them in a purposeful, appropriate, contextualised and open challenging activity.
- Promote collaboration through working together in-role as groups of would-be-scientists.

These features offered learning experiences that enabled pupils to begin to appreciate what it is like to work as a scientist, to think and act scientifically through being afforded opportunities to creatively solve accessible STEM problems.

13.4 Exploring Ways of Using Historical Stories for Promoting Learning

The involvement of pupils in dramatic inquiry, through activities that introduce how scientists/technologists have worked in the past can 'set-the-scene' for the development of creative thinking and STEM enquiry skills within a problem-solving situation. Historical stories can provide rich authentic contexts that engage pupils to imaginatively and creatively resolve STEM-based challenges. Engaging in a dramatic inquiry, framed as a story of well-known (or not so well known) scientists, can inspire and motivate pupils to discern and empathise with the work of a scientist (McGregor, 2016, 2019; McGregor & Frodsham, 2020). Through designing learning opportunities in which ideas are challenged, pupils can ask questions, see connections, discern patterns in data, process information, plan and carry out investigations, critique others' suggestions and utilise resources to make something work. These kinds of process skills contribute to creative thinking and support pupils to generate unique solutions to STEM problems.

For example, McGregor and Precious (2015, p. 171–227) illustrated, by drawing on stories from history, how inquiry activities (*ibid,* p. 121–124) could be presented to pupils in ways that prompted their thinking about the work of scientists from history or ways of solving open problems relating to the work of scientists today. Swanson (2016) also illustrated how pupils placed in the position of scientists, acting in role to investigate the sinking of the *Wahine* (a well-known New Zealand boat that sank in Wellington harbour in 1968), felt they worked like real scientists. Swanson demonstrated how the discussion and scientific thinking of the pupils was positively influenced by the adoption of an inquiry approach. Stagg (2020) identified a similar effect when exploring how an external visitor, an actor in role as *Linneaus*, impacted and augmented the botanical lexicon used by the pupils when they were discussing plants. Understanding of the nature of science and the associated inquiry practices were all improved by pupils being immersed in purposeful dramatised contexts, as observed in both the England and New Zealand cases (McGregor et al., 2019).

13.5 The Historical Story Drawn on to Inform This Dramatic STEM Inquiry

One of the narratives drawn on by McGregor et al. (2019) related to a historical story of the work of a technological scientist. This chapter focuses on a different character, (GWC), who, although born into slavery became a scientist and inventor. His careful observations, examination of soil nutrients and recognition that some plant crops depleted nitrogenous content and others enriched it, led him to develop his ideas about systematic crop rotation. GWC also demonstrated how new plants (such as peanuts, soybeans, pecans and sweet potatoes) could be profitably grown between the cotton crops. He conceived of over 300 applications for the peanut alone (American Chemical Society, 2005) which included a range of food stuffs and even other substances such as axle grease. These unique products were useful and economically valuable for poor farmers living in the deep south. The story of GWC demonstrated how his creativity was essential to solve problems. This historical narrative provided the context for a creative STEM inquiry.

13.6 The *Action Research Approach*

This research was conducted in a suburban Church of England Voluntary Aided state school in England. The school was located in a low-socio-economic area with roughly 200 pupils enrolled, ranging from four to 11 years. The final year class of 10–11 year-old pupils, having roughly equal proportions of boys and girls and a small number of Black, Asian and Minority Ethnic pupils, engaged in the action research project.

The *Action Research Approach*, summarised in Fig. 13.1, was adopted to explore how a dramatised inquiry, informed by GWC's historical story, supported pupils' STEM learning.

It should be noted that evidence and findings from this cycle of research activities, informed a second action cycle, but this is not reported on in this chapter. The pupils' classroom teacher collaborated with researchers, facilitated the activities and contributed to reflective analysis. Impact data was collected using mixed methods and included field notes, informal discussions, interviews and photographs. Each method, as elaborated below, contributed different forms of data that provided evidence indicating how adaptation of an imagined dramatised world of GWC promoted understandings about the nature of science and learner creativity.

- **Digital Still Images**: Photographs taken by the teacher-collaborator were transformed into line-illustrations of pupil's involvement in the drama conventions and development of creative outcomes (Fig. 13.2, 13.3, 13.4, 13.5 and 13.6)
- **Researchers' field notes:** Observations of teacher behaviours, nature of tasks presented, use of cultural artefacts, discussion with pupils, and learner responses to the drama activities (Table 13.2)

Fig. 13.2 Illustration from the classroom of activity 1: pupils listening to the teacher reading the George Washington Carver monologue

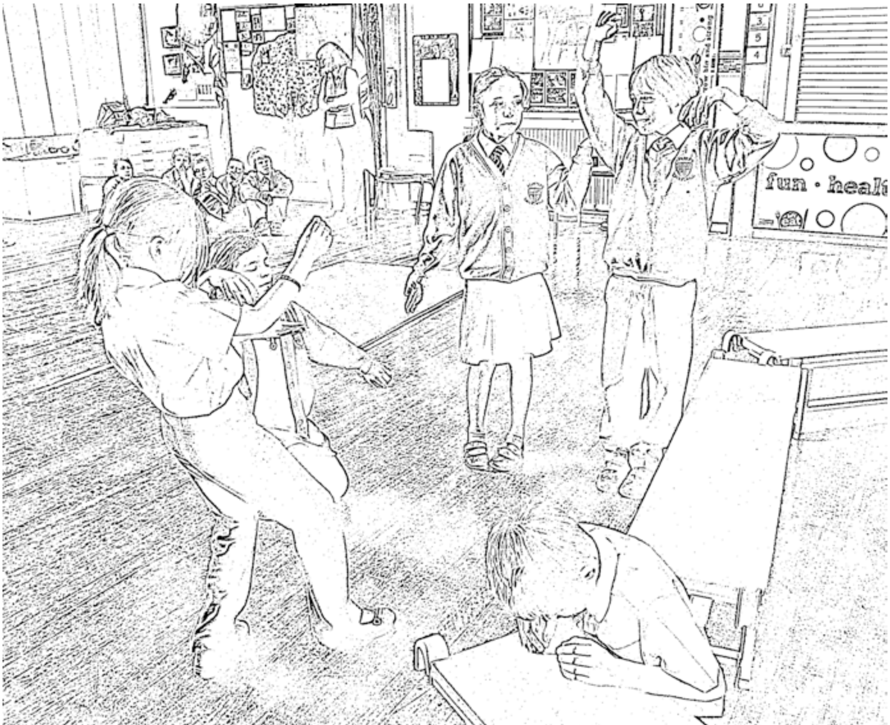


Fig. 13.3 Illustration from the classroom of activity 3: depicting the characteristics of George Washington Carver through the pupils enacting his attributes

Fig. 13.4 Illustration from the classroom of activity 2: hot seating the teacher in role (as GWC)

Fig. 13.5 (**i**) Illustration from the classroom of activity 4: modelling the beginning of the impact of depleted nitrogen on the growth of plants. (**ii**) Illustration from the classroom of activity 4: modelling the demise of more plants after repeated growing of the same crop in the same field

- **Interviews and teacher's reflective journal entries**: Illustrative quotations were drawn from both the pupils and the teacher. These were collated to inform interpretations of the observed and documented impact of the intervention (Table 13.3)

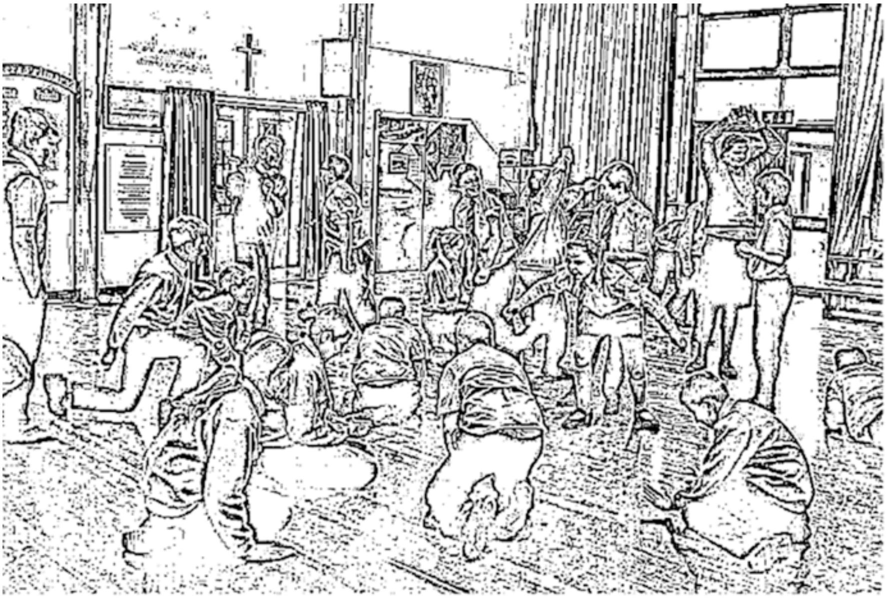
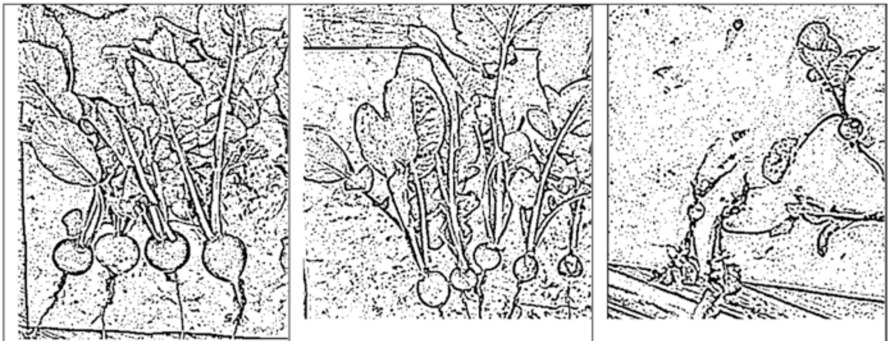


Fig. 13.5 (continued)



13.6i: First crop: Healthy range of rad-ishes	13.6ii: Second crop: Smaller radishes with less foliage	13.6iii: Final crop: Very small, mis-shapen and mis-coloured radishes

Fig. 13.6 Illustrations of impoverished growth of radishes three times over in the same soil. (**i**) First crop: healthy range of radishes. (**ii**) Second crop: smaller radishes with less foliage. (**iii**) Final crop: very small, mis-shapen and mis-coloured radishes

13.7 The Nature of the Intervention: A Sequence of Dramatised Activities

The activities comprising the intervention are summarised in Table 13.1. They began with the reading of a monologue entitled Products from peanuts (adapted from McGregor & Precious, 2015, p. 183). A teacher performed in role (as Teacher in Role, TiR) reading a reflective script (Fig. 13.2) informed by the life of GWC. The perspective taken was that of him, deceased, reading his tomb-stone and reflecting on what he had achieved and how others may have benefitted from his work. His keen observational and recording abilities enabled him to investigate and improve agricultural practices in the deep south where cotton yields were, at that time, diminishing. His introduction of rotating different crops, including peanuts, that fixed nitrogen and the increased soil nutrients availablity consequently improved the cotton crop output. Implementing this was no mean feat because the farmers, at that time, had no market for peanuts (Science History Institute, 2020). The tenacity of this man, his experimentation and exploration of the uses of peanuts (such as oils, inks, cosmetics, glue…), generated economic interest in growing the crop. Astutely aware that he had developed and created unique procedures for making new foods, industrial and commercial products including flour, sugar, vinegar, ink, paint, glue etc. from 'lowly' plants, GWC noted his techniques and processes carefully but 'in code' in order to retain his copyright (Perry, 2011).

Pupils are invited to learn more about GWC by 'hot seating' the teacher-in-role (Farmer, 2011, p. 28) (illustrated in Fig. 13.2). Once orientated by the teacher's responses to their questions, the pupils worked together in small groups, to depict GWC's attributes as a scientist (Fig. 13.3) in the form of a tableau (Farmer, 2011, p. 67) demonstrating the qualities he needed to succeed in his scientific endeavours. This immersed the pupils in the historical authentic context wherein the learning activities become more relatable and purposeful. Pupils then engaged with physically modelling (Farmer, 2011, p. 79) how plant growth was changed and affected by nutrient depletion (Fig. 13.4) and the teacher provided additional contextual information, as required, about the focus of GWC's work.

To extend the opportunity for the pupils to work-in-role as young scientists, two experimental activities were presented for them to engage with. The first was growing radish seeds repeatedly in the same soil (Fig. 13.5). The second was generating new products from plant material (Fig. 13.6i, ii, iii). Pupils' original thinking was evident in their outcomes and they demonstrated their creative thinking in quite unusual ways as they imagined and described new items produced from one plant product. For example, one small group of pupils, conceived many new products from a cantaloupe melon; such as paper, drink, using the skin as cups or bowls, making earrings and bracelets from the seeds, using the seeds to feed birds, drying the skin and seeds to make a gourd-type shaker and a stamp for a printing process, similar to potato prints.

13.8 Findings

Reflecting on the sequence of learning activities (Table 13.1), the teacher noted that the pupils' responded actively and creatively to the various drama conventions. Her reflective diary excerpts, as illustrated through quotations in Tables 13.2 and 13.3, indicated that as a consequence of being introduced to GWC's story through a sequence of drama conventions, the pupils were, in her opinion, afforded invaluable insights into his working context. Their immersion into the activities reportedly opened new avenues for creative inquiry. Thus, developing the classroom as an imagined, 'as if', figured world (Rainio, 2008). The dramatised activities appeared to successfully enable pupils to better appreciate the nature of GWC's scientific achievements.

Creating a figured world in the classroom environment by adopting resources, artefacts and materials as well as designing activities that directly related to the narrative of GWC's life, characterised the imagined world of a black American born into slavery who became a prominent agricultural scientist. Pupils, sequentially, enacted different aspects of his life and work (as depicted in Table 13.1). This enlivened pupils' participation in the creative teacher-generated figured world. In the case of GWC, there were many ways, as described in Tables 13.2 and 13.3, that the teacher mediated their engagement in scientific practices (Osborne, 2014; McGregor et al., 2019) and their developing appreciation of the nature of STEM related inquiries.

The pupils' reflections, as highlighted by their quotations in Table 13.2, on ways that the intervention impacted on their understanding of science and inquiry, are corroborated and complemented by the teacher's perspectives of the impact on the class in general. The teacher's reflections (Table 13.3) on the impact of the action research project, confirmed how it was possible to scaffold and mediate pupil's engagement with STEM inquiries, by employing drama conventions, and generating an 'as if' world that created a reconfigured and deeply contextualised classroom experience.

13.9 Discussion

This chapter has been written to consider, 'How can a dramatised inquiry, informed by GWC's historical story, support pupils' STEM learning?' Within a traditional classroom context, pupils engaged with a STEM activity are unlikely to produce the kinds of cultural and revolutionary innovations that renowned scientists like Newton, Einstein, Curie or Dunlop have produced. However, as McGregor (2016), McGregor et al. (2019), Swanson (2016) and Stagg (2020) demonstrate, by using drama techniques to create alternate contexts, young learners (aged 10 and 11 years old) can work-in-role as a scientist, construct understandings about the nature of science and act agentively in the ways they consider what could be done about problems posed.

The 20 divergent ideas, for example, suggesting alternate ways a cantaloupe melon could be used, was produced by one group of children from the class of 30 pupils. This resonates with GWC's innovative thinking, developing over 300 uses for the peanut. This activity illustrates Craft's (2001) everyday 'little-c' creativity as the pupils actively engaged in 'possibility thinking'. Runco (2003, p. 318) suggests how this type of everyday problem solving is linked to "… the construction of new meaning". These are arguably new "mental combinations that are expressed in the world" (Sawyer, 2012, p. 7) which are original to the creator [the pupil]. However, witnesses to this form of creativity (i.e. the teacher and peer group) are needed to verify pupils recognising their own expression of personal creativity, and innovative contribution to class thinking.

All four strands of creativity that Murcia et al. (2020) outline: Person, Place, Process and Product; were evident within this project. For example, the *Person*, the educator was creative in the way she generated the configured world of GWC and the ideas generated by the pupils were also original; the *Place*, the 'as-if' figured world provided an imagined environment for creative inquiry; the *Process*, the engagement in various tasks scaffolded and mediated learners' development of creativity as they designed, reviewed and conducted their inquiries and finally the *Product,* the outcomes from both planting radish seeds in re-used, depleted soil and the innovative creativity in suggesting multiple ways that different plant parts could be used to create new products.

13.10 Conclusion

Reflecting on the success of this project, the evidence suggested that the creative teaching was engaging, imaginative and highly original, and supported the emergence of learner creativity. There were a variety of ways that affordances were extended to generate the kind of classroom environment that promoted the development of the pupils' ingenuity, innovative thinking and agentive actions (Bruner, 1996). Elements of creative practice were clearly demonstrated in this project. A range of features supported pupil activity and development as young scientists, including how the teacher encouraged pupils to "question and challenge, make connections and see relationships, speculate, keep options open while pursuing a line of enquiry, and reflect critically on ideas, actions and results" (Ofsted, 2010, pp. 5–6), all actions demonstrating creativity in their inquiry practices. Whilst these are all qualities demonstrated by scientists, as suggested by McGregor and Frodsham (2019), simply acknowledging that these are desirable features, is not sufficient to pedagogically support the development of pupils' scientific creativity. Educators need help in recognising how to support learner creativity in various multifactated ways.

The adoption of a socio-cultural lens, highlighted how the creative teaching approach shared in this chapter, offered at least seven learning affordances (the seven As) that extended pupils' creative inquiry learning trajectories in STEM contexts:

1. Immersion into a historical context which related to a scientist's life and work, through adopting an '*as if*' figured world;
2. providing *artefacts* that resonate with the '*as if*' world and related directly to the presented learning tasks;
3. extending *accessible* tasks and affording authenticity for the pupils to work-in-role;
4. inviting pupils to *act* as scientists-in-role as they engaged in participatory activities;
5. enabling pupils to decide upon *actions* that are appropriate to undertake within the figured world of a scientist;
6. encouraging pupils to work with others, forming *alliances*, and collaborating to resolve problems;
7. celebrating the *artistic* and resourceful outcomes of the dramatised activities.

In summary, this chapter synthesised evidence from an action research project and explored the affordances offered by dramatic inquiry for promoting pupils' creativity in STEM. Scrutiny of the evidence suggested that dramatised activities extended affordances for learners beyond the 5A's identified by Glăveanu (2020). The creative teaching intervention enabled pupils to explore a scientific context that was historically imbued, and deeply engaged them in thinking and acting in informed ways within the STEM inquiry contexts. We aimed to illustrate through the presentation of the GWC activity series how adopting a socio-culturally informed approach and creating an imaginary 'as-if' figured world characterised by a real story of a scientist and his work from a historical perspective, successfully engaged pupils in inquiry and inquiry related activities. Analysing the impact of this approach by adopting mixed methods, provided rich and converging evidence of the many and varied ways inquiry learning, supported through the adoption of drama conventions, create an imaginary scientific world that could be described as containing elements of an enabling environment (Murcia et al., 2020).Therefore, adopting the framing of a figured world, constructed through the application of a series of immersive drama conventions, extended learning affordances, supported inquiry practices and enabled young pupils to creatively solve authentic STEM problems.

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Chapter 14
Leonardo da Vinci's Apprentices or Tinkering Belles and Boys at Ludic Play?

Debbie Myers

14.1 Introduction

Leonardo da Vinci (1452–1519) was an Italian polymath (from the Greek polymathes) who "learned much […] in different fields of study" including art, architecture, anatomy, mechanics and engineering (Kron & Krishnan, 2019, p. 403). He lived during the Renaissance, a time when art, architecture, science and engineering were closely linked, and innovation and invention flourished. The understanding he acquired in one domain he readily applied in other fields of knowledge, because he was free to think, without the imposition of artificial subject boundaries.

Endlessly curious, da Vinci investigated a range of phenomena in the world around him, using drawings, annotated diagrams and mirror-written reflections to capture his observations and his possibility thinking that would inspire future creative endeavours (West, 2017). Curiosity is recognised as an antecedent to learning (Litman, 2005). Curiosity is also a necessary pre-requisite to foster creativity including the generation of ideas (Hardy III et al., 2017), possibility thinking (Craft, 2002; Craft et al., 2005) and "imaginative activity fashioned so as to produce outcomes that are both original and of value" (National Advisory Committee on Creative and Cultural Education, (NACCCE), 1999: 30). Like da Vinci, children are naturally curious and inquisitive about the phenomena they encounter in their worlds (Spektor-Levy et al., 2013). In England, the Office for Standards in Education (Ofsted, 2013) report 'Maintaining Curiosity' identifies effective science teaching as that which "sets out to sustain pupils' natural curiosity" (p. 5).

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Heathcote and Bolton (1995) developed the dramatic inquiry pedagogy, Mantle of the Expert (MoE), in which educators position pupils as experts within a dramatic frame. The researcher created a sequence of teaching interventions, '*da Vinci's Apprentices*' to connect children's learning experiences in science, design technology, humanities and arts within creative contexts. This approach uses the pedagogy of dramatic inquiry (Heathcote & Bolton, 1995) to situate the practices of doing science and early engineering in imaginary contexts that cross subject boundaries (Kangas, 2010; Papert & Harel, 1991).

An exploratory case-study was carried out with a class of primary pupils aged 10 to 11 years, (N = 50) to examine the "particularity and complexity of a single case" (Stake, 1995, p. xi). The aim of this study was to demonstrate how the deployment of this initiative supports children's creative thinking during their initial generation of ideas (Craft, 2002; Hardy III et al., 2017) and in their resolution of problems as they apply their scientific knowledge to meet a rubric of scientific criteria.

14.2 Dramatic Inquiry, Framing and Improvisational Roles

Craft (2005, p. 44) observed that "a pedagogy which fosters creativity depends on practitioners being creative to provide the ethos for enabling children's creativity". Heathcote and Bolton (1995) developed the dramatic inquiry pedagogy, *Mantle of the Expert* (MoE), in which educators position pupils as experts within a dramatic frame. Dramatic inquiry supports whole class improvisation by situating problem-based learning in fictional worlds that mirror authentic contexts (Brown et al., 1989; Krajcik & Blumenfeld, 2005). Whole class improvisation can facilitate pupils' agency and creative thinking in the context of problem-based learning (Krajcik & Blumenfeld, 2005) when the educator shifts responsibility for decision-making to pupils.

In *da Vinci's Apprentices*, the educator positions pupils as apprentices, tasked to travel back in time to complete STEAM commissions, by seeking ideas from more knowledgeable scientists. Apprentices travel by Time Machine to scientists' places of inspiration, if known, for example, their dreaming places, (Alexander Graham Bell), libraries (of Alexandria or Ephesus), laboratories, exploratoria or invention centres (Menlo Park, Thomas Edison). The educator is positioned as an intermediary who initially contextualises the improvisation, introducing the commission or request for help from a patron, then acting in-role as the scientist and acting as a co-investigator alongside children. In these multiple roles the educator guides apprentices through an iterative engineering design process (EDP) enabling them to define the problem and to imagine a range of possible ideas that may contribute towards a possible solution (Fig. 14.1).

Arnold and Clarke (2014, p. 746) argue such pedagogical approaches facilitate the emergence of children's collective agency because "social meaning is made at the nexus of 'positions', 'storylines' and 'acts/action'". They maintain:

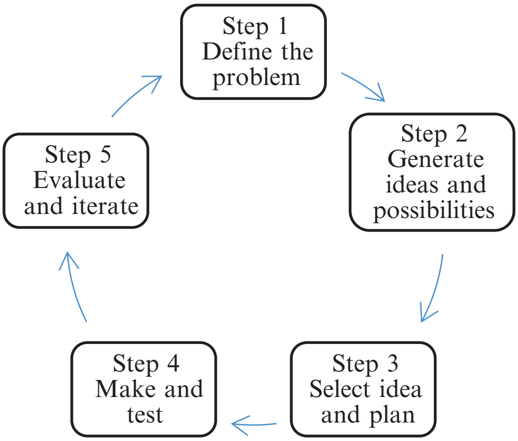


Fig. 14.1 An engineering design process followed during dramatic inquiry

> in positioning theory, a storyline is discursively performed when participants accept the affordances and constraints conferred on their speech acts by the conventions of the particular storyline (p. 746).

However, whole class improvisation requires learners to be simultaneously aware of two distinct worlds, the physical reality of the actual world and the fictitious, imagined world co-constructed through a process called metaxis (Boal, 1995). In drawing on the socio-cultural theory of Vygotsky (1978) Dorion; (2009) explains learners navigate these two distinct worlds concurrently by maintaining two dialogues, an internal dialogue with themselves and a shared external dialogue with their educator and fellow participants wherein:

> a semblance of truth sufficient to procure for these shadows of imagination that willing suspension of disbelief for the moment, which constitutes poetic faith (Coleridge, 1817, Chapter XIV).

14.3 Playful Learning

The arrival of a commission at da Vinci's apprentices' workshop provides groups of children with opportunities to define a problem, design, construct and evaluate an artefact that meets a rubric of criteria. Dewey (1916) observed when children are supported in their interactions with materials their initial explorations and interactions progress through "trial and error […] their inquiries are spontaneous and numerous, and the proposals of solution advanced, varied and ingenious" (p. 183). Indeed, children's interactions with materials could provide opportunities for both goal-orientated (telic) and recreational (paratelic) play (Apter, 1991) as they bring these physical artefacts into existence. Hutt (1981) observed and classified children's everyday types of play with materials and objects and delineated three types: epistemic, ludic and game play with rules.

Hutt (1981) characterised children's epistemic play with objects and materials as that based in knowledge seeking, wherein children ask what can this object do? In contrast she classified ludic play with objects as a context in which the child asks, what can I do with this object? During both epistemic and ludic play with objects and materials it is "the threshold of desired uncertainty in the environment which leads to exploratory behaviour" (Jirout & Klahr, 2012, p. 150). Children's curiosity drives learning because the physical materials made available offer a range of affordances (Gibson, 1976), provocations, and possibilities (Craft, 2005) prompting question-posing.

From a socio-cultural perspective, the generation of questions and the construction of concepts are psychological tools of the mind that support the development, organisation and elaboration of thinking (Vygotsky, 1978). Edwards and Mercer (1987, p. 20) maintain "talk is one of the materials from which a child constructs meaning", however, Lave (1988) and Hutchins (2000) extends this notion to embrace gestures, actions and interactions between individuals and individuals and objects or materials. Within their groups, the development of a shared understanding between apprentices is dependent upon the social distribution of cognition across individual apprentices' minds, bodies, objects and materials (Hutchins, 2000).

In contrast, ludic play encompasses socio-dramatic play that supports language development and imaginative ideas wherein children create fictional worlds, taking on roles and solving problems as a character within these worlds through improvisation. Vygotsky (1978) believed the development of cognitive processes including imaginative thought and understanding is founded in social interactions and mediated by cultural signs. Smith (1982), cited in Smith, 2016, p. 247 suggests the elaboration of both exploratory and social play into fantasy or symbolic play may have provided humans with the evolutionary advantage of inventiveness. The workshop in which these initiates are apprenticed is framed as a polymathist centre of learning. The procurement and creation of semiotic resources including artefacts, symbols and signs associated with scientists, science and technology enables educators and pupils to bring to life the dramatic frame through a process of transmediation (Kress & van Leeuwen, 2001).

Murcia et al. (2020) developed a framework identifying criteria that characterise children's creativity focusing on four components: product, person, place and process (Table 14.1).

This framework enables an educator to deconstruct and critically evaluate the characteristics of children's creative thinking in each step of the EDP during a dramatic inquiry.

14.4 Research Design

A small-scale, exploratory case-study is presented in this chapter. The study focused on a workshop that took place over two days during National Science Week, in the North of England. Two groups of pupils aged 10 to 11 years, participated (N = 50).

Table 14.1 The 'A' to 'E' of creativity: A framework for young children's creativity (Murcia et al., 2020)

<table>
<tr><td colspan="5">PRODUCT: Criteria for creative outcomes</td></tr>
<tr><td colspan="2">ORIGINAL</td><td colspan="3">FIT-FOR-PURPOSE</td></tr>
<tr><td colspan="5">PERSON: Perspectives on who does the original thinking</td></tr>
<tr><td colspan="2">CHILD ENGAGED BY EDUCATOR'S CREATIVITY</td><td>CHILD'S CREATIVE DOING</td><td colspan="2">CHILD'S CREATIVE THINKING</td></tr>
<tr><td colspan="5">PLACE: Elements of an enabling environment</td></tr>
<tr><td colspan="2">RESOURCES</td><td>COMMUNICATION</td><td colspan="2">SOCIO-EMOTIONAL CLIMATE</td></tr>
<tr><td colspan="2">Intentional provocations</td><td>Intentional learning conversations</td><td colspan="2">Stress and pressure free environment</td></tr>
<tr><td colspan="2">Stimulating materials</td><td>Hearing and valuing children's ideas</td><td colspan="2">Non-prescriptive</td></tr>
<tr><td colspan="2">Adequate materials for everyone</td><td>Open inquiry questioning</td><td colspan="2">Non-judgemental</td></tr>
<tr><td colspan="2">Time for creative exploration</td><td>Facilitating dialogic conversations</td><td colspan="2">Allowed to make mistakes</td></tr>
<tr><td colspan="5">PROCESS: Characteristics of children's creative thinking</td></tr>
<tr><td>AGENCY</td><td>BEING CURIOUS</td><td>CONNECTING</td><td>DARING</td><td>EXPERIMENTING</td></tr>
<tr><td>Displaying self-determination</td><td>Questioning</td><td>Making connections</td><td>Willing to be different</td><td>Trying out new ideas</td></tr>
<tr><td>Finding relevance and personal meaning</td><td>Wondering</td><td>Seeing patterns in ideas</td><td>Persisting when things get difficult</td><td>Playing with possibilities</td></tr>
<tr><td>Having a purpose</td><td>Imagining</td><td>Reflecting on what is and what could be</td><td>Learning from failure (resilience)</td><td>Investigating</td></tr>
<tr><td>Acting with autonomy</td><td>Exploring</td><td>Sharing with others</td><td>Tolerating uncertainty</td><td>Tinkering and adapting ideas</td></tr>
<tr><td>Demonstrating personal choice and freedom</td><td>Discovering</td><td>Combining ideas to form something new</td><td>Challenging assumptions</td><td>Using materials differently</td></tr>
<tr><td>Choosing to adjust and be agile</td><td>Engaging in "what if" thinking</td><td>Seeing different points of view</td><td>Putting ideas into action</td><td>Solving problems</td></tr>
</table>

The aim of this study was to demonstrate how *da Vinci's Apprentices* supports children's creative thinking during their initial generation of idea (Craft, 2002; Hardy III et al., 2017) and in their resolution of problems as they applied their scientific knowledge to meet a rubric of scientific criteria.

A case-study approach was taken as it is an empirical inquiry in which the 'boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used' (Yin, 1984, p. 23). This approach enabled the researcher to examine in depth the 'particularity and complexity of a single case'

(Stake, 1995, p. xi) and to understand the value to pupils in using this pedagogical approach.

14.5 Ethical Considerations

Ethical approval to undertake research was obtained from the researcher's employing university and permission to participate in the study was granted by the Headteacher on behalf of parents and children in accordance with the school's policy guidelines.

14.6 Data Collection

Data was collected using participant observations supported by field-notes, video-recordings and examination of children's models and drawings. Throughout the workshops the researcher was positioned as a participant observer, taking part of the events being studied, in order to identify the inter-play of variables that support the emergence of children's creativity (Denscombe, 2010). As a participant observer the researcher could also lead the teaching initiative, becoming immersed in the social worlds of two classes in order to experience and to "reflect the detail, the subtleties, the complexity and interconnectedness' of these social worlds" (Denscombe, 2010, p. 206). O'Leary (2004) also asserted that it is impossible for a researcher in this dual role to be objective because their observations must be subject to fluctuations in attention and biased in the selection of observational foci and the reactivity of pupils. To counteract subjectivities, video-recordings were made of the workshop and these were transcribed immediately afterwards, to ensure accuracy of verbal exchanges. The use of video technology to record observational data provides a detailed and accurate record of what is taking place in the field.

14.7 An Illustrative Example: The Bridge Commission

The Bridge Commission example was chosen because it is representative of the dramatic inquiry approach and enabled the researcher to evaluate to what extent children were supported to be creative at each step of the Engineering Design Process. It also illustrates the model and provides teaching strategies that could be adapted for delivery in a primary school setting.

14.7.1 Step 1 Define the Problem

The story *Iggy Peck, Architect* (Beatty, 2007) is shared with children to introduce images of bridges and essential vocabulary including the terms: beam, arch, cantilever, suspension, deck, abutments, keystone, and span. Further discussion of the story is interrupted by the arrival of a special commission from a client, *Future Worlds.*

Problem An old bridge has collapsed, trapping the residents of an island who are threatened by rising tides and further flooding. Children must travel to seek ideas for bridge designs from Leonardo da Vinci and use these to inform their own designs. Each bridge must meet a rubric of scientific criteria (Table 14.2).

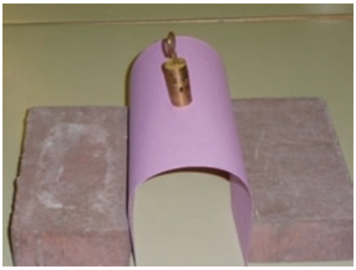
Apprentices travel to da Vinci's workshop, in 1502, with copies of the commission and the rubric. Leonardo (educator-in-role) is present in the workshop surrounded by sketches of beam bridges, arched bridges, bridges with gate towers and drawbridges. He explains Sultan Bayezid II, leader of the Ottoman Empire has

Table 14.2 A rubric of scientific criteria used to evaluate each bridge design

TEST	Performance	Test criteria	Equipment	PASS	FAIL
Dimensions	The bridge enables 'passengers' to cross a gap of 50 cms (minimum).	The bridge has a span of 50 cms. A wind-up toy and marble can travel across the bridge.	1 metre ruler		
Stability on land	The bridge is stable on the surface of a table.	The bridge stands securely on a display table.	Display table, timer.		
Stability in water	The bridge supports remain stable in water. The bridge supports remain intact in water.	The bridge stands for 10 mins in a water tray.	Water tray and timer.		
Strength	The bridge withstands the weight of falling objects during storms.	The bridge can support an increasing load minimum 2 kg.	kg and 600 g masses		
Wind resistant	The bridge remains intact during severe winds.	The bridge stays intact when blasted with a hair-drier for 5 minutes.	Hair drier		
Visual appearance	The bridge contains recognisable shapes and symmetry.		Aesthetic appeal to individual.		
Additional tests required by apprentices (for innovations)					

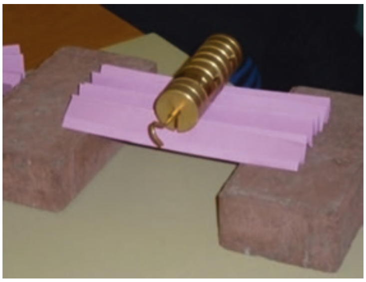
issued a commission inviting artists, architects and engineers to create designs for a new bridge to span the Golden Horn River. The bridge will link the cities of Constantinople (Istanbul) and Galata. He has submitted a design for an arched bridge and is waiting to hear if his design been successful. Leonardo shares his design for the bridge with the apprentices explaining its features and answering children's questions. Apprentices share news of their commission and rubric of scientific criteria. Leonardo expresses delight at the task and invites children to take part in some practical inquiries to examine key concepts related to bridge design e.g. stability and strength. In his workshop apprentices investigate the strength of materials by testing and comparing the different loads that can be supported by one sheet of paper, when folded in different ways, e.g. flat, arched (Fig. 14.2), folded into a cylinder or concertina (Fig. 14.3).

Guided by da Vinci, children's prior learning is operationalised, extended and made readily available for application in the context of their real-world problem. Da Vinci demonstrates how the blocks from which an arched bridge is constructed are held in place by the force of compression. This force pushes outwards in both directions from a centrally positioned key stone (the keystone) and is distributed along the curve into the abutments.



In this arched arrangement a single piece of paper supports a greater weight because the force exerted by the massses (load) is distributed across the curve of the paper bridge.

Fig. 14.2 Testing an arched structure



When folded in a concertina this single page paper bridge can support a greater weight because the load is distributed across the triangular structures.

Fig. 14.3 Testing the strength of a concertina structure

14.7.2 Step 2 Generate Ideas and Possibilities

Apprentices return to the present time and examine photographs of a range of bridges. The educator introduces the process of morphological analysis (Zwicky, 1969) in which apprentices write down key words, on a drawing board (consensus placemat) (Kagan, 1994) using ideas from all of the sources examined. This exercise allows children to engage in possibility thinking through word associations (Craft, 2002). Pedersen and Burton (2009, p. 29 cited in Newton & Newton, 2014, p. 583) observe these preparatory inquiries function as antecedents of creativity in real word design, arguing that supporting learners "to generate ideas is important, but equally important is preparing them to recognise ideas and use ideas from a variety of sources".

14.7.3 Step 3 Select Ideas and Plan

During the planning phase all responsibility for decision-making is shifted to children and no directions or instruction sheets are provided. The rubric of scientific criteria provided guidance to children on the kinds of tests their completed bridge would have to pass to be successful. Apprentices are invited to summarise the features they would like to include in a bridge design, justifying decisions and anticipating problems. They then create individual annotated drawings of a bridge, containing these key features. These drawings are pinned onto a display board and using post-it-notes, apprentices vote for one design they would like to make and test. Collectively apprentices plan how they will proceed. This process allows all children to express and make visible their ideas.

14.7.4 Step 4 Make and Test

Apprentices deconstruct, combine and recombine materials while interacting with one another using talk and gestures, until they bring into existence a physical artefact that meets a rubric of scientific criteria (Lave, 1988; Hutchins, 2000. The educator supports children by acting as a curious and naïve fellow investigator as they pursue diverging lines of enquiry by testing out their ideas first-hand—or through secondary research. When the bridge is completed, groups test the performance of their models using the rubric of scientific criteria to evaluate its performance.

14.7.5 Step 5 Evaluate and Iterate

Following the testing phase children engage in peer review and reflection to discuss the performance their bridges and to receive critique using a group-to-class feedback forum. Groups of apprentices identify possible ways to enhance the performance of their bridges and request further advice for improvement from other groups. The educator explains if a design is unsuccessful during the testing phase, following reflection and peer review the designers must ‘go back to the drawing board’ and modify their bridge design. Finally working in pairs as plenary pals, children are encouraged to summarise their experiences of working through an EDP. This process enables the educator to activate pupils as learning resources for one another (Wiliam & Thompson, 2007) and supports the development of children’s metacognition.

14.8 Findings

During the workshop, in response to the commission, each team of apprentices produced plans, drawings and an artefact that could be tested using the rubric of scientific criteria. Artefacts were brought into existence as a result of children’s talk, gestures, physical interactions and combinatorial play with materials, and with one another. A video-recording of the workshop was made and transcribed, supported by the researcher’s fieldnotes. Episodes of creativity demonstrated by Group A, at each step of the EDP, are deconstructed and analysed below using Murcia et al’s, (2020) framework (Table 14.3).

Within dramatic inquiry, talk supported the process of knowledge elaboration. An extract of dialogue reveals how children in Group A used talk to generate and explore ideas and to evaluate the feasibility of making a bridge that could float:

> Educator – Oh, that looks interesting, can you explain what you’re thinking about here (points to the sketch).
>
> Child A – It’s a float for when it rains…
>
> Child B – (Interrupting) …and if it floods, not just rains.
>
> Child A – (Gesturing) Yes, well if it floods the bridge will float on its floats. It floats anyway. It will be a floating bridge.
>
> Child C – (Shakes head in doubt) No, it won’t, it will get washed away. It will smash. The other bridge fell down in the rain, this one will fall down.
>
> Child A – No (shaking head and holding hands up in a cup shape) it fell down because it didn’t float, if it could’ve floated it would’ve floated, I mean it wouldn’t have fallen down.
>
> Educator – What are these? (Points to 4 square grids below the deck of Child A’s bridge design).
>
> Child D – Floats They are all float-rafts. That’s a raft (pointing to 4 flotation structures). That’s a raft.
>
> Educator – Where did you get that amazing ideas from? Have you ever seen or been on a floating bridge?

Table 14.3 Deconstructing children's creativity at each step of the EDP

Step in the EDP	Characteristics of children's creativity demonstrated during the dramatic inquiry
Step 1 Define the problem	**Place:** Children demonstrated curiosity, an antecedent of creativity during the story-telling session and at the arrival of the commission prompting question-posing. Da Vinci's workshop provided a range of materials and objects that offer affordances to children encouraging combinatorial play and experimentation (Craft, 2002) e.g. they began discussing which objects and materials float/sink; which were waterproof/not waterproof; they realised they could test, combine or fold materials.
Step 2 Generate ideas and possibilities	**Person**: Initially apprentices were guided through the process of morphogenesis to facilitate ideation drawing on sources including their prior learning, the storybook, the commission, the rubric, da Vinci's bridge design and their reflections on the learning acquired in the practical investigations and images of different bridges. They deconstructed the wording of the commission and the rubric of scientific criteria. They wrote down key words and generated all possible word associations, links and ideas in response to the key terms e.g., strength. Each apprentice mapped their ideas onto a collaborative 'drawing board'. Child A drew on previous knowledge from swimming lessons concerning the function and use of floats and attempted to persuade others to apply this knowledge in their design. The educator was sufficiently curious about children's ideas and flexible in encouraging children to research such possibilities. The educator asked this group to add the criteria 'floats for ten minutes' to their rubric, in the additional criteria column, because this was an agreed and an intentional design feature. **Process:** Using the iPad children searched for floating bridge and discover such bridges exist—built on pontoons. A further search of the term 'pontoon' yielded the explanation 'a watertight float or vessel used where buoyancy is required in water as in supporting a bridge…' (Collins on-line English dictionary) further supporting possibility thinking along this line of enquiry (Craft, 2002). When all of the children realised such bridges existed their design became a real possibility and agreed to construct and test it.
Step 3 Select idea and plan	**Process:** This rubric together with the materials available offered affordances and constraints to children allowing them to be imaginative in their planning ideas. Children used talk, gestures and physical interactions when explaining their ideas to one another and when combining and considering which materials to select. **Person:** Children demonstrated agency in their decision-making and choice of materials throughout the planning phase. This included examining the affordances offered by the materials by asking 'What does this object do?' and 'What can I do with this object?' leading to experimentation.

(continued)

Table 14.3 (continued)

Step in the EDP	Characteristics of children's creativity demonstrated during the dramatic inquiry
Step 4 Make and test	**Person**: Using the rubric of scientific criteria as a source of reference, groups select materials to use, or to test prior to use, to bring their design into existence. Children's interactions progressed through trial and error. Again, the educator acted as a fellow investigator—Encouraging but not directing. **Process:** Children pursued lines of enquiry by testing out their ideas—to see if their possibility thinking resulted in a resolution—or through secondary research. Groups tested the performance of their models using the rubric of scientific criteria to support their judgements. **Product**: Children began combining and recombining materials and interacting with one another using talk and gestures, until they brought into existence a physical artefact— a floating bridge—to meet a rubric of scientific criteria.
Step 5 Evaluate and iterate	**Product**: A physical artefact 'Floating Bridge' was produced. This bridge was declared fit for purpose passing all tests outlined on the rubric of scientific criteria and was original to the group. Group A worked collaboratively to create a pontoon bridge with a floating platform composed of small rafts each made from lollisticks and corks, with an upper deck for foot passengers. Following the testing phase children discussed the performance of their bridges using a group-to-class feedback forum. Groups identified possible ways to enhance the performance of their bridges requesting further advice for improvement from other groups. The educator shared news that da Vinci's design was rejected by Sultan Bayezid II because it looked unexciting. This aspect of the teaching initiative modelled to children that great scientists experienced rejection and failure, but cope by adopting a resilient, determined frame of mind. Apprentices learned that in recent years a team of architects and engineers from the Massachusetts Institute of Technology successfully built a prototype of da Vinci's bridge design using his drawing. This bridge design would have also survived earthquake shockwaves, saving lives in an earthquake prone area (Chandler, 2019).

Child C – (Looking surprised) Do they have them? Are they real?

Child A – We've been using floats in swimming to strengthen our legs. So, I thought we could use floats under the bridge.

Educator – Well, you could use an iPad to find out and then you can decide if you could all make it work. If you can imagine it—you can make it happen.

14.9 Discussion and Implications for Classroom Practice

Throughout the implementation of this adaptation of dramatic inquiry, improvisation supported pupils' agency and creative thinking in the context of a STEM challenge.

The provision of a rubric of scientific criteria supported children's creative thinking by placing demands upon them that influenced their collective decision-making. For example, the final artefact produced was required to fulfil specific criteria, these requirements provided both constraints and affordances; relating to the resources made available provoking possibility thinking, experimentation and combinatorial play. This resulted in episodes in which children alternated between epistemic and ludic play, asking themselves what does this object do and what can I/we do with this object? The rubric thus grants groups of children sufficient agency and autonomy to make decisions with reference to peers, rather than to their educator.

Within this improvisation talk was key to the generation and development of children's ideas and the inter-connection of these ideas enabling the elaboration of creative thinking and facilitating decision-making. Talk enabled children to engage in the process of morphogenesis, ideas generation, through the use of word associations and annotated drawings. Use of a consensus placemat style 'drawing board' (Kagan, 1994) encouraged idea generation, allowing all children to contribute a diverse range of ideas and to make all children's thinking visible to the group; encouraging tangential and divergent thinking. Providing these opportunities to allow children to map all possible ideas stimulates possibility thinking that constitutes creative thinking, as they formulate ideas, experiment with ideas, share, explore and refine ideas with others (Craft, 2002).

Talk also facilitated effective reflection and peer reviewing processes. Opportunities for peer review both prior to and after testing were very important to emphasise to children the primacy of evidence and testing as a basis for decision-making, generating explanations and understanding, correcting misconceptions and activating learners as resources for one another.

The availability of technology, while pursuing a line of enquiry, facilitated children's autonomous, in-the-moment research, for example, during their search for 'floating bridge', while the discovery of 'pontoon' generated such excitement at the realisation their possibility thinking was physically feasible.

14.10 Limitations of the Study

Given the unique nature and particularity of the teaching initiative, da Vinci's Apprentices, the transferability of the study's findings to other teaching initiatives are limited because they cannot easily be generalised to the wider population, however Opie (2004) argues:

> The merit of any piece of educational research is the extent to which the details are sufficient and appropriate for an educator working in a similar situation to relate his/her decision making to that described. In short, the reliability of the work is more important than its generalisability. (p. 5)

The use of video-recorded data confirmed the initiative provides a medium in which language, gestures and the manipulation of materials facilitate the creation and construction of new physical artefacts. A further line of enquiry will be to consider how the characteristics of creativity are developed through the social distribution of cognition during a STEAM Challenge. This will require observational data to examine the interactions of children with each other, through the use of language, gestures and collective reasoning with materials.

14.11 Conclusion

The deployment of an Engineering Design Process, integrated within dramatic inquiry, allows an educator to use creative, playful learning approaches, to support children's reasoning with materials, during a problem-based STEAM Challenge. By following da Vinci's polymathist approach to inquiry, children have an opportunity to connect their learning across many disciplines and to synthesise creative and innovative solutions to problems. *Da Vinci's Apprentices* is a teaching initiative that recognises the importance of operationalising children's curiosity as a necessary pre-requisite to facilitate their creativity and engagement in learning. Improvisation and the provision of a rubric of criteria support children's agency, autonomy and creativity. This adaptation of dramatic inquiry models to children that it is important to draw upon sources of ideas from more knowledgeable others and to deconstruct, play with and recombine these ideas to synthesise new and novel possibilities (Craft, 2002).

Da Vinci's Apprentices can provide educators with a means through which to design bespoke curricular projects that align with a school's long-term curricular plan. Within this initiative, children can be supported to work on specific projects from different periods of history with the assistance of a relevant key scientist/inventor using creative contexts in which to integrate science, arts and humanities**.** During the planning phase, the educator is required to undertake research about the work of the scientists, engineers and inventors who have actively contributed ideas appropriate to a topic focus. This provides educators with an opportunity to make links to contemporary problems and to make the curriculum relevant to their national, regional and local cultural circumstances, interests and concerns.

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Chapter 15
Working with Nature of Science in Early Childhood Education: Inspiring Children's Curiosity, Inquiry and Play

Lena Hansson, Lotta Leden, and Susanne Thulin

15.1 Introduction

> And now they [the children] automatically ask, just like that: "Do we have any microscopes here?" Do we have any magnifying glasses?" "How…?". Thus, an investigative mode has arisen among them.

This chapter takes as its point of departure the principle that the values and aims of democracy and social justice are central to ECE (see e.g. Margrain & Hultman, 2019; Mitchell, 2018). In this kind of education, empowerment and agency are highly valued goals. In the quote above, the preschool teacher describes how the research project they are involved in, which is about introducing nature of science (NOS) in preschool, has led to new questions being raised by the children, and a desire among them to investigate things in their surroundings.To teach about NOS means to highlight what characterises scientific knowledge, how it is developed and in what ways humans are involved in scientific knowledge processes (see e.g. Lederman, 2007; Erduran & Dagher, 2014; McComas, 2020). It can also involve "celebrat[ing] the creative aspects of science – the context of discovery" (Taber, 2012, p. 71). Creative elements are seldom communicated as being part of science and are often neglected in science teaching (Hadzigeorgiou et al., 2012; Kind & Kind, 2007; McComas, 2020; Taber, 2012). This chapter builds on a research project where the researchers (the authors) and five preschool teachers collaboratively explored possibilities for NOS teaching in the early years (children aged two to six). The teaching method was book talks about NOS, based on illustrated trade books with science content (Hansson et al., 2020). A book talk comprises both the reading and the teachers' and children's questions and discussions connected to the reading.

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Both fiction books (in the form of fairy tales) and non-fiction (expository) books were used. Even though the focus of the project was to teach NOS through book talks, the teachers described how the focus on NOS spilled over into other activities and stimulated children's play and curiosity as well as their desire to investigate (see quotation above). In this chapter, we use two events at the preschool to illustrate how NOS can become a tool and a source of inspiration for children and teachers when they engage in creative investigations of things of interest to the children; in this case snails and spiders. From these two events, we argue that NOS has the potential to contribute to empowerment and agency for young children.

15.2 Nature of Science in Preschool?

There is a great deal of research on NOS teaching (Lederman, 2007; Hodson, 2014), and different frameworks have been developed to describe important NOS aspects (Allchin, 2017; Erduran & Dagher, 2014; Lederman, 2007; McComas, 2020). In this project we have used a framework developed by McComas (2017, 2020). The framework has three overarching NOS-categories and became the starting point for discussion with the teachers, as well as for analysis. The NOS-categories are: "tools and products of science, the human elements of science, and science knowledge and its limits" (McComas, 2020, p. 40).

Most of the NOS teaching research has been oriented towards older children and students. Despite the lack of research on NOS in early years science, it has been suggested that NOS should be taught already in preschool (Bell & Clair, 2015; Akerson et al., 2011; Hansson et al., 2020, 2021). The few existing studies point to possibilities for a variety of NOS issues to be discussed with young children (Akerson et al., 2011; Hansson et al., 2020, 2021). In our own publications about NOS book-talks with two- to six-year-old children (Hansson et al., 2020, 2021), we have shown how the processes and tools of science became the focus of many of the book talks (Hansson et al., 2020, 2021). This focus included directing attention towards how we can know the facts described in the books (about dinosaurs, space, elephants, etc.); that is, the kinds of methods and tools that are used in scientific research. In relation to these aspects, teachers and children often came to discuss human elements of science. This could mean highlighting collaboration in science, or drawing attention to the fact that being a scientist is a profession or job that people with feelings and needs, like everyone else, are involved in. There are also examples of book talks highlighting characteristics and limits of scientific knowledge (e.g. that science does not know everything, that scientific research is ongoing, or that scientific knowledge is sometimes revised), but these are rarer.

Creativity, which is the particular focus of this book, is one aspect of the human elements of science (McComas, 2020). It is argued that creativity is an essential part of science: "Creativity and imagination are found throughout science /…/ Everything from the identification of a problem worth considering, the specific methods by which that problem may be addressed and, of course, the interpretation of results, has a creative component" (McComas, 2020, p. 52). However, as already mentioned, creativity seldom has a central role in the teaching of science or on other occasions when images of science are communicated. We have argued elsewhere (Hansson et al., 2021) that issues concerned with reserachers' use of creatitivy and imagination in different phases of the research process can be raised in ECE science. This can be done through connecting children's own experiences of creativity to creativity in scientific research, for example when they themselves engage in investigations.

The research literature provides different arguments as to why NOS should be taught as part of science. One argument put forth recently is that NOS can constitute an important part of a science teaching aimed at citizenship, democracy and social justice (e.g. Hodson, 2014; Yacoubian & Hansson, 2020). We have previously elaborated on this latter argument in relation to ECE (Hansson et al., 2021). One part of this argument is that focusing on NOS can provide diverse images of science and scientists, and thus offer alternatives to many of the stereotypical images that are often communicated in the media, for instance, in trade books aimed at children (Kelly, 2018), and sometimes in science teaching. Diverse images of science and scientists afford possibilities for more children to perceive science as relevant for them. Another related reason is that NOS can contribute to empowerment and agency in relation to everyday and societal issues that are essential when science in ECE emphasises democracy and social justice. Researchers in science education have engaged in discussions about teaching aims related to every day life and citizenship under the umbrella concept "scientific literacy" (e.g. Roberts, 2007). These discussions have focused on "science as a contributer to 'rational thinking' rather than creative empowerment" (Kind & Kind, 2007). In this chapter we will focus on the latter and illustrate how NOS teaching can stimulate children's raising of questions and creative engagement in investigations that are of interest to them, and thus have the potential to contribute to empowerment and agency for preschool children (aged two to six).

15.3 The Project

Swedish preschool is for children aged one to six. It is a voluntary school form that entails both education and play. Although it is voluntary, most children in Sweden attend preschool (i.e. 95% of children aged four to five, Swedish National Agency for Education, 2019). Swedish preschool is regulated by a national curriculum (Swedish National Agency for Education, 2018), which includes education goals related to both scientific content and scientific working methods.

We discussed the original idea for the project in Hansson and Leden (2019) where we suggested NOS book-talks as a method for teaching NOS. As previously mentioned, the project, using illustrated science trade books, was performed as a close collaboration between researchers and five preschool teachers at one preschool. Since the project was explorative it was beneficial for the project that it was characterised by close collaboration between researchers and teachers thereby building on previous research as well as on the teachers experiences. Research performed in this way, has the potential to be perceived as more relevant and accessible to other teachers, and since it is performed in authentic settings “there is no ‘translation problem’ when /…/ disseminating this knowledge to the profession” (Pramling et al., 2019, p. 179).

The project lasted one semester and included workshops where teachers and researchers discussed NOS and NOS teaching through book talks, focus groups where the preschool teachers shared their experiences from the NOS book-talks, and a large number of book talks. The book talks were led by the teachers at the preschool, and the children involved in the project were children that the teacher normally worked with. The empirical material consists of audio recordings from book talks and focus groups, documentation of children’s drawings, and artefacts used by the preschool teachers to illustrate certain aspects of NOS or contents of the books. Participating teachers as well as the children’s caregivers were informed about the purpose and the implementation of the research study prior to the start of the project. Caregivers gave written permission for the children’s participation. Also the children were informed prior to the start of the research project and before audio recordings, and were able to choose not to participate. Audio recodings of book talks and focus groups were transcribed. Excerpts used in this chapter have been translated from Swedish.

In this chapter, we focus on what the preschool teachers in the focus groups referred to as the spin-off effects of the project—for example, children who played scientist, who asked new kinds of questions or who engaged in investigations. The teachers viewed these spin-off effects as directly related to the NOS project and saw them as an indication that the focus on NOS during the book talks were meaningful for the children. Furthermore, the teachers claimed that as a result of the project they had begun to notice and respond in new ways to the children’s questions and the children’s desire to investigate (see Thulin et al., manuscript). Although we did not document most of these spin-off effects, a few instances were recorded because they occurred or were discussed during book talks. We will present two narratives about spin-off effects in the form of children’s engagement in investigations. They were constructed by making use of the teachers’ experiences which they related to us in the focus groups, in combination with children’s and teachers’ audio-recorded conversations. The events took place mid-project which meant that both teachers and children were used to the book talk format and the focus on NOS.

The first narrative is built around an investigation of the food preferences of a snail. This investigation took place with a group of two to three year-old children where Sara was the teacher. The second narrative is built around an investigation that took place with a group of children aged five to six which Marie taught. All names are pseudonyms; teachers’ names in uppercase in the transcripts.

We see these narratives as a way to articulate what both teachers and researchers found interesting and important, namely, that the introduction of NOS through the book talks seemed to fuel children’s curiosity and desire to investigate their surroundings. The intent with the narratives is not to describe everything that happened at the preschool that related to NOS, but to provide two examples that we consider illustrate the potential that NOS teaching has in a preschool setting with respect to empowerment and agency.

15.4 Results

The results are presented as two narratives, which both provide examples of children's curiosity and investigations in relation to animals.

15.4.1 Narrative 1: An Investigation of the Food Choices of a Snail (Children Aged Two to Three)

During a focus group, one of the teachers, Sara, described how the book, *Swift by the creek* (*'Vips vid bäcken',* Jonsson, 2018), inspired children's curiosity and inquiry. The book is a fairy tale about a shrew named Swift who investigates nature and finds himself in an adventure trying to save a larva. A page at the end of the book contains facts about animals and plants that are mentioned in the book. Sara shares her experiences of the children's increased curiosity about nature:

> …what he [Swift] finds and what we find when we go out has made them much more curious about things in nature. And we were on the excursion and we could bring stuff and so on with us and try out things, like he does, here [at the preschool], like float and sink and so on. And… that they eat. /…/ I brought this Burgundy snail [a snail common in the Southern part of Sweden] to work and we read about what it ate, and some people had written [on the Internet] that they eat melons and dandelions. But it didn't eat the melon [when the group of children investigated it]; it only ate the dandelions. But that it had really eaten all the dandelions by the next day, that was exciting. That they eat different things /…/ [Sara concludes:] Yes, that we, that he [Swift] discovers things and that we can discover things.

Sara claims that the children have increased their curiosity about nature and that they use Swift as a role model when they test things the same way he does. Previously, during book talks in this group, NOS aspects such as empirical investigations, tools and human involvement were highlighted. The book about Swift created opportunities for the teacher to reconnect to these aspects of NOS. The experiences that Sara shared in the focus group are further elaborated in this section through excerpts from her conversations with the children. During the very first book talk about Swift, Sara posed the question about how you can know what kinds of food an animal likes to eat:

SARA:	How can we know that fish eat flies?
Carl:	Uh, they don't eat flies.
SARA:	Yes, it says so here and it actually is so. They can probably eat other food too. But they can also eat flies. How can we know that?
Mia:	They eat such things too.

SARA: Yes, they can do that.
Carl: They can do that.
SARA: But how can we know that?
Carl: How can we know that?
Mia. They eat fish.
SARA: The fish can eat the flies that land on the water. Yes, because someone has been curious about the fish and what kinds of things they eat, so they have researched that, they have gone out to check.

Sara tries to engage the children in a discussion about how we can know what kind of food fish eat. She ends the discussion by saying that someone has been curious and has done research on this by watching ("they have gone out to check"). After the reading, Sara shows a snail that she has brought from her garden. They observe the snail together and talk about its tentacles. Then Sara poses a question about what it likes to eat. This was first explored through searching the Internet, followed by the investigation that Sara mentioned in the focus group (see above) about the kind of food the snail likes to eat. Sara and the children have given the snail possible things to eat from suggestions gleaned during the Internet search. In a follow-up talk Sara reminds the children that they collected food for the snail and asks the children if they remember the specific name of the snail. However, the children, rather than discussing the name of the snail, want to look inside the container in which they keep the snail:

SARA: We have also been on a voyage of discovery [just like Swift] /…/ what do we find when we go out into the courtyard?
Carl: Snail!
SARA: Yes, we do, we find a lot of snails and you gather snails all the time and you collected food for the snail. I had brought a snail, a large snail, yesterday. Do you remember its name?
Jack: [Child who cannot talk, makes utterances].
SARA: What was the name of the snail?
Carl: May I see?
Mia: Can we open the lid?
Fanny: Is that a melon in there?
/…/
Fanny: May I see?

Sara drops the question about the name of the snail but uses the correct name throughout the following discussion. Then she focuses on the investigation:

SARA: We googled Burgundy snail.
Jack: [Expresses something wordlessly but with animation].
SARA: Do you remember that?
Fanny: Is it a large snail?
SARA: Mm!
Mia: Has it eaten my food?
SARA: And we looked at Google for what it could eat, do you remember that? You collected food for the Burgundy snail. What kind of food did you collect?
Mia: Some flowers.
SARA: Yes, what kind of flowers? /…/ You collected some yellow flowers, what was their name?
Mia: Rose [in Sweden dandelions are called Maskros, i.e. Maggot-rose]

SARA:	Dandelions, yes/…/ can you see the dandelions? /…/ How many dandelions did you collect?
Carl:	Three.
SARA:	Three. Can you see them?
Fanny:	I can't see them.
Carl:	They have eaten [them] up.
SARA:	Yes, the snail has eaten your dandelions /.../ and look…
Carl:	They have eaten the dandelions.
SARA:	Yes, but look there [the children are squabbling to get a look] /…/ yes, the dandelions are gone, but the other, look at the red piece there; look, what is the red piece?
Fanny:	Melon.
SARA:	Yes, what has happened to that?
Mia:	Nothing.

Here the children and Sara recall that the day before, the children had given the snail dandelions and melon to eat and now the children can see that the snail has eaten the dandelions ("they have eaten [them] up"), but the melon is still there. The children have the opportunity to learn how empirical investigations, in combination with information from the Internet or books, can be used to develop knowledge, or check if a statement is correct. This event illustrates how the introduction of NOS in preschool can inspire children's curiosity and inspire teachers and children to investigate issues of interest to them. In this event, the story about Swift linked the discussions of different NOS aspects to the children's own investigations.

15.4.2 Narrative 2: Investigations About Spiders (Children Five to Six Years Old)

In one of the focus groups, the teacher Marie shared, as a positive outcome of the project, her experience about children's increasing desire to investigate different phenomena:

> But they are really interested, and they want to find out for themselves. There have been so many questions: how do they spin this thread, how does it vomit? They kind of want to go in and sit down now, to put a fly in the bathroom and they want to sit there and investigate. Is it really like this? Um, and they get to experience, on their own, that they are researching when they are outside. They have different theories about worms and birds. So they can kind of connect [things], which I don't think they would have been doing otherwise [if they had not been talking about NOS] /…/ And now they automatically ask, just like that: "Do we have any microscopes here? Do we have any magnifying glasses? How…" It's like an inquiring practice has arisen from themselves, which I feel they [explicitly] name as well. I feel they have gained another language.

Here, Marie talks about how the children in her group have become interested in spiders, and that they take initiative for further investigations. This particular focus of their engagement was something that occurred during a period when Marie and her group of children focused their book talks on the book *Spinderella Tarantella* (Lindahl, 2012). The book is a fairy tale about a spider lady in high heels who shares opinions on various topics from terrible children to tasty spider husbands. A page at the end of the book shares facts about real spiders such as their names and physical apperances. During these book talks, attention was directed towards not only various facts about spiders but also towards different NOS aspects such as human involvement in finding out the things we now know about spiders. The issue of *how we know* things like spider web being sticky was discussed during the first book talk related to this book and children suggested that "maybe someone has seen it". Issues like these were revisited many times during the book talks. When reading about spiders who wrap the flies they catch in silk, the children shared ideas about how the spiders do the wrapping:

MARIE:	Wrap them, that is something we don't know either, what she wrapped them in.
Morgan:	Now I know, maybe she takes some leaves and then when a fly comes, then she quickly ties it up so it doesn't sprawl and then it has a poisonous bite on it so it dies and then it vomits on it if it's hard and then eats it up.
MARIE:	Mm, it can be like that, one could check that, and maybe we could check that.
Sofia:	Or maybe the spider puts spider web and then it [the fly] sticks and then it [the spider] spins so the fly is stuck.
Axel:	Or the spider takes some web and ties it and then packs them in the bag.
Sofia:	But that's what I said.
MARIE:	Yes, one can have different thoughts and theories about how she does this.
Morgan:	Or maybe she spins a web around them so they become stuck but later she takes them and vomits on them.
MARIE:	Maybe we should keep that as a question at issue: how do spiders wrap them? Do you think we could find out somewhere?
Several children:	Yes!
Axel:	I think so too.

Marie confirms that there could be different ideas about how spiders wrap flies and suggests that this could be a question that could be more closely examined ("do you think we could find out somewhere?"). The children agree that this could be possible, and the teacher continues asking where they could go to find out:

MARIE:	Yes, where would we be able to find that out? We will have to check that.
Max:	In the bathroom.
MARIE:	Will we stand in the bathroom and wait?
AISHA	[another teacher has joined the group]: And then we will have to let a fly in and then we will see what happens.
MARIE:	Then we will have to be scouts there.
Lisa:	When we were outside…
Clara:	Or put a frog in there.

Here, Marie and the children engage in a joint discussion about how to find out how the spiders wrap the flies. One child suggests that they could try the bathroom, probably because they have seen spiders there, and Marie builds on this idea, suggesting that they could wait in the bathroom to see what happens, and maybe let a fly in. Another child suggests that they can instead let a frog in. During this talk about spiders, one of the children made a connection to non-teacher-led time at the preschool, when some of them were playing at being explorers:

Lisa: But when we were outside then we pretended, you, me and Albert, then we pretended to play explorers, then we saw a bird who had killed a lot of worms and then pooped on them and then flown away.
Nicolas: Yes!
MARIE: Did you see that when you were outside doing research?
Nicolas: We did not see the bird; we just saw that the worms were dead, and bird poop on them.
MARIE: Then you had a theory that it could have happened that way, that's exciting, you were a bit like explorers.

The first child describes how they saw a bird which had killed many worms, 'pooping' on the worms and then flying away. A second child corrects her saying that they did not actually see the bird, only the dead worms and the bird 'poop'. Marie confirms this as an interesting issue and explains that they had a theory about what could have happened, and that they were a little bit like explorers. After this connection to experiences from other activities at the preschool, the discussion and plans for the spider investigation continues, and one of the children revives his suggestion about letting a frog in:

Morgan: Maybe we will let a frog in there because spiders also like to eat frogs, so we can let a frog in so it jumps out, so that we have a frog in the hallway and open [the door] a little and then watch if a fly…
Sofia [protesting]: Spider!
Morgan: If a spider has come and then eats it.
MARIE: It is exciting that you are so on to it…
Sofia: Then it will take a very long time.
MARIE: Yes, we will do research, it is probably really hard work to find out about things.
Morgan: You have to wait all the time.

The discussion this time ended with Marie reflecting on how it is to research and try to find things out ("it is probably really hard work"), and one of the children agrees ("you have to wait all the time"). In this example, we can see how curious these preschool children are about a phenomenon that they hear about and were inspired to investigate. According to Marie, this desire to investigate increased during the project; the children started to develop a suitable language, and started to ask for appropriate tools. This implies that a focus on human involvement in research and how things are found out, for example, through empirical investigations, discussed as 'looking' and 'seeing', affects the actions of children at preschool. The event illustrates that the book talks about NOS, inspired children and teachers to engage in investigations of their own choice. The event further indicates that raising NOS perspectives in preschool might contribute to children's empowerment and perceived ability to investigate things of relevance to them.

15.5 Discussion and Concluding Remarks

In this chapter we have seen how attention directed towards NOS through book talks ‘spills over’ into other activities in preschool, and how children and teachers “celebrate the creative aspects of science” (Taber, 2012, p. 71). In the two narratives presented, we show how the NOS discussions inspired investigations of spiders and snails. Children and teachers were engaged in posing questions (What does the snail eat? How does the spider wrap the flies?), discussing what kinds of methods to use in investigations (letting a fly or perhaps a frog into the bathroom where the spider is) and drawing conclusions (the snail eats dandelions but not melon). To engage in the process of investigations in this way is a creative endeavour. It offers opportunities for children to experience science not only as a logical process, but also as a creative process which is a perspective requested in earlier research (Kind & Kind, 2007; McComas, 2020).

The narratives illustrate that NOS can function as fuel for children’s curiosity and for their desire to investigate. In the first narrative, where we meet the youngest children (aged two to three), the teacher, Sara, orchestrated the investigation, but the children were engaged in the observations and the drawing of conclusions regarding what the snail eats. In the second narrative, the older children (aged five to six) were active in formulating questions and planning for an investigation. They also shared experiences of observing and drawing conclusions during play. During focus groups, the teachers shared experiences of an increased curiosity among the youngest children, and increased questioning and a desire to investigate things among the older children. The narratives show how children’s curiosity, questions and desires were taken seriously and drew responses from the teachers. That kind of teacher response, which provides freedom and space for children, and supports them in carrying out their ideas, is important for the development of children’s agency (Siry et al., 2016). From the narratives presented here, we argue that the focus on NOS provided support for science teaching to become a creative endeavour. In the narratives we can see that the NOS book-talks inspired children to pose questions and take intitatives to investigate. Similary, the focus on NOS helps teachers notice and create space for children’s questions and desire to engage in investigations.

It has recently been suggested that NOS should be included in ECE (Bell & Clair, 2015; Akerson et al., 2011; Hansson et al. 2020, 2021). Many different reasons could be given for this. This chapter has taken as its point of departure the principle that the values and aims of democracy and social justice are central to ECE (see e.g. Margrain & Hultman, 2019; Mitchell, 2018). In such an education, empowerment and agency are highly valued goals. We hope this chapter helps to illustrate how NOS has the potential to contribute to these overall aims and goals. The narratives in the chapter exemplify how NOS teaching has the potential to support children and teachers to engage with creative elements of science, and to contribute to empowerment and agency for the children in the present. NOS teaching is also essential for long-term aims of science education related to empowerment and agency in everyday life, and as a citizens (see e.g. Hodson, 2014; Yacoubian &

Hansson, 2020). However, more research is needed on the role of NOS in various ECE contexts.

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Chapter 16
Taking STEM to STEAM and Enhancing Creativity

Marion Cahill and Jacinta Petersen

16.1 Introduction

In the last decade, STEM education has increasingly become part of Australian educational discourse. The Office of the Chief Scientist (2014) highlighted the importance of STEM, due to the potential of positively contributing to Australia's productivity, economy and job opportunities for its citizens. Arguably, a coordinated and strategic approach to STEM education may contribute to the development of key competencies that have been identified as vital to life in the twenty-first century, such as critical thinking, creativity and communication (Office of the Chief Scientist, 2014; El Sayary et al., 2015). Other identified benefits of embedding STEM in classrooms have included opportunities for real-world problems to be explored in context and a positive impact on student motivation for traditional STEM disciplines (Department for Education and Training, 2017; El Sayary et al., 2015). It is for these reasons that the *National Science and Innovation Agenda* emphasises the importance of STEM being prioritised in the *Australian Curriculum* (Australian Government, 2015) and that a national STEM school education strategy was developed in Australia (Australian Government, 2017).

However, the implementation of STEM approaches that are rationalised on the importance of STEM for the economy have been criticised for their narrow curricular focus (Harris, 2017). The prioritisation on STEM disciplines has led to perceptions that the arts are undervalued by some within the Australian educational

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community (Parliament of the Commonwealth of Australia, 2017). Such criticisms led to a recommendation by the *Inquiry into Innovation and Creativity: Workforce for the New Economy* that the *National Innovation and Science Agenda* to highlight the significance of incorporating the arts with STEM (STEAM) (Parliament of the Commonwealth of Australia, 2017, p. xix).

To begin this chapter, key literature on the movement from STEM to STEAM and the influence on creativity will be discussed. Following this, the findings of an illustrative case study will be presented, where we are investigating the perceptions of two teachers involved in the implementation of a STEAM approach at Hammond Park Catholic Primary School, a school established in 2014 in Perth, Western Australia. Through a semi-structured interview, the authors sought to understand the implementation of this school's STEAM approach and ascertain how teachers perceived the influence of the approach on student creativity. From the case study, we identified and discuss in this chapter, key findings in light of the literature and proposes recommendations for future research.

16.2 STEM to STEAM

Challenges have been identified with the implementation of STEM approaches internationally and in Australia. While the exploration of real-world issues has been identified as a perceived benefit of STEM programmes, it has also been identified that students do not always make connections between STEM disciplines and their everyday lives (Parliament of the Commonwealth of Australia, 2017). Countries such as Singapore and Taiwan, that have been more successful than Australia in implementing STEM approaches, have higher societal regard and renumeration for teachers and teachers themselves have stronger backgrounds in these disciplines (Parliament of the Commonwealth for Australia, 2017). It has been noted that while there is government support and the development of policies in relation to STEM, this has occurred without guidance about how STEM can be meaningfully implemented into the pedagogy and practice of schools (Bybee, 2013; Harris and de Bruin, 2017).

STEAM "merges the arts with STEM subjects to improve student engagement, creativity, innovation, problem solving and learning" (Perignat & Katz-Buonincontro, 2019, p. 31). The arts provide an avenue for fostering imagination and creative expression (Harris, 2017; Perignat & Katz-Buonincontro, 2019) and are essential for innovation (Madden et al., 2013; Parliament of the Commonwealth of Australia, 2017; Simpson Steele et al., 2016). Arguably, taking a STEAM approach can assist in breaking down the traditional barriers between learning areas, with the arts being considered as another discipline to incorporate (Harris and de Bruin, 2017). In the literature, STEAM approaches can be characterised as: ***interdisciplinary***, focusing on several disciplines under a common theme but as discrete areas; ***cross-disciplinary***, focusing on one discipline as a lens into another discipline; ***transdisciplinary***, where all disciplines are fully integrated focused on a central inquiry or problem; and ***multidisciplinary***, which explores the relationships between two or more discipline areas, without interacting each discipline (Perignat & Katz-Buonincontro, 2019). In critiquing the economic rationale of the current STEM movement, Pirrie (2020) maintains that putting the A in STEM needs to go beyond simply using the arts as a servant of the other areas. This is supported by Peppler & Wohlwend (2017, p. 88) who state that "the promise of STEAM approaches is that, by coupling STEM and the arts, new understandings and artifacts emerge that transcend either discipline".

Numerous benefits have been identified through the implementation of STEAM approaches and many authors advocate for the importance of STEAM (Conradty & Bogner, 2019; Harris and de Bruin, 2017; Henriksen, 2017; Korean Foundation for the Advancement of Science and Creativity, 2017; Parliament of the Commonwealth of Australia, 2017; Simpson Steele et al., 2016; Walshe et al., 2020). It has been argued that the integration of the arts into STEM allows a richer and deeper exploration of content (Harris and de Bruin, 2017; Henriksen, 2017). Embedding the arts in STEM can enhance student motivation in the other discipline areas and foster thinking and problem solving in the context of real-world issues (Conradty & Bogner, 2019). Research conducted by Walshe et al. (2020) found that STEAM approaches can facilitate positive outcomes in the area of student wellbeing, through the focus on imagination, experiential learning and the facilitation of empathy, autonomy and collaboration. Inquiry and opportunities for active involvement in STEAM activities has been found to be beneficial for girls (Thuneberg et al., 2018). Some studies have also reported gains in student creativity through STEAM approaches (Harris & de Bruin, 2018; Kim & Kim. 2016; Ozkan & Topsakal, 2019).

However, as an emerging area, several challenges have been highlighted in the literature. Firstly, there are varying definitions of what constitutes the arts in STEM, with some studies narrowing down the focus to simply visual art and others focusing on a broad definition that includes the creative arts, liberal arts and humanities (Perignat & Katz-Buonincontro, 2019). In some cases, the arts are actually used as a term to represent inquiry or problem-based learning (Perignat & Katz-Buonincontro, 2019). Critiques have focused on how embedding the arts may not provide enough focus on the STEM disciplines (McAuliffe, 2016; Simpson Steele et al., 2016). Teacher confidence in the arts and STEM areas can be low (Simpson Steele et al., 2016) and some teachers are unsure about their own creativity (Cropley, 2016; Harris & de Bruin, 2018). Other constraints that teachers have identified include an overcrowded curriculum, systems that focus on separate subject areas, increased accountability measures including standardised testing, timetable issues and challenges with collaborating with other teachers (Harris & de Bruin, 2018; McAuliffe, 2016). It can be also be surmised that as STEAM approaches are less developed than STEM approaches in Australia, that similar concerns and confusion around implementation in terms of moving beyond policy exist (Bybee, 2015; Harris and de Bruin, 2017).

16.3 Nurturing Creativity Through STEAM Approaches

A reason that STEAM approaches are advocated for, and even STEM approaches to a lesser extent, are the perceived benefits on student creativity. Creativity is considered a "new paradigmatic currency in education" (Harris, 2017, p. 56). This is partly connected to the identification of creativity as a necessary skill for enhancing the economy and lifelong success (Perignat & Katz-Buonincontro, 2019). Another reason is that students in primary school are at their most curious, providing an opportunity for teachers to harness the development of creativity (Parliament of the Commonwealth of Australia, 2017).

Creativity can be a challenging concept to define and measure (Conradty & Bogner, 2019; Harris & de Bruin, 2018; Lucas, 2016). Creativity is considered a universal trait (Harris, 2017) and words associated with creativity include novelty, originality and impact (Craft, 2015). Craft (2015) differentiates between *little c* and *big C* creativity, with *little c* creativity being the creativity an individual uses in everyday life in coming up with novel and original solutions to problems. In contrast, *big C* is the large-scale creativity that "changes the world or that generates novel ideas which transforms paradigms" (Craft, 2015, p. 154). Lucas (2016) describes five creative habits: ***inquisitiveness***, evident through wondering and questioning, exploring and investigating, and challenging assumptions; ***imagination***, evident through playing with possibilities, making connections and using intuition; ***persistence***, evident through sticking with difficulty, daring to be different and tolerating uncertainty; *collaboration*, evident through sharing the product, giving and receiving feedback and cooperating appropriately; and ***discipline***, evident through developing techniques, reflecting critically and crafting and improving. Some of these habits are supported by the work of Csikszentmihalyi (2014), who maintains that interest plays a key role in the creative process:

> To make a creative contribution, it is not enough that a person have all the necessary information in a given domain, and that he or she knows what to do with it. The creative person must be interested in the information that constitutes the domain—not just the ordinary interest a person must have to gather information necessary to adapt to his or her environment, but an unusually acute curiosity about a particular aspect of it (p. 162).

Also of importance to the creative process is perseverance, a dissatisfaction with how things are and a desire to search for alternatives, as well as dependence on the social context (Csikszentmihalyi, 2014). In research conducted by Harris and de Bruin (2018), teachers in the study maintained that creativity is something that can be taught and is transferrable to other situations. In this same study, many teachers felt that they could be successful in fostering creativity in their own classrooms (Harris & de Bruin, 2018).Some researchers have identified factors that support the teaching and learning of creativity. Teachers need to be given opportunities to collaborate across disciplines, be provided with meaningful professional development, have access to quality resources and be explicitly supported by school leadership (Harris, 2017; Harris & de Bruin, 2018). Pedagogies that allow for student leadership, collaboration, autonomy and inquiry are also deemed to be important (Conradty

& Bogner, 2019; Harris, 2017). Therefore, approaches that foster creativity will have an explicit focus on the teaching of real world skills (Harris, 2017) and be capabilities focused (Parliament of the Commonwealth of Australia, 2017).

STEAM approaches may be one way to support the teaching and learning of creativity in line with the factors identified above. This is because the arts are considered a key way that creativity can be nurtured (Perignat & Katz-Buonincontro, 2019). Harris (2017) believes that the arts foster experiential and relational learning experiences and that opportunities for creativity are inherent in artistic endeavours. This is supported by Kamienski and Radziwill (2018), who believe that incorporating arts within STEM disciplines nurture student creativity due to the emphasis on personal creative exploration, inquiry, engagement, personal agency and opportunities for creation. However, it is important to note that creativity is naturally inherent in all areas and can therefore be a focus of all disciplines (Perignat & Katz-Buonincontro, 2019). Studies that investigate different STEAM approaches on student creativity is an emerging area of research (Ozkan & Topsakal, 2019).

16.4 Case Study: Hammond Park Catholic Primary School

To investigate the perceptions of how teachers believed a STEAM approach could influence creativity, the authors selected Hammond Park Catholic Primary School (HPCPS) as an illustrative case study. This case study will include contextual information about the school and present qualitative results from the investigation.

HPCPS has implemented and developed a formal STEAM approach from 2017 and student representatives presented their learning at a Catholic Education Western Australia (CEWA) STEM Showcase in 2019. The CEWA STEM Showcase provided an opportunity for Catholic schools across Western Australia to demonstrate their STEM learning to a wider audience.

Hammond Park is a suburb of the Perth metropolitan area, located approximately 25 kilometres south of the Western Australia capital city of Perth. Established in 2003, this suburb has in the last decade experienced a period of rapid growth, with many young families settling in the area. In the 2016 census, the median age of people in Hammond Park was 31 years old, with children between the ages of zero to 14 comprising almost 25% of the total population of this suburb (Australian Bureau of Statistics, 2017).

HPCPS is a Pre-Kindergarten to Year Six school following the traditions of the Catholic Church. Students enrolled at the school are aged from three to 12 years. The school opened in 2013, recognising the demand for an alternate educational choice to meet the needs of the growing number of families establishing in Hammond Park. The increase in student enrolments at HPCPS reflected the growth of the suburb, with student numbers rising from 17 in the foundation year to 375 in 2020.

The vision and mission of HPCPS is directed towards an engaging style of education that encourages the students' natural curiosity and creativity, challenging them to become lifelong and lifewide learners into the future. The individual learning style of each student is accommodated through a contemporary, flexible learning approach. The teaching staff scaffold learning opportunities that challenge the students to think more deeply about their learning. Acknowledging the increasing complexity of skills required for employment into the future, they provide opportunities for the students to develop capabilities in how to learn, more than just what content to learn.

Two teachers were invited to participate in this study in consultation with the school principal. A semi-structured interview was utilised in line with qualitative research design, as it was important to understand their perceptions and interpretations (Martella et al., 2013). Qualitative research recognises the importance of context for how individuals make meaning of their lived experiences, beliefs and opinions (Cowling, 2015; Cowling & Lawson, 2015; Roulston, 2013). The teachers were interviewed together and the interview was recorded, transcribed and analysed through a process of data reduction, coding and categorisation (Roulston, 2013). The questions for the interview were developed in an attempt to understand the school's approach to STEAM and how the teachers perceived the influence of STEAM on student creativity. The semi-structured interview questions are included in Table 16.1.

The participants in this study were Teacher A, who was a specialist teacher in the school and Teacher B, who was a classroom teacher. Both teachers had been involved in the approach since its emerging stages and were instrumental in its ongoing development.

The school's STEAM enrichment initiative is centred on the arts and creativity, underpinned by a belief that student learning is enhanced by incorporating creativity into all learning areas. Through the arts, the STEAM approach integrates the other disciplines, breaking down the divisions that can form between them. At the time of developing the approach at HPCPS, several staff members, both specialist and classroom teachers, had a background in visual or the performing arts.

Table 16.1 Semi-structured interview questions

Guiding questions
1. Can you tell us about your school's approach to the teaching of STEM?
2. How are the arts incorporated in your approach?
3. What students does the approach involve?
4. How did the approach begin at your school?
5. How long has your school implemented this approach for?
6. What have been the strengths or positives of your approach?
7. What have been the challenges?
8. What aspects are critical to the success of the approach?
9. What aspects hinder the success of the approach?
10. Do you have any plans for the future development of your approach?
11. Do you see any benefits of integrating the arts into the teaching of STEM?
12. Do you see any challenges of integrating the arts into the teaching of STEM?
13. How do you see student creativity being enhanced through the approach?
14. What do you believe contributes to the enhancement of student creativity in the approach?

STEAM at HPCPS commenced in 2016, as a single event to celebrate National Science Week, which is an annual initiative from the Australian government to promote science in schools. The theme of *Robots, Drones and Droids* stimulated conversations between the science and visual art specialist teachers about ways to draw the learning areas together, after both observed points of commonality and intersection. There were also wider staff discussions occurring around about how to support students to enhance their problem solving, thinking skills and creativity. The high level of engagement by both the students and teachers observed at this event indicated a possible avenue to develop a wider and more systematic approach, as discussed by Teacher A in the following comment:

> The engagement was just crazy. They absolutely loved it. They were just so engaged with it the whole time. We knew that that was already a winner. We had a look at how we could connect things so it wasn't just STEM, because the arts were so embedded in what we do, it's not just STEM. We didn't want it to be engineering and maths, we didn't want it to be science, technology. We looked at how that worked with the kids and then went "Right, okay, so what can we do with this?" (Teacher A, 6 October, 2020).

In 2017, accommodating timetable constraints, the STEAM initiative was expanded to one afternoon per week for students from Year Two to Five, which was the year level to which the school had grown. There was a recognition that while the single event had produced positive results, it was important that teachers still had sufficient time with their own classes to meet curriculum requirements. It was also necessary to ensure specialist teacher availability, hence only one afternoon was planned for. This was a timetabled area, with teachers working in teams comprised of one classroom teacher and one specialist teacher, delivering a term programme around a central theme, focusing on one STEM discipline and one arts area, such as music, visual arts, drama, dance or media arts. There was a focus by the teaching staff to embed opportunities to develop the six key future skills articulated by Fullan and Langworthy (2014): character education, citizenship, communication, critical thinking and problem solving, collaboration and creativity and imagination. Students worked in multi-age groups with the aim that peer mentoring could occur. After each term, the teaching partnership, theme and student groups changed with the aim of maintaining the level of enthusiasm and novelty. According to the teachers, there was an attempt to allocate students into groups based on their interests, but the overall perception of both the approach and student grouping was that it was predominantly teacher-directed. During ongoing reflection during the year, there was a sense by teachers that it was "hard to let go" (Teacher B, 6 October 2020), but as the year progressed, teachers increasingly began to relinquish control of the learning process, enabling the students to take greater ownership and responsibility. According to the teachers, there was a desire to increasingly connect the learning to real-world contexts. There was also a sense that the multi-age grouping was also not working effectively, due to the different skill set and gaps in understanding of the students in the different year levels.

With further iterations of the STEAM initiative over subsequent years, the current model involves students in same year level groupings from Pre-Primary to Year Six, which is most suited to the current school environment. For Pre-Primary and

Year One students, teachers determine a time that suits the students' needs, but from Years Two to Six, there is a consistently scheduled time that STEAM occurs for the entire cohort. In the current model, classroom teachers work in partnership with their partner teacher to develop STEAM inquiry-based projects that involve students exploring contemporary global and local issues, aiming to increase student awareness about care and service in the community. Students worked collaboratively to brainstorm ideas and explore solutions to challenges posed by the projects, responding to provocations presented by their teachers. Classroom teachers, guided by these discussions, planned the projects across all STEAM discipline areas and delivered them as a team, modelling the collaborative approach underpinning the initiative. Sometimes these programmes continued for a school term and even longer, depending on how interested the students remained in the topic. They ensured that the projects promoted development of key skills, such as problem solving, digital fluency, creativity and innovation in the students.

Student learning was communicated to parents via the educational app Seesaw throughout the inquiry process. Teachers were constantly examining student work to identify key learning and to guide the student inquiries, which was documented on a shared *Microsoft OneNote*. Teachers also used backwards planning to document the curriculum areas that they explored with the students. There was a deliberate choice that STEAM would not be formally reported, to encourage teachers to risk-take and build confidence with the inquiry-based approach. The teachers described the approach as "messy, exciting, daunting and evolving". This is illustrated in the following comment:

> I think that's always been our approach, that we've never had this thought that we're going to get to a place of "This is what our STEAM looks like here, it's finished, we're done," it's always we're looking at where the teachers are at, where the students are at, how the students are responding to that and making those adjustments as we go. I don't think we've ever had that "This is what it looks like," it's always changing. We're always looking for that feedback and talking about how the students are responding (Teacher B, 6 October, 2020).

An example of this STEAM approach is presented here in the form of an almost year-long Year Three STEAM project. This project began in Term 2, 2020, following the COVID lockdown in March and April. The Year Three teachers decided that sustainability would be the key concept to be explored in their STEAM time, as this is a cross-curricular priority in Australia. To begin this focus, their first STEAM session was an exploration of provocations connected to this concept, and aimed to find out what the students already knew about sustainability. This included watching clips from the *War on Waste* documentary series. Through these conversations with the students, an emphasis was placed on pollution, specifically the problems it creates and how their school works to help or hinder pollution. With the assistance of their teachers, the students investigated the rubbish in the school and identified that rubbish from the canteen was a significant issue. The students decided that they needed to educate the school community about the issue of pollution and created posters to put up around the school. For this task, they learnt design elements and made use of digital technology tools. They also brainstormed ideas for solving the school canteen rubbish issue, including making canteen bags out of scrap paper and requesting that everyone have reusable canteen bags. Many of the questions the students had throughout this exploration were focused on plastic and its impact on the environment, particularly after observing the types of rubbish found in the school. The level of student interest in this topic was sustained, even after coming back to school following the Term Two school holidays. The Year Three classroom teachers, in consultation with the Science and Visual Art Specialist teachers, decided to extend their learning in Term Three, by connecting to the Australian National Science Week theme for 2020, which was *Deep blue: innovation for the future of our oceans*. As part of their STEAM learning, the students learnt about endangered animals in the ocean, with a particular focus on improving the student's research skills. This was then used in STEAM, Science and Visual Art classes, to enhance their understanding about the impact of pollution on ocean animals, which then linked back into their classroom work.

In Term Four, the questions the students focused on in STEAM were how they could do something with the information that they had learnt about the impact of pollution on ocean animals. The teachers felt the learning at this point had become much more student-directed, as the students were guiding the direction of their learning. The students decided that they wanted to create an invention to solve the problem of pollution in oceans and chose to work either individually or collaboratively to design a prototype to clean the oceans. This challenged the students to consider a range of key questions, such as how would the design tell the difference between rubbish and animals and where would the rubbish go when it was collected? The students then presented their prototype to a *Shark Tank* inspired panel of teachers. This required them to create a marketing pitch for their product, describe key features and outline the pricing. For this presentation, the students made use of digital technology to assist them to create a logo and presentation for their product. The panel provided the students with feedback and ideas to extend their thinking.

According to the teachers interviewed, there had been numerous benefits associated with the STEAM initiative at HPCPS. The teachers commented that student 'voice' was vital to the success of this pedagogical approach and had become increasingly encouraged by the teachers, much stronger than when the STEAM initiative was first introduced in 2016. The approach was increasingly student-led and there were observable improvements in the students' resilience, as they were prepared to have a go at new and unfamiliar challenges and they demonstrated ownership of their learning. For one of the teachers, this was most evident when students in Year Three presented their learning at the CEWA STEM Showcase, as evident in this comment:

> I was amazed at how those kids were just explaining to people who were coming up, explaining what they were doing, explaining what they were talking about and taking that complete ownership of what they had done. It's a really great thing to see, and they're doing that with the other learning areas in the classroom as well, with taking ownership of what they've learned and sharing that more with how they're doing that (Teacher A, 6 October, 2020.

Through the STEAM project approach, there was an explicit focus on teaching students how to ask effective questions and to develop their research skills. The teachers noted that in a relatively short space of time, more insightful questions were emerging and the teachers believed that at this point, deep learning was starting to occur. Another area of observed improvement was that collaboration between students had increased. The teachers shared that while some students preferred to work individually in the classroom, they deliberately choose to work collaboratively in the STEAM sessions, recognising the variety of strengths that a group of students brought to a project. When reflecting on benefits of the approach for students, one of the teachers reported:

> I think one of the positives that comes to mind is the kids that have surprised us. There's kids that might not necessarily excel usually, they're the moments where you go "Wow," they're able to really show their understanding, and I think they've been huge moments for us…They just amaze us with what they're able to show us (Teacher B, 6 October, 2020).

Of significant importance was the ongoing enhancement of student engagement, learning and creativity. The teachers reported that they would often field questions such as "Are we doing STEAM today?", "When do we do STEAM?" and "Can we work on STEAM?". Students were seemingly making connections between their learning in STEAM and their learning from the key curriculum learning areas, as illustrated in the following comments:

> The year threes are bringing a lot of stuff in from their STEAM learning that I'm actually doing with them in art, and I know that they're also talking about it in their writing as well… And there's a lot of links that the teachers are making with Humanities and Social Sciences and other areas as well (Teacher A, 6 October, 2020).

> Hearing them make a lot more connections between things that they're learning rather than seeing everything as standalone, they're always connecting the dots and drawing things in (Teacher B, 6 October, 2020).

The main way that the teachers observed student creativity was through the curiosity that the students demonstrated in their learning, evident through their enthusiasm and questioning. The students appeared more confident in using their creative skills to demonstrate their understanding, and by using a range of styles and modes to present their outcomes. It was also noted by the classroom teachers that students chose their own way of showing their learning and they were presenting their work in more creative and imaginative ways outside of the STEAM lessons. One of the teachers stated:

> I find they're willing to have a go at "Can I show it this way?" And they'll try different things before they figure out how they're going to do it (Teacher B, 6 October 2020).

Benefits were also identified for teachers in relation to the implementation of this STEAM initiative. With experience of facilitating student inquiry in STEAM, "the classroom teachers become more familiar and more confident with this learning approach" (Teacher B, 6 October, 2020), which led to it being a part of regular classroom teaching and learning. Teachers also shared that the STEAM approach was supported by the school's leadership, which was evident in many ways, including being a focus of school improvement planning, timetabled in the weekly schedule, promoted on the school's website, the basis of professional learning community meetings and providing time for staff to be coached by the STEAM coordinator. Several challenges were identified in relation to the implementation of this whole-school STEAM initiative. A primary challenge reported by the teachers was their ability to relinquish management of the student learning and to place trust in the students' ability to effectively explore their own interests. It was noted that STEAM learning projects could sometimes become messy and appear chaotic, with a great deal of noise as students collaborate on projects. This could be challenging and may even hinder the ongoing success of this approach, as some teachers struggled when they were taken out of their comfort zones. This is discussed in the following comment:

> The only thing that I can see potentially doing that is with staff changes and everything else, people not understanding our approach, not understanding where it's come from and how it's evolved. It doesn't really hinder us at the moment because we share that and we make sure that people understand how this works, what we're doing, where we've come from (Teacher B, 6 October, 2020).

An emerging challenge in the current STEAM model was the inclusion of the arts. The arts are pivotal to the STEAM initiative and needed to be honoured, but this could be daunting for those teachers who do not have a strong artistic skill base. This is reflected in the following comment:

> If a teacher is not confident with themselves as what they know or understand about the arts, they're sometimes a little hesitant to go "This term we're going to be talking about media arts," or "We've got a visual arts specialist in the school, do we really want to go in this area?" or "I don't know anything about music, how am I going to do music in STEAM?" That probably makes people a little bit more hesitant in how are we going to put the arts in there (Teacher A, 6 October, 2020).

An area identified as vital to the success of the STEAM approach, was teachers' and students' willingness to be flexible. It was evident that the teaching culture associated with the initiative was strongly linked to a safe environment for innovation. The staff were willing to trial new ideas, without fear of judgement as learnings were valued from any failures. The teachers also recognised that critical reflection was essential to supporting the ongoing refinement of the approach. Finally, teacher accountability was deemed significant, through visible planning and sharing of learning to parents.In looking towards the future, these teachers were aiming to create a visual representation of the inquiry model which could support other teachers' as they implemented the STEAM approach. There was also a desire to develop a scope and sequence of key skills that students could work towards achieving, and which would arguably contribute to their overall learning success. However, the teachers' most significant aim was to continue working with the school's leadership team and staff more widely to ensure STEAM remained a priority, even when challenged by other school-wide initiatives. This is illustrated in the following comment: "What we want to make sure is that STEAM is always a priority in the school". (Teacher A, 6 October, 2020).

16.5 Discussion and Implications

There were many positive outcomes evident in the exploration of the STEAM initiative at HPCPS. The teachers were striving to harness the power of the arts in order to foster student creativity, while looking for meaningful opportunities to break down the barriers between learning areas (Parliament of the Commonwealth of Australia, 2017). Over time, the approach at HPCPS evolved to be authentically transdisciplinary (Perignat & Katz-Buonincontro, 2019), as teachers develop learning experiences around a central inquiry that emerged from the students' questions and integrated all STEAM disciplines. This was in contrast to the initial stages of the approach, where there was a narrower interdisciplinary or cross-disciplinary focus on just two STEAM discipline areas (Perignat & Katz-Buonincontro, 2019).

In the example of the Year Three project presented in this chapter, each of the STEAM discipline areas were authentically included: Science, in relation to the focus on living things, the environment and sustainability; Technology, in relation to digital technology utilised for students to demonstrate their learning and design technology in relation to the design of their prototype; Engineering, in relation to the students finding solutions to problems; Arts, in relation to the Media Arts that were explicitly taught and demonstrated through the student presentations; and Mathematics, which included the analysis of data in relation to the school's rubbish, the geometric skills that formed part of invention design and the connection to money in their invention challenge. Similar to reports from Peppler and Wohlwend (2017) and Harris and de Bruin (2017), the teachers at HPCPS continued to honour the role of the arts in supporting student creativity and their deep exploration of a real-world problem and learning of curriculum content.

Previous studies also identified the potential benefits of STEAM for enhancing student motivation, skill development and wellbeing (Conradty & Bogner, 2019; Harris, 2017; Kamienski & Radziwill, 2018; Walshe et al., 2020). These benefits were also evident in the current study and the participating teachers reported a high level of student engagement. Factors that seem to contribute to this engagement at HPCPS included the whole-school inquiry pedagogy underpinning the approach and the focus on student voice and agency in driving the learning. When examining the perceptions of the teachers through the lens of Lucas' (2016) five creative habits, there seems to be indications that student creativity was fostered through the approach, as evidence of inquisitiveness, imagination, persistence, collaboration and discipline were present in students' STEAM learning experiences. The example reported in this chapter, highlighted students demonstrating *little c* creativity, in that they were coming up with novel solutions to the problem that they had identified in relation to ocean pollution and the impact on the environment. However, it should be noted that the generalisability of findings from this study is limited by the number of teachers that were interviewed, as well as not specifically exploring the perspectives of the students themselves.

This investigation also highlighted some key outcomes for the teachers involved in the initiative. There was evidence of teachers enhancing their skills and understanding of inquiry pedagogy and developing their own collaboration skills as they facilitate students' STEAM learning projects. In many ways, the teachers themselves were developing their own creative habits, as they too demonstrated inquisitiveness, imagination, persistence, collaboration and discipline (Lucas, 2016). The STEAM programme and teachers' innovations were explicitly supported by the leadership of the school through timetabling allowances, professional development, coaching and promotion of the approach; all factors identified as important to an initiative's success (Harris, 2017; Harris & de Bruin, 2018). There was also recognition in this current investigation that in order for the STEAM approach to continue, it needed to be identified as an ongoing school priority with suitable resourcing. This resourcing could include targeted professional learning for teachers as those new to the approach may lack confidence with the arts and the inquiry approach, which has been previously identified as a barrier to successful implementation by Simpson Steele et al. (2016).

In conclusion, this illustrative case study of Hammond Park Catholic Primary School represents an exciting example of the potential that STEAM approaches can have on creativity. Future studies that investigate the features of high-quality STEAM approaches and the perceptions of students themselves in relation to their experiences of STEAM and creativity would enhance this emerging research area and could contribute to positive student outcomes.

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Part IV
Digital Creativity in Children's STEM Learning – Looking Forward in the Digital Era

Chapter 17
Integrating Tangible Technologies with Young Children's STREAM Project

Victoria Damjanovic and Jordan Simmons

17.1 Introduction

Over the last 20 years the U.S. has seen a shift in thinking with regard to young children and their utilisation of technology. Technology was seen as an inhibitor to child development and highly restricted in high quality academic programmes. Technology was viewed as passive and unproductive for young children, with some professionals feeling it was harmful to their development all together. Until 2016 the Council on Communications and Media (2016) recommended no screen time for children under the age of two and under two hours a week for children up to age five. Over the course of the twenty-first century, we have seen a shift in support for technology in early childhood contexts. Especially in recent years due to the development of tangible technologies that provide opportunities for young children to code and interact directly with technologies (Berson & Berson, 2010). The rapid advancements in technology have led to the vast support of STEM at all academic levels, including early childhood. As a result, high quality preschool and elementary programmes have worked diligently to incorporate STEM into the classroom in meaningful ways.

The STEM movement gained traction in the U.S. in 2001 with the US National Science Foundation's (NSF) existing SMET acronym (Committee of STEM Education, 2018). This rearrangement was an effort to enhance their curricular outreach programme in response to the perceived deficit of American students in

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science-related studies compared to their international counterparts (Committee of STEM Education, 2018). In 2011, STEM evolved into STEAM with the infusion of art into the curricular focus during an NSF-funded workshop at the Rhode Island School of Design entitled, *Bridging STEM to STEAM: Developing new frameworks for art-science-design pedagogy* (McKeown, 2019; Rose & Smith, 2011). This led to an interdisciplinary approach to education to enhance the quality of student learning by creating educational activities with a strong STEM focus while emphasising artistic expression. Within a few years, educators and researchers sought for STEAM to evolve into the acronym STREAM via the inclusion of explicit reading and writing instruction (thus, the "R"). Rather than adding in additional fields of study for students, these additions focus more on the integration of reading and writing strategies throughout existing STEAM activities.

During this same time frame, organisations and companies collaborated to create *The partnership for twenty-first century learning* that strives for all students to have the opportunity to learn in a way that will develop the skills they need for the future. This movement champions the 4C's that include critical thinking, communication, collaboration, and creativity (Scott, 2019). As these skills were prioritised, U.S. schools moved to inquiry-based teaching pedagogies (Kennedy & Heineke, 2014). In elementary school settings (K-5) STEM based curriculums were created to meet the need. For early childhood programmes (birth-five), multiple approaches have been used. The Project Approach is one of the frameworks used in early childhood programmes that focus on inquiry-based teaching that aligns with STEM/STREAM curricular approaches.

Curriculum in the United States has been shifted in recent years to include and reinforce twenty-first century learning framework in addition to all other content areas (Kennedy & Heineke, 2014). This framework advocates the integration of critical thinking, collaboration, communication, creativity, technology literacy, and social-emotional development (Scott, 2019). A central part of this framework is termed the 4C's which include creativity, critical thinking, communication, and collaboration. For the purpose of this study we will use the following definitions for each of the 4C's. Creativity demonstrates originality and inventiveness alone or in collaboration with others. This can include ideas, evaluation of ideas, creating a product, and refining of ideas (Scott, 2019). Critical thinking uses a range of problem-solving techniques, using various reasoning skills, synthesises and makes connections, and uses conventional and non-conventional ways to solve problems. Communication is the ability to articulate ideas effectively using multiple mediums for a range of purposes in diverse environments. Collaboration demonstrates ability to work effectively with a diverse range of people while showing flexibility and shared responsibility to accomplish a goal (Scott, 2019).

The Project Approach supports an interdisciplinary framework that allows children to engage with multiple content areas through intentionally designed integrated experiences. Focusing not only on how things work, but how they have evolved over time and their role in our shared human experience gives STREAM-based learning activities a necessary grounding in student's lives. The school featured in this chapter employs the Project Approach as a curricular framework to support engagement with authentic and meaningful inquiry. The Project Approach highlights the importance of listening to children, following their lead, seeing them as capable researchers, and providing real life experiences to question and explore (Chard et al., 2017; Katz et al., 2014). The Project Approach is a form of inquiry-based teaching and learning that is divided into three distinct phases. In Phase 1, a topic is chosen and children share their experiences with the topic. Teachers are able to identify the conceptions and misconceptions children have about a particular topic. Children and teachers map what they know about the topic at hand and identify research questions of what they want to learn during the project. In Phase 2, data collection begins. The children engage in fieldwork in order to collect data and learn more about their topic. During this time, the children demonstrate their learning in a variety of ways through multiple mediums of representation. In Phase 3, children share their learning to others showcasing their documentation and representations throughout the project.

This chapter shares the story of one project that connected children, families, and their community in a meaningful way while integrating STREAM. The purpose of this study was to find the ways in which teachers and children engage with tangible technologies integrated with science, technology, reading, engineering, art and math while fostering the 4C's that include creativity, critical thinking, collaboration, and communication. Following the student's interests, working with the director, and reflecting on teaching experiences brought to light the ways in which both teachers and children learn through the use of STREAM approaches and the impact it has on the 4C's. During these meetings the teachers and director carefully thought of ways to authentically embed science, technology, reading, engineering, art, and math into the project which was critical to this complex project. This story highlights the power, possibility, and joy of interdisciplinary work with young children with technology as the connecting thread that tied the project together.

17.2 Methods

This qualitative case takes place in a university teacher educator lab preschool in the southeastern United States. Case study was used in order to describe and explain, rather than identifying cause and effect (Stake, 2010). Case study involves generating data in natural conditions; the data in this study will be generated during everyday happenings at a preschool. Constructivism is the theoretical framework that informed this research. Social interaction is a construct that drives the historical perspectives of constructivism and links to support for inquiry-based teacher learning (Vygotsky, 1994). Vygotsky's constructivist learning theory implored the importance of social interaction for the transformation of knowledge. Learners have the ability to imitate and model others through the use of observation. The use of social interaction and discourse with others allows for deeper understanding and knowledge. Through discussion, facilitators can provide support and promote learning. Vygotsky purported social interaction as the key to learning in all individuals.

The use of collaboration is derivative of learning for both adults and children alike. The use of collaboration allows for learners to work together and reflect together leading to deeper learning. When learners participate in a range of activities in learning communities and internalise the effects of working together, this leads to acquiring new strategies and knowledge relating to the culture of the school (Vygotsky, 1978).

17.2.1 School Context

Situated within an R1 university, the preschool exemplifies an inquiry approach to teaching and learning, innovating and improving early childhood education through teacher education, research, and community engagement. The mission of the programme is to provide a site to demonstrate, observe, study, and teach exemplary practices in early childhood education. The school seeks to innovate through interdisciplinary teaching approaches to situate content into the projects that children are engaged in. In particular, technology is interwoven into projects with tangible technologies in ways that are not technocentric (Berson & Berson, 2010). Rather than focus on technology, technology is used to enhance and expand learning experiences within the context of the project of study. The following project exemplifies this practice and shares the power and possibility of inquiry-based teaching and learning.

A teacher at an educator lab school has a unique role. Teachers are expected to engage in research and mentor pre-service teachers, in addition to teaching young children. The teachers utilise action research to study their classroom practices and children's learning. Teaching as inquiry is described in many different ways, including "teacher research and action research" (Webster-Wright, 2009). A central shared idea is that inquiring teachers pose questions to their practice and engage in critical study of their own classroom teaching experiences in order to inform practice. In conjunction with the teacher's use of action research, the classroom uses long term in-depth projects to naturally create opportunities to integrate content in authentic contexts for young children. Author 2 is one of the teacher's in the classroom and engaged in action research to explore the question, in what ways do teachers and children engage with tangible technologies integrated with science, technology, reading, engineering, art and math to fostering creativity, critical thinking, collaboration, and communication.

17.2.2 Data Collection and Analysis

The teacher and director utilised several data sources to draw conclusions on her teaching practice and children's learning including photographs, anecdotal records, recordings of conversations, and children's work samples. These data sources were collected as a part of her typical teaching practice in order to inform her future lessons. The teacher met for ten weeks with the director (Author 1) to look closely at the data collected in order to draw conclusions and decide next steps for the project. All of the data sources were used to create what the school calls 'storyboards'. These storyboards tell the story of the project and include important data for each week from the classroom that includes photographs, children's dialog, descriptions of events, and the Florida Early Learning Standards achieved by the lessons depicted. This is another point of reflection and analysis for the teacher as they decide what are the most important artefacts to share with the families. The storyboards are distributed weekly to families to provide families with a detailed record of their child's classroom learning for the week. For the purpose of this research the teacher and the director analysed the ten storyboards for the ten-week project to draw conclusions.

The analysis process involved the director and the teacher carefully reading and re-reading each storyboard over the ten-week period. The storyboard was treated much like a transcript. Each storyboard was read line by line to highlight the topic of each line. The data generated was coded in order to identify emerging patterns between both the director and teacher's codes. Labels were created and listed as codes in the margins of data records. The codes were categorised across data sources in order to show that they are instances illustrative of a larger category. These codes included how teachers and children engaged in the 4C's in unique ways. These themes were analysed to gain a deeper understanding of the research questions posed (Stake, 2010). The research question posed was, in what ways do teachers and children engage with tangible technologies integrated with science, technology, reading, engineering, art and math while fostering the 4C's that include creativity, critical thinking, collaboration, and communication.

17.2.3 Classroom Context

The Computer Project took place in the Magnolia Classroom comprised of three and four-year-old children with two bachelor's degree certified teachers. The diverse classroom contained 18 children with seven countries and languages represented. Teachers in the classroom often work on their iPads and computers to document children's learning and to engage in authentic assessment. Children began to ask about the devices they were using and shared what they knew about them. Many children were very familiar with iPads but had less experience with a desktop computer. The interest in the devices increased and the teachers knew it was the perfect project to start off the school year. Teachers asked families to bring in any old computer equipment they could share and if families had jobs that used different types of computers. This launched into a rich project that explored typical computers, tangible technologies, as well as children's families within the community.

This chapter follows the story of one classroom teachers research to gain a deeper understanding of the ways in which teachers and children engage with tangible technologies integrated with science, technology, reading, engineering, art and math while fostering the 4C's that include creativity, critical thinking, collaboration, and communication while engaging in project work. Vignettes of the project will be shared, then the authors will reflect on how the 4C's were enacted through their analysis. Below is the teacher's narrative of the *Computer Project* highlights and the analysis of the teacher and director on implications to learning.

17.3 The Computer Project

17.3.1 What Is a Computer?

To begin the computer project, the teachers wanted to gather anecdotal records of student background knowledge about computers. The students answered provocations such as: "what is a computer?" "what do computers help us do?" and "why do we use computers?". In addition, these one-on-one conversations allowed the teachers to make note of questions students may have, record comments, and identify possible misconceptions they may have about computers through hands-on experiences. During the beginning phase of our project, the teachers introduced Cubetto and Sphero, coding robots that use internal computers to move. Students explored directional words like left, right, straight, and backward as they coded the robots around the classroom. Through conversations with the children, the teacher created

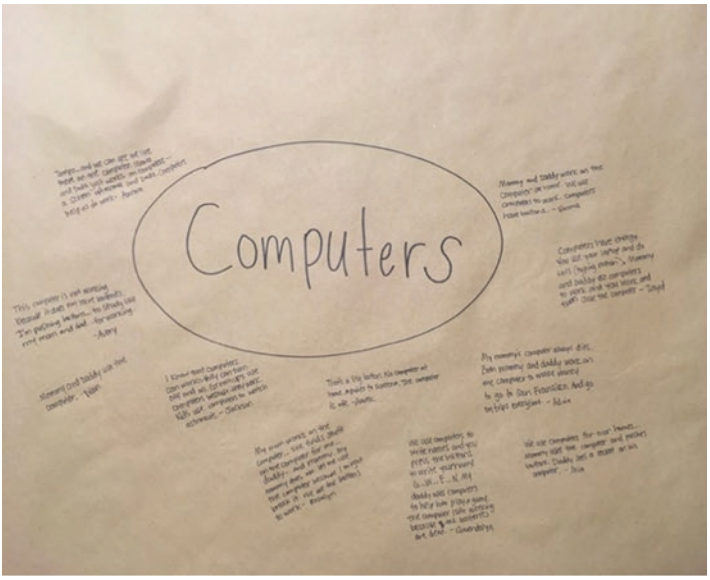

Fig. 17.1 Computer web

a web with the children to demonstrated what they knew about computers at the beginning of the project as depicted in Fig. 17.1 below. After listening to the children share their conception and misconceptions about computers with each other, the children were able to explore different types of computers first hand. Families brought in older computer devices for the children to explore as shown in Fig. 17.2 below. This allowed the children to touch and feel the computers to gain a deeper understanding of all the parts needed and used in a computer.

To begin the project the teacher must first identify what children know as well as their misconceptions. When answering these questions, the children had to *communicate* their knowledge to teachers through multiple mediums including drawing and orally telling the teachers what they knew. Teachers wrote down their words to help children see the connection between speaking and the written word as a form of literacy. This process also allows for children to *collaborate* by sharing what they know with others and creating a shared classroom knowledge to work from.

As the children were introduced to a few of the tangible technologies the teacher stepped back to allow the children to *critically think* about how these devices worked. The teacher gave a brief description and then provided a space for the children to explore and figure it out on their own. The teacher was ready to step in when frustration increased and children needed some support. The teacher was always careful to provide the minimum amount support necessary for the children to succeed. For instance, when *Cubetto* was introduced it became clear that the children needed to understand the directions of left and right. The teacher then set time aside to work on this skill through game play.

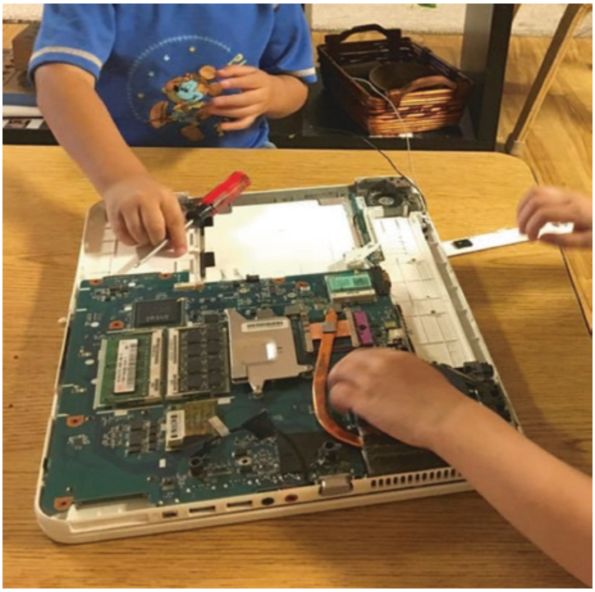

Fig. 17.2 Dissecting a computer

17.3.2 What Makes a Computer a Computer?

After gathering student background knowledge and experiences during Phase 1, the teachers recognised that there was a misconception about the term computer and how it applied to different tangible technologies (i.e *iPad*, *Promethean Board*, coding robots). This encouraged the conversation about whether *Cubetto* and *Sphero* use computers to move, since they don't externally look like conventional computers the children see in everyday experiences. During circle time, the teachers asked, "is *Cubetto* a computer?". Several responses from the students indicated that no, *Cubetto* was not a computer because he didn't look like a laptop or desktop computer that many students had seen before. However, both of the robots in the classroom function by use of a tiny computer inside and are coded accordingly. To support new learning, teachers used the Promethean board to show students primary sources photographs of what computers have looked like across time. We began by observing the world's first computer that encompassed an entire room and required multiple people to control it and ended with looking at pictures of a computer microchip used in many small devices today like a phone, *iPad*, or coding robot. After gathering data through anecdotal record and computer observations, the teachers formulated a definition that would encompass all technologies that function by use of a computer. Then during circle time, the teachers explained the definition by breaking it down into small parts, explaining what each part meant, and introducing new vocabulary. The teachers used this definition to create a checklist to apply to other tangible technologies in the classroom; throughout the rest of the project, the class constantly referred back to this definition to reinforce learned vocabulary and concepts about various types of computers. Once common terms and a definition of the word computer was established the children were able to dismantle old keyboards, laptops, and desktops that were donated by families who no longer used those devices.

By starting out deciding what is and what is not considered a computer, the children had to *critically think* about what parts make a computer a computer. The teachers supported the children through this process by sharing important vocabulary of the parts a computer should have. This again ebbed into *communication* and literacy while the children created definitions with the teachers and created a check list for future use. This checklist is a great beginning scientific practice for young children because they are able to refer to it throughout the process to decide if an object meets those terms. The use of primary sources integrated both scientific practice as well as social studies by looking at computers over time with real photographs from the past. This helped the children develop a framework for what would be considered a computer.

17.3.3 Playing Office

Through gathering background knowledge about computers in Phase 1, the project moved into Phase 2 in which the children investigate, answer questions and address misconceptions about the topic. Many parents in the Magnolia classroom use computers daily, whether at home or in an office to complete tasks for work. After observing students engaging in pretend play by *working* on computers while in the dramatic play centre, the teachers asked families to donate any extra computers or laptops that they may have at home or work to incorporate in various centres throughout the classroom. During investigation time, students used tools to dissect a laptop by removing and observing different pieces, making predictions about the function each piece served to make the computer operate as demonstrated below in Fig. 17.2. Other computers/ computer parts were used at the writing table where children identified letters, typed on their computer, or pretended to send emails to their friends and family. The children spent a lot of time engaged in pretend play working on different computer devices as shown in Fig. 17.3.

The children were very proud to bring the items in from home, and the families appeared invested. The *collaboration* and connection from home ignited an investment in the children and their families at home. Once the materials were integrated into the classroom the children immediately began pretending they worked in an office. Many of the children emulated their parents by showcasing their *creativity* in the story lines they created for their play. Another layer of learning from this vignette is the creation of space for the children to *critically think* by exploring first hand different technologies by deconstruction, which overarches several content areas such as science, technology and even the process of engineering in reverse form. During the exploration time of real technologies, the children were highly engaged

Fig. 17.3 "Working" on a computer

and invested in the process, therefore the teachers created a centre that could be revisited multiple times over the course of a week.

17.3.4 Creating the Magnolia Office

Following a few days of observing students using the computers and laptops donated to the Magnolia room, the teachers noticed that many students announced that they were "working" or "doing work" while pretending to type on the keyboard. While engaged in play, one student recalled that Ms. Tori (the preschool director) uses a computer in her office. The next day, small groups of students brought clipboards, paper, and writing utensils to observe and document Ms. Tori's office. The students observed her desktop computer, the corded phone, sticky notes, a rolling desk chair, and a large water jug. The teachers worked together to gather these materials and incorporate them into our dramatic play area, deemed "The Magnolia Office". The children engaged in both parallel and associative play, using computers to 'work' and send messages to each other. As a result, the teachers incorporated a mailbox so that the students could send written messages to their friends and families. Using a movie projector and long blinds, the teachers displayed skylines from around the world and discussed how people have different views out of their office windows; children also completed observational drawings of different city views from all over the world.

Following the children's lead the Magnolia Office was created. The children engaged in the inquiry process by collecting data at the field visit. They asked the director questions engaging in extensive *communication* and *critical thinking* by asking clarifying questions and studying the space. The children each had individual jobs lending to collaboration to share information following the field visit. Following the visit, the children identified what they wanted to add to their Magnolia Office and created the objects that they wanted to include based on the photographs the photographers took during the field visit. During the two week time period to study and create an office the children engaged in science on their field visit by collecting data, math by analysing their tally data to determine quantities to add to the space as, literacy/reading to create signage for their office space, art by creating items to hang on the walls, engineering by designing the space and situating the items in the office to make the space functional, technology was included into the office space for the children to explore and utilise while they play in the space.

17.3.5 Parents as Experts

Since many children discussed and engaged in play emulating their parent's work, the teachers reached out to the Magnolia families to investigate what type of work that they do on their computers. One parent responded and said that she is a local high school teacher and has an office in her classroom! So, the teachers coordinated a time and used our computer to *Skype* with her while she was in her classroom office. During this *Skype* call, the children asked questions like "do you have a computer in your office?" "do you have any animals in your office?" "what is inside of your desk?" and "do you have lights in your office?".

Another parent who reached out to the teachers is a computer programmer on campus at the University of South Florida (USF) and offered to come in and show the children how he uses a computer at his job. Using single-digit numbers suggested by the children, he was able to plug those numbers into a computer programming system which, when input, generated a coloured graph on the screen. He told the children that numbers and computers, when they work together, can create all sorts of beautiful and unique images. Figure 17.4 depicts one of the fathers that joined the class to share about computer programming.

Many parents in the classroom to share what they did at work and how they used technology. This *collaboration* personalised the project for the children, it also led to an increased investment in the project for the parents. The children were fascinated by what each of the parents did and demonstrated increased engagement. Some of the parents were worried that the children would not understand. However, the teachers encouraged them to talk to the children while they scaffolded the information when necessary. Several parents seemed surprised to see how much the children understood through their *communication* and realised their children were more capable than they previously believed.

Connecting the technology children were exploring in the classroom with how it is used in the 'real world' made it more meaningful. The technology was not some

Fig. 17.4 Making pictures with computers

random materials the children engaged with, but items used in the professional world. When the children would play in the office they would play different parents depending on what job they wanted. This demonstrated that they understood not only the technology but how it is used in natural settings.

17.3.6 Locating Parents Work Places

We learned that a dad works on campus at our school, the children were interested to see where he worked and what his building looked like. To answer this question, the teachers introduced *Google Maps*, a computer programme that uses locations to show the user what places look like. The children were able to type in the name of his building and see what it looks like from above. The children were fascinated to find that, if you click and drag the mouse, you could move the camera around to see locations from an aerial view. This computer programme began a conversation about what our preschool building and other buildings in our community look like.

Mapping was not originally planned as a part of this project. The children's fascination with where parents worked caused the teachers to change course. The teachers thought it would be worthwhile to explore this. The children decided after using *Google Maps* to locate the parents work places on campus, they created their own maps to display. The process of using *Google Maps*, investigating locations in relation to others, and then creating a representation of a map requires a considerable amount of *critical thinking*. At the end of the project they made a map of their own classroom community they created.

17.3.7 Including City Structures

In Tampa, there is a large building called Amalie Arena where concerts, sporting events, and children's shows are held. Many of the children were very familiar with Amalie Arena and asked about where it was. Using *Google Maps*, the children sounded out the words "Amalie Arena" and typed the letters into the computer programme so that they could observe the building as shown in Fig. 17.5. During this time of exploring *Google Maps*, the students were also coding with *Cubetto* and *Sphero* and they suggested that we needed to create a home for our robots that resembled buildings in our community. Children further investigated what the inside of Amalie Arena looks like including seating arrangements, the ice-skating rink, lights, the jumbotron, and how people enter and exit the building. Using an empty light table and loose materials in the classroom, the children collaborated and problem solved to create a replica of Amalie Arena. Figure 17.6 below shows the children creating the seating part of arena and Fig. 17.7 is an image of the final creation. Amalie Arena. When they were finished creating the Arena, the children's goal was to code *Cubetto* and *Sphero* to go inside so that the robots could ice skate on the rink

Fig. 17.5 Using *Google Maps* to search for arena

Fig. 17.6 Creating a model of arena

just like the local hockey team, the Lightening. However, they were faced with a problem: the robots were getting stuck on the opening of the light table and couldn't enter the building. Using carboard and tape, the children worked together to make a ramp for the robots so that they could smoothly go into Amalie Arena.

The teachers followed the children's interest by looking up the arena they kept talking about which led to high level engagement by the children. This series of lessons incorporated content areas including science, technology, reading, engineering, art, math, and social studies. The children started by using digital literacy skills to look up information on the computer. Next the children *collaborated* and *communicated* about what needed to be included in their arena representation. The children then had to engage in *critical thinking* to decide how to create their structure. The children created the arena with an empty light table, egg carton, small disco ball with lights for the jumbotron, photographs, twinkle lights, cardboard, and tape. This

Fig. 17.7 Model of arena

process demonstrated strong *creativity* skills by all of the students. When Cubetto could not get into their arena the children had to *critically think* about how to solve this problem. It took some time, *collaboration*, *communication* and *creativity* to figure out how to create a ramp that Cubetto could get up to enter the structure.

17.3.8 Navigation

After exploring Amalie Arena using *Google Maps*, the students were interested in how the robots would move around the classroom and know how to get back to their homes. During circle time, the teachers introduced the computer programme called *GPS* (global positioning system) as a way to show how computers help us to navigate to places that we want to go. The teachers compared the *GPS* to coding *Cubetto* because they both tell things how to move and where to go. Using a phone, one teacher used her *GPS* app to put in directions from the preschool to Amalie Arena. The *GPS* started by saying "starting route to Amalie Arena" and continued with driving directions to the destination. During centre time, the children began to code themselves, drawing maps with arrows to show how they could move themselves from centre to centre. Centre time is a prolonged work time in the classroom where children work in small groups in teacher directed lessons, or working on their own in a variety of learning centres including science, literacy, dramatic play, math, and art. The teachers extended this idea and continued to work with students on coding themselves around the classroom using directional words like forward, right, left, and stop. Figure 17.8 depicts a child mapping the area out on the classroom laptop.

The teachers focused on connecting the technology to the children's daily lives. The children *collaborated* with each other in order to figure out how to code *Cubetto* and themselves to move about to different places in the classroom. The process of

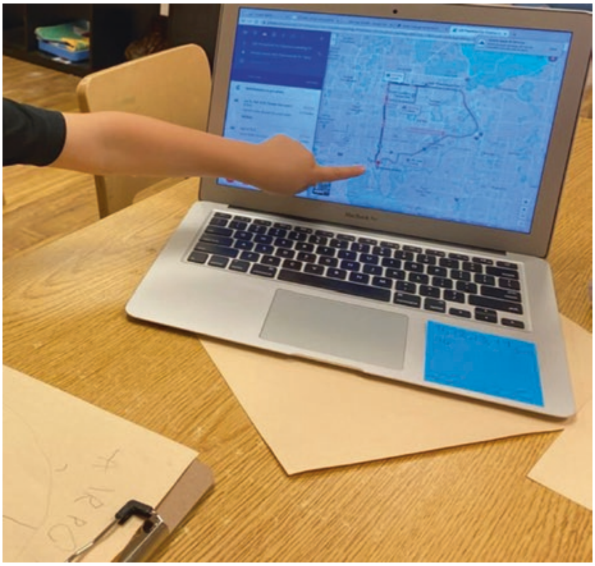

Fig. 17.8 Using *Google Maps* to create codes for the classroom

using the *GPS* and figuring out the directions for themselves and the devices takes a considerable about of *critical thinking*. Through this work, children had the opportunity to work on their special awareness all while connecting various technologies.

17.3.9 Mapping Our Classroom

After investigating the topic in Phase 2, the project entered Phase 3 in which the students worked together to put together a culminating event to show others what they have learned. Following student interest in the *GPS*, the teachers decided that the Magnolias could make their own *GPS*, using children's voices to give directions and code people to go to different places around the classroom. The teachers helped students to map out a *GPS* plan using directional words. After creating the map, the teachers recorded the student's voices giving directions like "go forward," "go left," "go right" and used *iMovie* (a computer programme) to make videos of different *GPS* directions to each place in the classroom; one video coded people to *Cubetto* and *Sphero's* houses, while another coded people to the Magnolia office. For each video, the teachers created individual QR codes (that could be scanned with a phone or *iPad*) which brought up a *YouTube* link to its associated *GPS* video. Before the culminating event, the children observed pictures of the inside of Amalie Arena and noticed that there were concession stands that sold soft pretzels and lemonade to customers. So, the children decided that we needed to have one in our classroom to distribute food and beverage as well. During the culminating event, parents were invited to come into the classroom, scan each QR code, and use the Magnolia *GPS* to navigate to different destinations around the classroom. Figure 17.9 shows one of the family members scanning the QR code to find out where to go next in the classroom.

The children showed a great interest in the *GPS* and giving directions. The teachers adding extra layers of technology by using both *iMovie* as well as QR coding shows the teachers flexibility as well as comfort in taking risks in the classroom. The creation of the movie and mapping with QR codes required all of the *4 C's* to be used throughout the entire process. The creativity of the movie, mapping, and even providing a concession stand for the event is overwhelmingly clear. The families that attended the event were very surprised to see their children engaged in this level of work.

17.4 Discussion

The Computer Project that took place over the course of several months is a strong example of the power of authentic STREAM's learning. Through natural exploration the children were able to engage in science, technology, reading, engineering, art, and math in meaningful ways. This project provided ample opportunities for the teachers to engage in twenty-first century learning as is proposed to include critical thinking, communication, collaboration, and creativity. The teachers were able to provide opportunities for the children to use high level technologies that are often thought of as too complex for young children. However, by connecting these technologies in authentic ways that relate to the children's life they were able to introduce children to very complex ideas. This project also approached creative thinking in multiple ways. The children were able to question, problem solve and create

Fig. 17.9 Families use QR codes to find places in classroom

throughout the project leading to the creation of an interactive classroom map for families to come and follow.

Including the families in the project connected home and school in a unique way. Parents were able to show their area of expertise and share the types of technology and work space they engage with. The families became more invested as a result and were active participants throughout the project. They were more interactive in their communication and participation during this time. The children became more engrossed in the project when they saw the level of the parent interest in the project. They showed great pride when their parent was in the room and they were able to assist their parent.

17.5 Conclusion

This is only one example of a project that took place in a preschool. However, the possibilities are endless. When taking the time to integrate tangible technologies in a classroom utilising an inquiry-based approach to learning children engage in science, technology, reading, engineering, art, and math authentically children learn about the modern world around them. The result is a deep understanding of the project topic and the way things work in the real world. This educational approach fosters more than basic content skill learning, it allows for children to critically think, collaborate, communicate, and create in meaningful ways. Children were engaged in the learning because it was hands-on and they were able to incorporate their families into the project through the use of a variety of technologies. More research on how children that engage in this type of learning at a young age perform later on in school settings would be beneficial. Teachers had to be flexible and truly let children take the lead on where the project went. The teachers also had a strong disposition for the importance of incorporating technology and project work. More research on how teachers develop these skills and dispositions would be beneficial, as well as how to bridge the gap of knowledge on inquiry-based teaching and enacting it within a real classroom.

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Chapter 18
The Creative in Computational Thinking

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18.1 Introduction

Computational thinking (CT) is a form of meaning-making that allows students to become more critical thinkers and problem-solvers. Similarly, creative thinking (CrT) is increasingly valued by those in education as critical to students' development as citizens of a future in which they will need to make sense of an increasingly complex world that is infused with the challenges and interdisciplinary potential of STEM (Science Technology Engineering and Mathematics). The potential synergy of distinct disciplines provides a challenge and opportunity that we would do well to explore to better understand CrT in STEM, indeed that is the aim of this book. We are particularly interested in what creative STEM opportunities for students and teachers might follow from a focus on CT.

18.1.1 Computational Thinking

CT is a form of thinking that has great impact around the world in terms of how computer science and CT concepts and skills are taught in schools. Conceived of as a skill set that programmers develop over time, it was popularised by Wing (2006) as a useful problem-solving skill that everyone should learn. She was clear in her conception that it was about computing processes but did not differentiate whether they needed to be executed by a human or a machine (Curzon et al., 2019). However, there is debate as to what CT should be. Advocates such as Peter Denning (2017;

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Denning & Tedre, 2019) question the basis of including code that will not be run by a computer. They argue that the teaching of CT should not be primarily associated with problem-solving but the teaching of programming. Bers (2008) similarly proposes that the value of CT should not be seen in its potential for problem-solving, but rather how it allows students to instruct computers to do things and express their inner creativity. These two perspectives focus on the purpose of teaching CT, whether that be as something essentially utilised to develop a generation of programmers or to focus more narrowly on problem-solving.

The basis of what constitutes CT is widely debated. Within an education context, the underlying concepts of CT have been separately proposed by the Computer Science Teachers Association (2011), the Computing at School's subdivision of the British Computer Society (Csizmadia et al., 2015) and the International Society for Technology in Education (ISTE) (2016). The common concepts across their proposals include: logical and algorithmic thinking, abstraction, evaluation and generalisation while additional concepts and skills proposed by the ISTE include automation, testing, parallelisation and simulation. The scope of CT concepts and skills were investigated by Selby and Woollard (2013) who reviewed the literature to ascertain which concepts were consistently related to CT and if they were central to its definition. Their review indicated broad support for the concepts: *abstraction, algorithmic thinking, logical thinking, generalisation, decomposition and evaluation*. However, there is still some contention as logical thinking is considered ill-defined. For this chapter, we will consider the purpose of CT to be consistent with Curzon's (2019) notion that it has to do with teaching programming, but also utilises a wide range of approaches to understanding computing concepts.

18.1.2 Creative Thinking

There is growing global interest in CrT as a capability that is needed by young people to develop into scientifically literate citizens who are responsible and productive in their STEM careers and daily lives (Australian Government, 2016; Australia's Chief Scientist, 2012). Various intergovernmental organisations such as the OECD (Yamanaka, 2019) and UNESCO (Marope et al., 2019) highlight the importance of these competencies, with both the Australian Council for Education Research (ACER) (2019) and the PISA (Program for International Student Assessment) panel (OECD, 2019) developing and testing instruments to assess creativity. The OECD's 'Centre for Educational Innovation' reported that "teachers often find it unclear what creativity and critical thinking mean and entail in their daily teaching practice" (Vincent-Lancrin et al., 2019, p. 13). In addition, there is minimal agreement among researchers as to the nature of creativity in STEM, despite widespread acknowledgement that it involves elements of both originality and usefulness. Therefore, much work still needs to be done to determine how to conceptualise and assess this capability that informs its contribution to learning in STEM and how this notion of creativity can usefully inform teacher practice in STEM (Tytler et al., 2020a, b). As

Glaveanu et al. (2020) highlighted in their recent manifesto on creativity, there is a need to develop and embrace socio-cultural approaches.

18.1.3 The Intersection of Computational Thinking and Creative Thinking in Unplugged Programming

In this paper, we are confronted with the elusiveness of *both* CT and CrT but are excited by the potential of the synergy between these two capabilities to make STEM more rewarding for both teachers and students (Mishra et al., 2013). As Hershkovitz et al. (2019) point out, "creativity and computational thinking have some complex relationships" (p. 628) with much of this due to their reciprocal impact on each other. While CrT can propel CT in new and productive directions, opportunities for students to be creative and develop CrT can be opened up by CT and contexts that foster this capability (Romero et al., 2017; Yadav & Cooper, 2017). Our focus is working with teachers and students to realise contexts in which CrT and CT overlap in productive ways. In doing so, we keep in mind that CT and CrT seem to operate (conceptually and in practice) at different scales, with CrT operating at a broader level than CT.

Our research focus is *creativity in computational thinking*, where we explore CrT specifically within the context of CT. Hershkovitz et al. (2019) argue that this research can play out in two different ways; "creativity within the scope of CT", that is research which focuses "on creative artifacts, which are products of the CT learning process" (p. 630), or research that focuses on "the relationship between measures of creativity outside the scope of CT and variables associated with the acquisition of CT" (p. 631). In both cases, Hershkovitz et al. (2019) show that characteristics of the task are significant in shaping students' CrT and CT. Our research is most closely aligned with this first research agenda, but it also touches on the second research agenda.

Our study involved students undertaking Unplugged Programming (UP) (also known as Unplugged Activities) which refers to ways of engaging with and learning computing concepts and programming without a computer (Bell et al., 2009). This is a *constructivist* perspective which has been used to teach students between early childhood and higher education as well as adult educators (Curzon et al., 2019). It utilises a range of activities including drawing, problem-solving, role-play, manipulation of real-world objects and physical actions of the body which can allow students to explore computer science ideas (Aranda & Ferguson, 2018; Bell et al., 2009). The version of UP we are focussing on in this paper is Flowchart Programming (FCP) which is considered a type of *pseudocode* that constitutes a range of strategies using *computer science speak* (Cutts et al., 2012; Curzon et al., 2019), which is a midpoint between plain language descriptions of code and code itself. FCPs utilise the structure of flowcharts with boxes and arrows indicating the structure and flow of the code. Of course, the construction of FCPs as pseudocode could be considered to be a form of design-based learning (DBL) (Zhang et al., 2020) where students are engaged in design-based practices. These practices are based on an iterative design process that has been seen as valuable in the development of STEM skills (Apedoe & Schunn, 2013). The influence of DBL and task design in regards to CT and CrT will be considered in the discussion section.

In focusing our research on CrT and CT specifically in the context of FCP, we consider Tsortanidou's et al. (2019) *3C multiple moments pedagogical model* (3C model) as a useful socio-cultural conceptual framework. They argue that CT, CrT and collaboration can be cultivated in students (with teacher support) through various means that they term *micromoments*. These include *non-technical, socio-cultural, imaginative, multimodal* as well as *media* factors. It is through the integration of these different *micromoments* that students can be provided with opportunities to undertake creative meaning making through collaborative CT. While the 3C model is yet to be empirically validated in various classroom contexts it is still highly useful for conceptualising the linking of CT and CrT for the purposes of progressing the creative-CT thinking agenda in STEM education.

Tsortanidou et al. (2019) identify UP as a key aspect of students' non-technological CT experiences, arguing that the scope for CrT and collaboration when it comes to CT is potentially greater in those contexts in which students work with their hands to engage with physical materials. They highlight the power of writing and drawing to afford students' creativity and collaboration including when it comes to CT and argue that it needs to be recognised as "a social, communal practice because we create to share with others … CT should be thought [of] as computational participation" (p. 709). CT needs to be social and situated if it's to be meaningful and useful for students, by allowing them to create shareable artefacts (Tsortanidou et al., 2019). These artefacts as part of imaginative tasks are valuable for student learning if they are multimodal in combining different representational modes in creative and epistemically useful ways. Tsortanidou et al. (2019) propose that CT can enhance creativity because "CT practices include computational artifacts, which are products that draw upon imaginative capacity" (p. 710) that includes those artefacts generated through UP. They argue that UP can be fertile ground for creative CT, in both individual and collective form, because imaginative approaches to teaching such as storytelling, role play, exploration etc. can be implemented in these contexts. In considering CrT and CT in the context of media studies, Tsortanidou et al. (2019) make an important point in proposing that CT is more than just creating code.

Research exploring the potentially productive overlaps between CT and CrT, particularly when it comes to STEM, is only just starting to emerge as a research agenda. As part of this rapidly developing field of CrT in CT, in this chapter we address the following research question in relation to the STEM context: *How do computational thinking and creative thinking overlap in productive ways when students undertake a collaborative unplugged programming task?* In order to do so we conducted an analysis of video data of two focus groups of students through which we identified and coded moments of CT and CrT by implementing Selby and Woollard's model of CT (2013) and the PISA model of CrT (OECD, 2019). Next we make use of the 3C model (Tsortanidou et al., 2019) to discuss the ways in which CT and CrT overlapped in productive ways for the students. We finish the paper by suggesting possible future directions for further unpacking of the relationship between CT and CrT and how teachers might observe creative-computational thinking when undertaking STEM inquiry with students.

18.2 Methodology

This research project was run with four teachers at a primary school in Melbourne, Australia. Two professional learning sessions were conducted to provide them with the fundamentals of CT and FCP. Teachers then introduced these ideas into digital technology lessons at their school over approximately 4 weeks where students developed experience using FCP.

Two sessions were conducted at the Science of Learning Research Centre (SLRC), University of Melbourne, with two different groups of year five/ six students. Each session lasted approximately 100 min. Session One was conducted by the researcher GA due to the teacher requesting that he run the session with their support. Session Two was run by the students' teacher, Emma (pseudonym).

18.2.1 Sessions

The two sessions were run in the same way with students working in pairs situated on tables with another pair.

Task A—Hopscotch. Students were provided with an introductory activity where they explored a worked example of an FCP of the game of Hopscotch printed on pieces of paper. This task was designed to acclimatise students to the SLRC space (see below), think about what was required for their FCP to be suitable for an audience of players, and what issues or ideas would need to be considered.

Task B—Tic-tac-toe (also known as *Noughts and Crosses*). In the same pairs, students were challenged to develop an FCP of the game Tic-tac-toe. A whole class discussion took place, involving a demonstration of the game with students offering their suggestions and justifications for where to place the Xs and Os. This unpacked the game for the group and some of its strategies and rules (e.g. "How do you know if you win?"). Pairs were given 5 min to play games of Tic-tac-toe with their partner in order to consider what was needed in their planning of the FCP. In a whole class discussion students suggested elements of their FCP and the educator highlighted particular ideas and clarified any ambiguities in the FCP challenge. Student pairs were given approximately 1 h and provided with a whiteboard, a single marker and eraser. They were free to interact with other members of the class and educators (ie. teacher and researchers) in the room. Afterwards, a whole class discussion took place where the educators selected two student pairs to present their FCP to the class and discuss what they had created. The educators highlighted aspects of these examples that were valuable for learning CT concepts and the students were questioned by the class. The student pairs swapped their FCP with the other pair on the table and proceeded to 'debug' each other's programme by annotating it using a different coloured marker.

Supporting students to create game-centred FCPs was utilised to provide challenges that students might already be familiar with. All students were familiar with Tic-tac-toe, a game that requires turn-taking between two players, has a maximum of nine moves, eight possible winning scenarios based on aligning three Xs or Os (three vertical, three horizontal, two diagonal) and frequently ends in a draw. This allowed for: a reasonably complex game for the students to plan for and design; encouraged the use of conditional and loop statements; to consider win, draw and lose conditions; and focused students on how to include two player interactivity. In our version, FCPs had a small number of elements: rounded boxes indicated the beginning and end of the programme, rectangles represented statements or actions, diamonds represented conditional statements and arrows with text annotations connecting them. Combined, these elements allow code to flow in different directions, including conditional statements, and could be scaled to represent algorithms of varying complexity and size.

The sessions took place in the SLRC which was fitted with ten wall- and ceiling-mounted video cameras and radio microphones on each group's table to record students' and the educators' multimodal engagement with the challenge. Two of the tables were filmed with cameras from side- and top-down views of students constructing their FCP on whiteboards with markers and an eraser. This provided a valuable perspective on the construction process as evident in the changing inscriptions on the whiteboards. Student artefacts in the form of their planning notes and photographs of their final whiteboard inscriptions (FCPs) were also collected for analysis.

18.2.2 Data Collection and Analysis

The methodology was micro-ethnographic (Erickson, 2006) in that video/ audio records and student produced artefacts were analysed in detail to explore the way groups of students engaged in CrT and CT through coordinating talk, gesture, writing, and visual representation construction. Each author focused on engaging with the data from a different SLRC session. With such a rich and extensive data set, selection became a significant methodological issue that defined our analysis (Ferguson et al., 2019). In undertaking the analysis we were not aiming to generate universal claims about students' creative-computational thinking based on the entire group. Rather, we aimed to identify how particular pairs went about utilising CT and CrT to resolve the challenge. We focused on the two tables in each session that were filmed from above as this captured important aspects of the inscription process, then each author further refined the focus by selecting one pair (from the four pairs spread over the two tables) that was deemed most on task and thus most likely to undertake the activity in creative ways that involved CT.

We then identified instances of these students exhibiting aspects of CrT and CT according to definitions and descriptions in the literature of these phenomena and the authors' research experience of these processes in science classrooms. We generated a coding scheme derived from the PISA competency model of CrT (2019) and Selby and Woollard's model of CT (2013), then applied this scheme to the instances, cross-checking the coding and then focusing on two to three relevant examples. These 'examples' were not representative in the traditional sense of providing the basis for making general claims about students' CrT and CT. Rather, we followed Massumi (2002) and MacLure (2010) in considering these examples as yielding rich insights into the interlinking of CrT and CT as students engaged in FCP. These were instances capable of providing insights into the unique generative links between CrT and CT that only emerge when implemented by these processes in context.

18.2.3 Operationalising Creative Thinking

We defined CrT according to the PISA competency model (OECD, 2019) that will frame testing of creativity for PISA in 2022 (see Table 18.1). This defines CrT as "coming up with new ideas and solutions" that consists of two broad thematic areas, *creative expression* and *knowledge creation and creative problem solving*, with each of these consisting of two domains. *Written expression* and *visual expression* make up the creative expression domain, while *scientific problem solving* and *social problem solving* make up the knowledge creation and creative problem solving domain. Operating within and across each of these domains are three facets: *generate diverse ideas*, *generate creative ideas* and *evaluate and improve ideas*. We used these categories to code the students' construction of the FCP, in particular focusing in detail on the *facets* in the analysis while considering the *domains* in the discussion in order to frame the students' interactions with each other and their unfolding FCP.

18.2.4 Operationalising Computational Thinking

CT consists of a number of concepts that are contested as to whether they are essential to this type of thinking (see Table 18.2). Selby and Woollard (2013) developed criteria as to which concepts should be included via consensus across the literature. For the purposes of this chapter, we have adopted the concepts they indicated were supported by the literature, with our inclusion of *logical thinking*. In their review this was considered ill-defined, but we will refer to logical thinking as this is consistently used in the literature.

Table 18.1 Broad thematic areas, domains and facets of the competency model of creativity

Broad thematic areas	Definition
Creative expression	Creative thinking is involved in communicating one's inner world to others.
Knowledge creation and creative problem solving	Functional employment of creative thinking that is related to the investigation of open questions/problems.
Domain	**Definition**
Written expression	Requires logical consistency; asks readers to understand and believe in the author's imagination and reflects upon the craft and process of writing. Applies to fiction and non-fiction writing.
Visual expression	Explore, experiment and communicate ideas of their own experiences using a range of media, materials and processes.
Scientific problem solving	Engage in open problem-solving tasks in a scientific context; generate ideas for hypotheses/solutions; and suggest original improvements to experiments/problem solutions.
Social problem solving	Looking at the problem from a technical and social perspective; trying to understand and address the needs of others to find solutions to central problems.
Facets	**Definition**
Generate diverse ideas	Ideational flexibility across domains and avoiding functional fixedness in the idea generation process, remaining relevant/specific to the task.
Generate creative ideas	Creative outputs need to be both novel and useful relative to the responses of other others who complete the same task. The response complies with the requirements of the task, its constraints, and is useful to the response.
Evaluate and improve ideas	Identify and provide feedback on the strengths and weaknesses of others' ideas. Evaluate limitations in given ideas and find original ways to improve them, preserving the essence of the idea and incorporating the original elements.

As adapted from the PISA competency model (OECD, 2019)

Table 18.2 Components of CT as derived from Selby and Woollard (2013)

CT component	Definition
Abstraction	Refers to simplifying or hiding of detail to get at the essence of something of interest.
Decomposition	The idea that a problem can be broken into smaller parts which can then be solved separately.
Logical thinking	Involves thinking clearly and precisely, including avoiding errors and with attention to detail.
Algorithmic thinking	Involves solving a problem in an efficient step-by-step manner which focuses on selection, sequencing and iteration.
Evaluation	Involves examining a solution and judging whether it is doing what it is designed to do and how it could be improved.
Generalisation	Taking the solution, or parts of the solution to a problem which may be reused and reapplied to similar or unique problems.

18.3 Results

In this section we refer to two vignettes. Vignette 1 is taken from one session in which students S1 and S2 were planning the construction of their FCP. Figure 18.1 is their completed FCP and annotations described in this vignette refer to this figure. Vignette 2 is taken from the other session in which students S3 and S4 are starting to construct their FCP. Figure 18.2 is their completed FCP and annotations described in this vignette refer to this figure.

Vignette 1

Description. In Vignette 1, the students play games of Tic-tac-toe to familiarise themselves with the game and consider which game elements need to be represented in the FCP that they are going to create. Students S1 and S2 discuss the elements they might include. S1 begins to focus on the visual elements of the game and how they could be described:

1. S1: You have to draw the board…
2. S2: No, that's like…
3. S1: But what's the board [gestures drawing a vertical line in air] … how could you? [pauses] A cross ….
4. S2: Draw …Wait, can I have the blue for a second [gestures towards markers]
5. S1: Oh. Two vertical lines [draws two vertical lines in air with finger] and two [draws horizontal lines]
6. S2: Draw. It's easier for me.

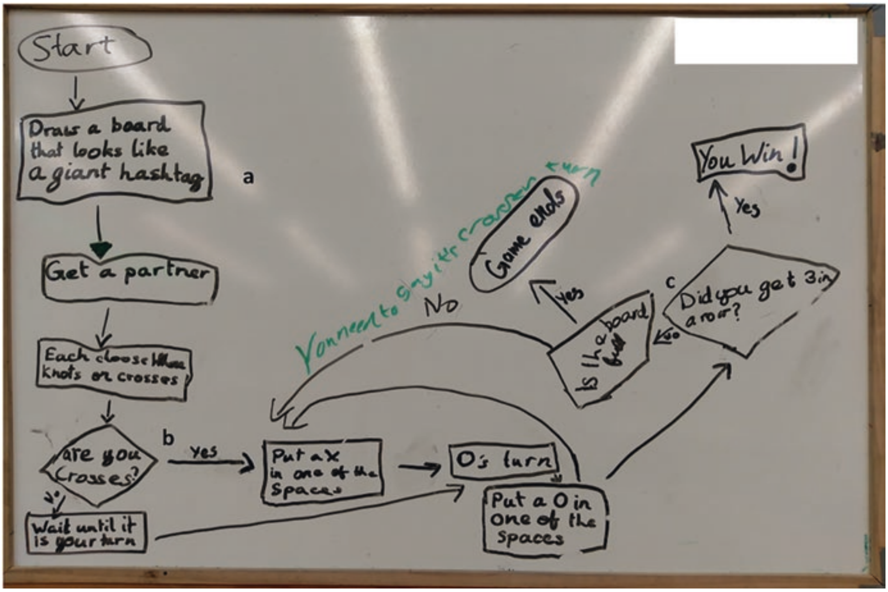

Fig. 18.1 Final FCP developed by S1 and S2 in Vignette 1

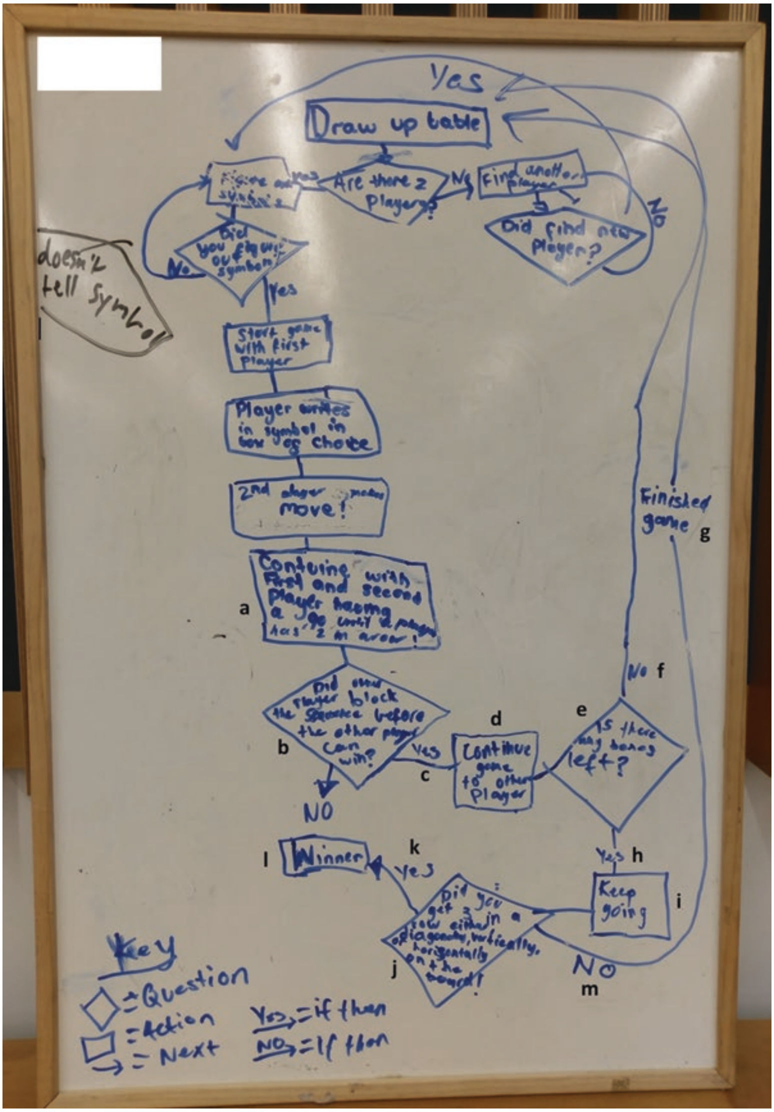

Fig. 18.2 Final FCP developed by S3 and S4 in Vignette 2

7. S1: Seriously. A hashtag. Oh. Draw a big hashtag. That's good!
8. Other pair: A hashtag?
9. S1: That's what naughts and crosses looks like. Draw a big hashtag.

The other pair on the table appreciate S1's idea of drawing a giant hashtag. S1 and S2 continue to write down in point form what they consider to be important parts of the game. These include: specifying the rules of the game such as having three in-a-row vertically, horizontally or diagonally; the draw condition; the order of gameplay; and playing the game.

Computational Thinking

- *Decomposition.* Vignette 1 provides an example of planning that occurs before the students begin to represent their ideas as the flowchart. The students *decompose* the problem by breaking it down into smaller components by using dot points which end up in the final FCP. These include: visual elements (drawing a giant hashtag (A)), social elements (game play order (B)), and rules (conditions to win the game (C)).

Abstraction. Another aspect of CT demonstrated is S1's insight, where she voices and gestures her idea that the visual element of the board could be characterised as a "hashtag" (A). The use of this symbol is an example of abstraction where the precise visual and spatial arrangement of the lines of the board are quickly characterised and simplified by reference to an outside object.

Creative Thinking

- *Generate Creative Ideas*. S1 has an insightful moment where she indicates that a hashtag would be an efficient way to describe the board for Tic-tac-toe. This moment demonstrates original thinking by S1 and is reflected by how the other group at the table take up her idea and eventually use it in their own FCP. It demonstrates her ability to visually express her own experiences of using social media and using it effectively within this new context.

Generate Diverse Ideas. In decomposing the task, the students demonstrate their ability to plan for social problem-solving by which they incorporate the needs of the players of the game such as turn-taking and rules that will be required in the completed FCP.

Vignette 2

<u>Description</u>. Vignette 2 is composed of two sequences with S3 and S4 that follow on from each other in the course of the students' construction of the FCP. This vignette thus focuses solely on certain moments that occurred during the construction of the code during one part of the session.

The first part of this vignette involves S3 pointing out a problem with the 'Yes' **(c)** command that led from the 'Did one player block the sequence before the other player can win?' **(b)** conditional to the 'Continue with first and second player having a go until a player has two in a row' **(a)** command. This series of codes forms a problematic infinite loop that does not progress the game. S4 does not immediately recognise this as an issue but comes to the same realisation as S3 that this is a problem with their code.

1. S3: Olga, you know this is going to be an everlasting…[points out the infinite loop on the whiteboard by tracing it out through **b to a via c**]
2. S4: Yeah, yeah that's what it has to be.
3. S3: Okay.
4. S4: Oh, but then…
5. S3: Yeah.

6. S4: …You need to do something off this one…
7. S3: Yeah.
8. S4: …Off this one [points to **b**] saying…Yeah, so we have to do another box.
9. S3: Yeah.

The students then proceed to propose possible alterations to these commands (**a, b and c**) that might resolve the current issue with the infinite loop and allow the programme to proceed.

10. S4: We have to do another box and then say [erases the arrow linking **b to a via c**]…

S3 and S4 collaboratively propose and evaluate these possibilities as they consider the implications of altering the preceding and subsequent code (**a, b and c**). They discuss possible solutions by tracing out the ramifications on the whiteboard through pointing and gesturing. They decide on **'**Continue game to other player' **(d)** and so inscribe this as a command on the whiteboard. They've thus resolved the issue of the infinite loop.

However, S3 points out another problem with their code, this time to do with the winning condition in regard to the player that is not the focus of the code at that point of the flowchart. S3 explains by tracing out her ideas and their ramifications on the whiteboard by pointing to the relevant code. Again, the focus of these changes is on the preceding and subsequent code; the students are always looking as to what has preceded and what will have to follow.

1. S3: Oh! But what if…We've got that [points to **d**]…But what if then another player also wins [points to **a**]?
2. S4: That doesn't make sense.
3. S3: Yeah, so, you've got this option [points to **d**], right? But what if, the other player…
4. S4: Oh!
5. S3: …Wins?

As before, the students propose and evaluate possible solutions to the winning condition **(d)**, through verbalisations and gesturing to the whiteboard. They then inscribe 'Is there any boxes left**?' (e)** on the whiteboard as the conditional that follows from **d**. This is followed by determining that the **'No' (f)** option will lead back to the start (**'**Draw up table') via **'**Finished game' **(g)**. S4 inscribes this on the whiteboard and S3 makes clear that this then forms a complete loop; the code as a programme is complete.

Computational Thinking

- *Logical thinking.* S3 and S4 demonstrate logical thinking which is evident in these students' attention to detail in avoiding errors in the programming so the code forms a complete loop. More specifically, (1) identifying a problematic infinite loop (**a, b, c**) that effectively stops the game running and (2) the possibility of the non-turn player winning (at **a**). They determine a need for solutions and after proposing and considering a few ideas they decide on **d** for error one and **e** for error two.

Algorithmic thinking. S3 and S4 also demonstrate algorithmic thinking that is evident in the way they carefully consider the selection and sequence of the commands of the two programming errors (one and two). They explore and decide on commands that make for an efficient game, although there is quite a lot of redundancy in their programming. They demonstrate that solutions to problems do not have a single solution by rapidly proposing and evaluating possible solutions. In doing so, they are considering how to make a complete loop that enables winning and restarting of the game. In this they are clearly considering: sequencing, selection and iteration as regards the code of the flowchart.

Evaluation. S3 and S4 consistently engage in evaluation of their FCP in a self-initiated and self-directed manner. This is evident as S3 identifies problems in the code (error one and error two) and with S4 they resolve these issues as they seek to improve their code. This valuing and undertaking of evaluation by these students is perhaps most strongly reflected in S3's focus on "what if" scenarios as she leads a systematic evaluation of the flowchart. The students are driven in their evaluation by a need to make sure that the requirements of a Tic-tac-toe FCP are met, most importantly the formation of a complete loop that enables a winner and restarting of the game. They undertake this evaluation with usability and future users in mind as they step through the code, using verbalisations and pointing/ gestures to evaluate whether the game flows as it should.

Creative Thinking

- *Generate diverse ideas.* S3 and S4 exhibit the *generation of diverse ideas* in creatively responding to the problem posed by error one and error two, with these students generating and evaluating a range of possible solutions. For the first problem the solution is **d** which corrects error one and for error two this is **e**, which renders their FCP as resolved in the sense that it forms a complete loop (satisfies the winning condition and/or restarts the game).

Generate creative ideas. In generating diverse ideas, S3 and S4 also demonstrate the generation of creative ideas in the sense that the solutions that they propose comply with the basic requirements of the task, task constraints, and a level of usefulness in resolving the problem. The solutions that they propose are less novel than they are useful, relative to the work of their peers on the same task.

Evaluate and improve ideas: Similar to CT, S3 and S4 are engaging in considered and ongoing evaluation of their FCP to ensure that it forms a complete loop. By considering this evaluation through the lens of CrT, it becomes evident that these students are undertaking this evaluation in order to improve their ideas in the sense of the code as a whole forming a resolved flowchart that enables a winner and restarting of the game.

18.4 Discussion

In this chapter we have examined, in response to the research question *how do computational thinking and creative thinking overlap in productive ways when students undertake a collaborative unplugged programming task?*, a UP challenge in which students developed a FCP to 'play' a game of Tic-tac-toe. Video-recordings were created of student-pairs who used markers, erasers and whiteboards to collaboratively design their programmes. We examined the overlap between CT and CrT as they developed their programmes.

18.4.1 Computational Thinking and Creative Thinking

The nature of the task is consistent with DBL (Zhang et al., 2020) and its influence on CT and CrT was apparent in the students' construction of their FCPs in the two vignettes discussed in this chapter. According to Stempfle and Badke-Schaube (2002) designers begin with 'exploration' and 'generation' which widen the problem space by focusing on the development of early ideas and exploring the nature of the problem. In this study, this promoted the use of CT concepts such as decomposition and abstraction which allowed students to take apart the problem and consider aspects of it in more simple terms; CrT facets allowed for the generation of original ideas which could be built upon. In later phases, designers continue with 'comparison' and 'selection' which narrow the problem space by focusing on the continued development of ideas and making these ideas concrete. In this study, this promoted the use of CT concepts such as logical and algorithmic thinking and evaluation whereby students started laying their ideas out on the whiteboard, reasoning through possibilities and coming to a decision about their utility in relation to the overall goals of the task; CrT concepts allowed for students to creatively rearrange aspects of the FCP in an iterative process as they moved towards finding the optimal solution to the problem. In relation to Stempfle and Badke-Schaube's (2002) model, it highlighted the role of CT as an analytical skill (Curzon et al., 2019) which provided a mechanism for students to consider the elements of the problem and lay out a pathway in the FCP that could be logically considered and organised, whereas CrT provided a mechanism for innovative and diverse ideas to be developed that allowed the problem space of the FCP to be broadened or narrowed as necessary during the task (Altan & Tan, 2020). Of course, these ways of thinking do not occur separately, they are specific to the nature of the problem and occur in parallel in an iterative fashion as ideas are considered, evaluated and reconsidered in a new light.

This interlinking of CrT, CT and UP is usefully instantiated in Tsortanidou et al.'s (2019) 3C model and as such we can use it to further consider the overlap between CrT and CT in our study. In undertaking the UP task, students were provided with opportunities to create imaginative, material and multimodal artefacts in the form of their FCPs that they shared with each other as they solved the problem of how to appropriately programme the game of Tic-tac-toe using the available tools (whiteboards, markers, erasers). We observe a productive overlap between CrT and CT when students were able to integrate and move between the different *micromoments*. It was when students purposefully used these tools to collaborate with each other to imaginatively construct code in multimodal form (written, pictorial, verbal, gestural) that they could realise the FCPs as more than just outputs of a process, but as the consummation of a productive synergy between CrT and CT. We argue that students' CrT was heightened by the CT which was made possible by the task. By engaging with opportunities to undertake decomposition, abstraction, logical thinking and algorithmic thinking, students were supported to be creative through the generation of diverse ideas, some of these genuinely creative ideas, and evaluating proposed solutions to problems as a means of improving their ideas.

18.4.2 Limitations

The nature of the challenge itself may have constrained the expression of student CrT and CT. The CT concept of generalisation, which is difficult to learn (Selby, 2014) was not clearly observed as students did not necessarily have the opportunity or experience to apply different parts of their code to another programme. Similarly, certain aspects of the CrT model were not able to be supported, as it focussed on visual and written expression but not necessarily on systematic mulitmodal representations inherent in FCPs (e.g. shapes and arrows). Previous research has indicated that the ability to express one's ideas can be supported and constrained by the choice of medium and the nature of the task (Tytler et al., 2020a, b). It may be that the PISA competency model of CrT needs to take into consideration mixed expressions of creativity that involve both visual and written forms. In addition, providing a more open task, such as allowing students to create any game in a range of mediums (e.g. card game, role-play, storyboard), may heighten students' creative potential, but in a classroom setting would arguably increase the teacher's challenge of assessing such a task and providing the required support to students.

18.4.3 Future Directions

In continuing with our research that explores the synergy between CrT and CT in the context of UP and what this might offer STEM education, we seek to follow Hershkovitz et al. (2019) in striving to develop nuanced and contextualised notions of what we mean by these processes. CrT and CT are not unidimensional constructs and they do not play out as entirely separate processes. In our case, we are interested in creative-computational thinking which we propose is a very particular synergy between CrT and CT which manifests in a specific way in the context of FCP. The 3C model proposed by Tsortanidou et al. (2019) is a useful conceptual framework for us moving forward in determining the value of the PISA competency model of CrT (OECD, 2019) and Shelby and Woollard's CT model (2013) to enable a contextualised and nuanced understanding of creative-computational thinking. We need to further test the range of these models to make sure that they can capture the richness and complexity of student and teacher experiences in the 'messiness' of the classroom as they undertake FCP challenges.

In further developing our research agenda, we propose that UP challenges, such as FCP activities, provide opportunities for students to bring together CrT and CT in empowering ways which enable them to authentically and meaningfully experience STEM. While there is a growing tendency in STEM contexts to focus on 'high-tech' tools and instruments when it comes to coding, we argue that there is much to be gained by students and teachers engaging with 'low-tech' resources in the form of markers, erasers and whiteboards to construct FCPs (Aranda & Ferguson, 2018) that afford creative-computational thinking in ways that are otherwise not possible. We propose that the inclusion of UP provides opportunities for students to undertake CT in creative ways that can potentially enrich and diversify CrT in STEM, and in this chapter we have started to map out ways for how teachers might identify and support students to undertake this creative-computational thinking.

18.5 Conclusion and Implications

In this chapter, we have started to unpack the link between CrT and CT in ways that can support teachers to 'see' these processes in action as their students undertake STEM tasks/ challenges. The operationalisation of CrT and CT models that we've presented may help teachers to better support students to be creative in their computational thinking. We suggest that such an approach is valuable for both students having difficulties with STEM tasks/ challenges and those students who need to be extended when it comes to CrT and CT. More specifically, we have extended the validity of UP in classrooms that we first proposed in Aranda and Ferguson (2018) and which we plan to continue to explore in future research.

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Chapter 19
Young Children's Playful Engagement and Learning with a Fairy-Tale Themed Augmented Reality Coding App

Fiona Scott

19.1 Introduction

This chapter speaks to the book's core theme of children's creative inquiry in Science, Technology, Engineering and Maths (STEM) by questioning the extent to which children are being creative when they engage in STEM learning in a particular digital context. The digital context in question is a fairy-tale themed *Augmented Reality* (AR) app, whilst the STEM learning is simple coding skills.

The chapter draws on a small-scale study conducted in 2019 in Sheffield, United Kingdom. The research, a co-production with Twinkl Educational Publishing, examined young children's playful learning and engagement with a fairy-tale themed AR coding application. This research attended to coding in early years as a prescient issue for contemporary early childhood. Although coding tends not to be an explicit focus of early years curricula, it is occupying an increasingly important position in STEM curricula globally (Balanskat & Engelhardt, 2014; Smith, 2016). In the UK, for example, the *Early Years Foundation Stage Statutory Framework* (EYFS) (DfE, 2017) provides minimal digital literacy guidance for early childhood educators, whilst coding and computational thinking are important parts of the *National Curriculum for Key Stages 1–4*, or ages 5–16 (DfE, 2014). As such, it is useful to consider the skills and knowledge very young children may be developing in relation to recently emerging coding apps, which are readily available to families and early years educators alike. To date, there is no known research examining children's early coding skills in relation to an AR app. The study sought to identify the skills young children develop through their engagement with the *Little Red Coding Club* (*LRCC)* app. In doing so, it focused on both the social contexts in which the

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app was used and the affordances (Gibson, 1977) of the app as a digital artefact. Two frameworks formed the basis of the analysis. The first, the *Makerspace Learning Assessment Framework* (MLAF), Kay et al., 2019), adapted from the *Bristol Characteristics of Effective Learning* (CoEL), (Bristol Learning City, 2017) was employed to assess children's learning across five broad categories. The second, the *Early Coding Skills and Knowledge Framework* (ECSKF), (Scott & Marsh, 2019), was developed specifically for use in the study, based on a review of relevant literature. It was designed to enable the identification of early coding skills and knowledge through observable behaviour.

This chapter draws on this broader study to reflect more specifically on the extent to which young children's play with the app *LRRC* can be considered creative. Little is known about the types of creativity and creative thinking made possible by children's engagement with coding apps and even less about the creativity specific to AR coding apps. The two frameworks discussed above serve as starting points for this inquiry. The chapter also attends to the relationships between creativity, the social contexts of use and the affordances of the app. Digital (Scott & Marsh, 2018) and media (Dezuanni, 2011) literacies theories provide a theoretical basis for understanding children's engagements with apps in the chapter. In order to orient the reader for the findings that follow, the next section provides some brief introductory information about the app itself.

19.2 Introducing *Little Red Coding Club*

LRCC[1] was released in 2018. It is currently marketed as suitable for players aged five and over. The multi-player app was designed and developed by Twinkl Educational Publishing to teach simple coding skills. It is intended to be used collaboratively by children, supporting up to four devices (two players, two viewers). It was the first educational game in the world to employ AR to support multiple players across multiple devices. It was designed to teach children to code quickly and easily, to complement the English National Curriculum and to promote other skills, including collaboration and communication. *LRRC* was informed by the children's fairy tale, Little Red Riding Hood. In centering on this well-loved story, the designers hoped the game could be used to support other subjects and schemes of work, so coding could be integrated into multiple lessons. Working individually or in groups, children use a mobile device to guide characters including Little Red Riding Hood through a forest to reach Grandma's house. AR enables the app to bring a 3D forest to life. This forest can be explored by physically moving the device in any direction.

On opening the app, children are greeted with buttons offering a choice between 'Play' and 'Create' modes. 'Play' mode prompts children to scan their physical

[1] For more information, see https://www.twinkl.co.uk/apps

environment with their device, enabling the placement of an AR game board. A story book then appears, offering ten game levels. When children select a level, a short introductory video presents the necessary information to complete the corresponding level. They are then prompted to press (or drag and drop) directional commands to create a sequence used to direct two characters on the AR game board: Little Red Riding Hood and The Woodcutter. 'Play' mode consists of the sub-modes of '1-player' or '2-player'. In the latter mode, children playing on a second, third or fourth device connect to the same AR game board as the first player. Children playing on two devices can programme the characters, whilst other children can join as observers on up to a further two devices. In the game's 'Create' mode, children are again able to scan their physical environment to place the game's AR board. However, they are provided with a blank game board on which they can create their own (playable) level from scratch. A variety of components are available to be dragged and dropped, including the same characters, buildings, decorations and landscape features available in the 'Play' mode. Having introduced the AR coding app, *LRRC*, the next section reviews some relevant literature pertaining to children's digital engagement, coding, AR and creativity.

19.3 Creativity in Young Children's Playful Engagement and Learning with a Fairy-Tale Themed Augmented Reality Coding App

19.3.1 Creativity and Young Children's Digital Engagement

Though young children's tablet use at home is increasingly prevalent (Ofcom, 2018), research suggests that many early years practitioners[2] (EYPs) highlight knowledge gaps regarding how to successfully embed digital technologies in their own professional practice (Marsh et al., 2017). Meanwhile, commercial organisations continue to design digital play experiences drawing on ever more sophisticated technology, including those ostensibly designed to foster STEM skills and knowledge. There is a need to understand the skills and knowledge afforded and supported by children's playful engagements with such digital experiences. Since children's playful engagements with apps commonly occur in social contexts (particularly at home and in early childhood settings), there is also a need to consider the roles played by others, including adults. Children's uses of touchscreen devices can be playful, collaborative and interactive (Marsh et al., 2016). It has been shown that children who have access to tablets engage in a range of activities promoting play and creativity (Marsh et al., 2018). Existing literature has considered the role of tablets in supporting preschool children's creativity, particularly in preschool

[2] In the UK, early years practitioner denotes an individual who works with children under the age of five in any early years setting.

settings. Studies demonstrate that tablet use supports creative thinking through problem solving (Harwood et al., 2015) and artistic and drawing skills (Price et al., 2015). Research also demonstrates how EYPs support preschool children in using tablets for a range of creative purposes, e.g. creating photographs, films and music (Dezuanni et al., 2015; Yelland & Gilbert, 2014) or digital books (Sandvik et al., 2012).

19.3.2 Creativity and Coding in Early Childhood

Whilst such studies are important for understanding and evidencing creativity in relation to children's use of apps, there is still a knowledge gap relating to the types of creativity and creative thinking made possible by children's engagements with coding apps more specifically. Some emergent literature on coding in early childhood touches on issues of creativity (Bers, 2017, 2018, Geist, 2016; Yu & Roque, 2019), but it is unclear how creativity is being conceptualised. It has been suggested that coding and computational thinking are intrinsically creative and expressive processes, since they enable children to become creative producers (rather than merely consumers) of technology (Bers, 2017, 2018). Others identify particular activities they consider creative in relation to young children's coding play, for example creating programmes and modifying them when they fail to achieve the expected result (Geist, 2016) and storytelling in relation to tangible coding technologies (Yu & Roque, 2019). It has been suggested that pedagogical approaches to teaching coding in early childhood should focus on creativity (Bers, 2019). The present chapter extends this recent work by considering the nature of the creativity implicit in children's play with a AR coding app in more depth.

19.3.3 Creativity, Augmented Reality and Coding in Early Childhood

LRCC is unique in employing AR technology to support the development of coding skills and knowledge. AR apps bring together children's play in so-called real-world spaces with a range of on-screen activities afforded by devices (Azuma, 1997). There is little extant literature examining AR play and learning in early childhood, although some work focusing on AR picture books for children can be found (Cheng & Tsai, 2014; Yilmaz et al., 2017). The present study, which investigates the use of an AR app to promote early coding skills and knowledge in early childhood is, therefore, novel.

19.3.4 Attending to Creativity and Coding in the Present Study

Diverse definitions of creativity, and frameworks for understanding and identifying creativity, proliferate. In the UK, the *National Advisory Committee on Creative and Cultural Education* (NACCCE, 1999) foreground imagination and the production of a particular outcome, defining creativity as 'imaginative activity fashioned so as to produce outcomes that are both original and of value' (p. 29) in relation to its objective. However, as Marsh et al. (2018) hint, value in creative production is both contested and contextually specific. Thus, a shift in focus towards the process of creativity is potentially more useful. Marsh et al. (2018) employed Robson's (2014) *Analysing Children's Creative Thinking* (ACCT) Framework to identify apps fostering imaginative thinking or behaviour. The ACCT Framework enables the process of creative thinking to be traced through observable behaviours in the categories of exploration and engagement (exploring; engaging in new activity; knowing what you want to do), involvement and enjoyment (trying out ideas; analysing ideas; speculating; involving others) and persistence (persisting; risk-taking; completing challenges). In line with NACCCE, the A–E Framework (Murcia et al., 2020) focuses on outcomes (or 'products') that are original and 'fit-for-purpose'. However, like the ACCT Framework, it also characterises the process of creative thinking as having agency, being curious, connecting, daring and experimenting. In addition, it highlights the importance of reflecting on the material and social contexts of children's creative activity by adding the dimensions of person and place.

In the present study, the creativity associated with young children's engagements with an AR coding app was examined in various ways. The *Early Coding Skills and Knowledge Framework* (ECSKF) (Scott & Marsh, 2019, see Table 19.1) was used to identify examples of early coding skills and knowledge. Bers (2017, 2018) suggests coding and computational thinking are intrinsically creative, enabling children to become creative producers through a skillset that allows for new ways to communicate, tell stories and convey ideas. The ECSKF thus provided a way to keep track of this skillset. However, a further tool was necessary to understand the nature of creativity afforded by playful engagement with an AR coding app. An adapted *Makerspace Learning Assessment Framework* (MLAF) (Kay et al., 2019, see Table 19.2) was thus employed for this purpose.

Aspects of the MLAF (Kay et al., 2019) relate to creativity. The five dimensions of the category Creativity and Design (CD) most explicitly address creativity (CD1: Explore materials; CD2: Use materials creatively; CD3: Trialling; CD4: Workaround; CD5: Adjusting goals; CD6: Suggesting improvements). However, other categories of the MLAF also clearly map onto dimensions of creativity identified in the literature review, across the additional MLAF categories of Playing and exploring (PE), Active learning (AL), Critical thinking (CT) and Social learning (S), e.g. PE1: Exploring and PE2: Transforming Resources. Table 19.1 highlights the characteristics of children's creative thinking classified in the A–E Framework, cross-referenced with categories and dimensions of children's playful learning encompassed in the MLAF. The MLAF incorporates some, but not all, creative processes summarised

Table 19.1 Early coding skills and knowledge framework

Coding skill or knowledge	Definition
ECSK1: Directional language	Child uses directional language (left, right, backwards, forwards, up, down).
ECSK2: Counting	Child counts using ordinals (first, second, third).
ECSK3: One-one correspondence	Child understands one-one correspondence.
ECSK4: Identifies patterns	Child can identify patterns.
ECSK5: Sequencing	Child can create/re-create a sequence.
ECSK6: Directions	Child is able to give and follow directions.
ECSK7: Cause and effect	Child understands cause and effect (if… then…)
ECSK8: Defines algorithms	Child defines a list of steps (algorithm) to complete a task
ECSK9: Decomposes	Child decomposes (breaks down) the steps needed to solve a problem into a precise sequence of instructions.
ECSK10: De-bugs	Child identifies and addresses bugs or errors in sequenced instructions (de-bugging).
ECSK11: Identifies loops	Child identifies repeated patterns in code that could be replaced with a loop.

Scott and Marsh (2019)

in the A–E Framework. Some interesting and important characteristics of creative thinking, then, were not coded in the data and may or may not have been exhibited in children's engagement with the *LRRC* app (e.g. finding relevance and personal meaning or challenging assumptions).

The preceding section has outlined some core literature concerning children's digital engagement, coding, AR and creativity. The next section outlines the methodology used in the present study to address these gaps in knowledge.

19.4 Methodology

As described above, the present chapter draws on a broader study, which employed a case study approach. The research questions informing the broader study were as follows:

1. To what extent does the AR app *Little Red Coding Club* promote young children's (4–6) playful learning and early coding skills and knowledge?
2. What are the affordances of the AR app *Little Red Coding Club* that promote young children's (4–6) playful learning and early coding skills and knowledge?
3. What characterises the social interactions and learning practices that emerge through engagement with *Little Red Coding Club* in classrooms and early years settings?
4. How do variables including age, gender and children's specific physical or educational needs impact on access and use?

Table 19.2 Comparison between creative categories and dimensions of the makerspace learning assessment framework (adapted from Kay et al. (2019)) and the A–E framework (Murcia et al., 2020))

Categories and dimensions	Description	A–E framework creative processes
PE: Playing and exploring		
PE1: Exploring	Child uses their senses to explore and make sense of their world.	B: Being curious (exploring)
PE2: Transforming resources	Child uses their senses to explore and make sense of their world.	E: Experimenting (using materials differently)
PE3: Sustained interest	Child demonstrates sustained interest in the task	–
PE4: Positive attitude	Child demonstrates a 'can do' attitude.	A: Agency (displaying self determination)
PE5: Trying	Child is eager to try out new ideas (rather than just staying with what they are familiar with).	E: Experimenting (trying out new ideas)
PE6: Unafraid	Child is unafraid to make mistakes and work outside their comfort zone.	D: Daring (persisting when things get difficult)
AL: Active learning		
AL1: Absorbed	There are times when child is absorbed in their own learning.	–
AL2: Purposeful	Child demonstrates a sense of purpose.	A: Agency (having a purpose)
AL3: Persistent	Child shows persistence—not going up even though it means starting again.	D: Daring (learning from failure (resilience))
AL4: Goal-setting	Child is able to set their own goals.	–
AL5: Pride in achievements	Child demonstrates pride in their achievements.	–
AL6: Meeting challenges	Child enjoys meeting their own challenges.	–
CT: Critical thinking		
CT1: Ideas and initiative	Child has their own ideas and uses their own initiative when planning designs.	D: Daring (putting ideas into action)
CT2: Curiosity and imagination	Child demonstrates curiosity, imagination, spontaneity and innovation.	B: Being curious (imagining)
CT3: Problem solving	Child uses strategies to solve problems or challenges in their designs.	E: Experimenting (solving problems)
CT4: Extending learning	Child challenges and extends their own learning.	–
CT5: Novelty	Child does something different rather than follow what someone else has done.	D: Daring (willing to be different)
CT6: Try and repeat	Child tries out and repeats their ideas to see if they work.	E: Experimenting (playing with possibilities)

(continued)

Table 19.2 (continued)

Categories and dimensions	Description	A–E framework creative processes
CD: Creativity and design		
CD1: Explore materials	Child explores the properties of materials and uses their understanding of them to achieve design goals.	–
CD2: Use materials creatively	Child uses materials in creative ways.	E: Experimenting (using materials differently)
CD3: Trialling	Child is confident using a 'trial and error' approach and they show or talk about why some things do or don't work.	E: Experimenting (playing with possibilities)
CD4: Workaround	Child uses previous experience and knowledge to develop practical workarounds.	E: Experimenting (tinkering and adapting ideas)
CD5: Adjusting goals	Child adjusts their goals based on feedback and evidence.	A: Agency (choosing to adjust and be agile)
CD6: Suggesting improvements	Child makes suggestions as to how the artefact could be improved.	–
S: Social learning		
S1: Listening	Child listens to the ideas of others.	C: Connecting (seeing different points of view)
S2: Building on ideas	Child builds on the ideas of others.	C: Connecting (combining ideas to form something new)
S3: Supporting	Child supports the learning of other children.	–
S4: Effective collaboration	Child collaborates effectively with other children.	C: Connecting (sharing with others)
S5: Seek assistance	Child seeks ideas, assistance and expertise from others.	–
S6: Feed back	Child gives feedback on the outputs of others, if asked to do so.	–

5. To what extent are children are being creative when they engage in simple coding learning with *Little Red Coding Club*?

Four case studies were conducted across three individual early years[3] settings in Sheffield, UK. Throughout the chapter, the early years settings are referred to by pseudonyms, based on wildlife native to Yorkshire, UK. Two case studies were conducted in the same setting ('Brown Hare Infant School'). Case study 1 was conducted in the Foundation Stage of Brown Hare Infant School and Case study 2 in the school's Year One class. Case study 3 was undertaken in the Year One class of 'Red Squirrel Primary School' and Case study 4 in the Foundation Stage of 'Dormouse Infant School'. Schools were approached through established networks, which constituted convenience sampling.

[3] In the UK, early years settings are educational care settings for children under the age of 5.

The research involved two phases: (1) video observations of children using the app in classrooms and early years settings; and (2) interviews with EYPs. Staff members in each early years setting supported the research team in selecting and recruiting child participants for the study. A structured sample was constructed to ensure distribution across gender and specific physical or educational needs. In phase one, two researchers introduced small groups of children to the *LRCC* app, which was installed on four tablets. A total of thirty children aged between 4 and 6 years took part (Table 19.3).

The video observation took place on eight separate days in February and March 2019. Two researchers collected data, one of whom was present on each visit. The researchers introduced the children to *LRRC* and video recorded them engaging with the app. The research took place in a range of settings, including in classrooms, adjacent rooms and playgrounds. It was intended that the researchers would observe the children using all three modes of the game: 'Play' ('1–player'); 'Play' ('2–player'); and 'Create'. Technical problems arose, meaning the game was used predominantly in the '1–player' and 'Create' modes. Despite the failure of '2–player' mode, the children still used the app both individually (one child per tablet) and collaboratively (in groups of two, sharing a tablet). The researchers were instructed to focus the filming on the child's interactions with the screen wherever possible. A total of 11 h, 54 min and 21 s of video data were collected. Of that, 36 min and 34 s of data were excluded from the analysis because these recordings were not focused on children's interactions with the app or because they were too short to be usable (e.g. under 10 s) (e.g. Therefore, 90 videos, lasting a total of 11 h, 17 min and 47 s were analysed.

In the second phase, researchers made eight visits to the three early years settings in February and March 2019. During semi-structured interviews, six EYPs responded to questions about *LRRC* and how it was being used in their settings. Researchers questioned the EYPs about any possible skills they felt the app had promoted, how they thought the app could be improved and how they might embed the app in their curriculum planning. All of the interviewees were female. Though the researchers sought a balanced gender sample, this cohort reflects the high representation of women in the early childhood education sector. Data suggests fewer

Table 19.3 Phase 1 participants

Pseudonyms	Gender	Age	Class	Setting
Grace, Bruce, Owen, Elliot, Abir, Arthur, Vicky, Brian, Audrey, Fern	4 female; 6 male	9 aged 5 years; 1 aged 4 years	Foundation stage	Brown hare infant school
Louise, Cathy, Hadrian, Sam, Isla, Jenny, Grant, Jane, Bennett, Rylan	5 female; 5 male	6 aged 6 years; 4 aged 5 years	Year 1	Brown hare infant school
Esther, Sadie, Jeremy, Adrian, Emily, Sandrine	4 female; 2 male	1 aged 6 years; 5 aged 5 years	Year 1	Red squirrel primary school
Dylan, Zane, Verity, Kyle	1 female; 3 male	4 aged 4 years	Foundation stage	Dormouse infant school

than 2% of staff working in early childhood education and care in England are men (Mistry & Sood, 2015). Table 19.4 presents the profiles of the practitioner interviewees.

A range of data were generated, including video recordings, audio-recorded interviews and fieldnotes. Whilst groups of children were selected and they were encouraged by researchers to play with the *LRCC* app, the nature of the research was naturalistic. The children's play with *LRCC*, therefore, unfolded in a variety of complex sequences, which frequently involved multiple children and more than one device. Children freely joined in, and left, moments of play. Accordingly, the video data were analysed as a series of play sequences. A play sequence was defined as a continuous, self-contained episode of play involving one or more children, as captured in one or more video clips by the researchers. A new play sequence was assessed to have begun when a child or group of children began playing, who had not been playing in the previous sequence. In total, 15 unique play sequences were analysed. These varied in length and complexity. The longest sequence lasted 1 h, 31 min and 44 s, whilst the shortest lasted only 7 min and 52 s. The play sequences involved between two and six children.

The data were analysed in relation to relevant typologies of both playful learning and early coding skills and knowledge. The MLAF (see Table 19.1) was used to classify playful learning behaviours, including creative thinking and behaviours (discussed above). The MLAF enabled researchers to identify how apps promoted a range of playful and creative learning types. Since no existing typology existed, the ECSKF was developed for the study to enable identification of early coding skills and knowledge types. Each video clip was coded deductively and multimodally against both the MLAF and the ECSKF. Attention to both visual observation and the children's verbal expressions informed the coding of behaviours. Each clip was coded against the 30 dimensions of the MLAF and 11 dimensions of the ECSKF. A '1' was recorded if a dimension was observed in the clip at all and a '0' if not. In total, 15 play sequences across 90 individual clips were coded this way. Additionally, all 90 clips were coded inductively and multimodally, to identify phenomena that lay beyond either of the frameworks. The inductive coding was then arranged into themes, some of which are reported below. The majority of the data were coded by a single researcher, but reliability was improved by inviting a second researcher to code a proportion of the data (three of the 90 clips). Intercoder reliability was

Table 19.4 Phase 2 participants

Pseudonym	Gender	Setting	Class
EYP1	Female	Brown Hare Infant School	Foundation stage
EYP2	Female	Brown Hare Infant School	Year 1
EYP3	Female	Red Squirrel Primary School	Year 1
EYP4	Female	Red Squirrel Primary School	Year 1
EYP5	Female	Dormouse Infant School	Foundation stage
EYP6	Female	Dormouse Infant School	Foundation stage

84.55%. Validity was addressed by checking how well the results corresponded to established theories, as discussed in the discussion section.

Braun and Clark's (2006) thematic analysis informed the transcription and analysis of the EYP interview data. These data were coded deductively and inductively. Deductive coding focused on observed skills, the characteristics of the observed social interactions and children's engagement. These codes were then arranged into themes, some of which are discussed below. BERA's Ethical Guidelines (BERA, 2011) informed the ethical approach. Though parental consent was initially sought on behalf of the child participants, Dockett and Perry's (2011) notion of assent guided the approach to working ethically with young children. Attention was paid to children's body language, as well as other potential markers of discomfort. The informed consent of EYPs was sought in relation to the practitioner interviews. In order to acknowledge the contribution the early years settings made to the research, each received a £100 voucher.

The next section highlights some of the core findings of the study. In order to focus closely on the relationship between young children's play with an AR coding app and their creativity, the discussion is framed by Murcia et al.'s (2020) A–E Framework.

19.5 Findings and Discussion

The A–E Framework (Murcia et al., 2020) suggests children's creativity can be conceptualised at four different levels: Product, Person, Place and Process. In this section, the findings of the study are discussed in relation to these levels.

19.5.1 Process

All of the characteristics of children's playful learning encompassed in the MLAF were observed, including the six dimensions of creativity and design (CD1–6). As such, the study evidences that the AR coding app, *LRCC*, fosters creative thinking and behaviour in young children, in particular: the exploration of materials; the creative use of materials; trialling; developing workarounds; adjusting goals; and suggesting improvements. As discussed above, other categories of the MLAF also clearly map onto other characteristics of children's creative thinking, as conceptualised at the 'Process' level of the A to E framework. As such, it can be seen that *LRCC* fosters a variety of other characteristics of children's creative thinking, e.g. exploration, the transformation of resources, being unafraid and many more (see Table 19.1).

19.5.2 Place

'Place' relates to the elements of an environment enabling creativity. In the context of *LRRC*, it is useful to consider place in relation to the affordances of the digital game. The analysis identified some differences in children's behaviours across the 90 video clips, in particular in relation to the game's different modes. In the 'Create' mode, children are able to design their own game levels, drawing on the digital elements provided (paths, characters, landscape features and objects). Whilst playing the game in 'Create' mode, the children more frequently exhibited some of the dimensions of engagement, creativity and design and critical thinking. Specifically, children were more likely to demonstrate PE2: Transform resources; CT1: Ideas and initiative; CT2: Curiosity and imagination; CD1: Explore materials; and CD2: Use materials creatively when playing in 'Create' mode. On the other hand, children were more likely to exhibit some of the early coding skills and knowledge types while using the 'Play' ('1–player') mode of the game. In particular, ECSK5: Sequencing; ECSK8: Defines algorithms; ECSK9: Decomposes; and ECSK10: De-bugs. Marsh et al.'s (2018) research into preschoolers' use of apps previously demonstrated that some apps which claim to foster creativity do so in a way that constrains children's choice and agency, e.g. when only a limited number of options or materials are available to them. The authors highlight the finding that children's creative practices are most prominent when they use apps in ways that enable them to develop their own texts or artefacts. This finding is useful as a lens for considering the different affordances of *LRRC* across its 'Create' and '1–player' modes. Though the 'Play' ('1-player') mode is an important context for teaching children the basics of early coding skills and knowledge, the children more frequently exhibited some of the dimensions of creativity and design, engagement and critical thinking when they played the game in the 'Create' mode, which provided them with the resources necessary to freely create their own texts or artefacts. However, it is important to consider the complementary relationship between the 'Create' and 'Play' ('1–player') modes. It was observed that the children began to engage in more creative behaviours once they had gained a level of confidence in the basic coding competencies. Indeed, children's imaginative play and oral storytelling incorporated aspects of their new found coding knowledge.

> At Brown Hare Infant School (Year 1), during play sequence 2d, Hadrian and Sam have been creating a level that looks like a maze in 'Create' mode, by placing paths on the grass. They proceed to co-construct a narrative about a maze based on their creation. Little Red Riding Hood, they suggest, can hide and surprise the wolf, biting him when the time comes to attack.
>
> At Red Squirrel Primary School, during play sequence 3b, Esther has designed a level with a good deal of water in 'Create' mode. She says that she is creating an island in the centre of the water that will be safe from the wolf, and begins to add multiple food items onto her 'island', where the wolf can't get them.

In their play in the 'Create' mode, children drew on multiple resources in the production of their own digital and non-digital texts and artefacts. These resources included the affordances of the app itself: game components that could be dragged and dropped; the logic of computational thinking; and the narrative inspiration of Little Red Riding Hood. They also likely included resources from children's own lives and cultural worlds. The methodology of the present study does not allow for tracing the interconnectedness of these elements with the digital game, although past research demonstrates how, in their everyday engagements with digital texts and devices, preschool children amalgamate fragments of media texts with other material and/ or immaterial 'things' to constitute 'synthesised texts' (Scott, 2018). The data, then, suggest that, when learning early coding skills and knowledge in a digital context, children are enabled to be creative when equipped with both technical understanding of conventions of coding and provided with contexts conducive to 'freeplay' and the production of their own digital creations.

This finding expands on the earlier comments of Bers (2017, 2018), who suggests that coding and computational thinking are intrinsically creative because they enable children to become creative producers through a skillset that allows for new ways to communicate, tell stories and convey ideas. The LRCC app was found to promote such a skillset. The ECSKF details 11 types of early coding skills and knowledge, ten of which were observed in the study. The only exception was ECSK11 (Identifies loops). It can thus be seen that early coding skills and knowledge are functioning as a form of literacy in the present study. Although there is little existing research concerning children's creativity in relation to early coding skills and knowledge, media literacy scholarship provides a useful lens for thinking about this phenomenon more generally. Drawing on the Derridean notion of bricolage, Dezuanni (2011) demonstrates how a teenage student's newly acquired operational digital skills are deployed creatively to produce a new digital artefact that is not a mere repetition of the conventions of the fantasy genre, but rather a unique contribution to the development of the genre. As in the present study, a (much older) child is mastering an operational digital skillset, which then facilitates creativity. The present study was small scale in nature and specific to a unique app. The complex and complementary relationship between technical coding skills and their creative deployment requires further research.

A further finding concerning the unique affordances of *LRRC* relates to its use of AR to teach coding skills. The specific nature of AR meant specific types of play were afforded that are not likely to be observed in relation to children's play with entirely digital or entirely non-digital games. To exemplify, some of the children exhibited great excitement in exploring the relationship between tablets and screens as physical objects and the game board as a perceived or imagined physical space. They children were observed exploring the materiality of the tablets subversively, physically tapping and even licking the reverse of each other's devices. They also played with the affordances of AR, moving their devices and game boards to position and view their classmates 'on' or 'behind' the game boards 'in real life'. Similarly, several children navigated the imagined physical space behind the tablet's camera, intentionally positioning themselves where they imagined the board would be.

> At Brown Hare Infant School (Year 1), Hadrian, who has been interested in the Woodcutter's axe, holds an imaginary axe some distance behind Sam's tablet in the space where he imagines Sam's board must be. Hadrian goes to Sam's screen and peers round to check where the board is, then returns. Holding the tablet, Sam guides Hadrian to where he must stand to be holding the Woodcutter's axe (Play sequence 2d).

The play afforded by AR was associated with (and coded against) multiple creative dimensions of the MLAF, including CT2: Curiosity and imagination and CT5: Novelty. This imaginative play episode connects with the NACCCE (1999) definition of creativity as 'imaginative activity fashioned so as to produce outcomes that are both original and of value' (p. 29). Thus, it can be seen that the AR technology employed in *LRRC* supported novel forms of creativity. The unique affordances of AR in teaching early coding skills and knowledge warrant further research.

19.5.3 Product

In the A–E Framework, 'Product' relates to the outcomes regarded as creative. In the context of *LRRC*, it is useful to consider product in terms of the practices and texts produced when young children engage with the app. In their playful engagement with the app, the children successfully defined and de-bugged lists of steps (algorithms) to complete tasks within the game. As Bers (2018) suggests, such processes can be considered intrinsically creative, enabling children to become creative producers. In the present study, children were creative producers of sequences and algorithms. They also created otherwise (Wohlwend, 2018), originating a range of novel texts and artefacts. Some examples included creating on-screen assemblages and narrating short stories.

19.5.4 Person

In the A–E Framework, 'Person' relates to who does the original thinking. In the context of *LRRC*, it is useful to consider person in relation to the pedagogical interventions of the EYPs. Whilst many of the skills discussed above were observed in children's solo or peer play with *LRRC*, it was found that certain skills were only observed in the presence of appropriate pedagogical intervention from an adult. For example, CD6: Suggesting improvements was only coded in two of the 90 video clips collected. This dimension of creativity and design relates to a child suggesting how an artefact could be improved. This behaviour was observed in two play sequences within one setting (Red Squirrel Primary School). In both play sequences (3b and 3c), a child made suggestions in response to an adult prompting them to critically reflect on the game. For example, Jeremy (who was very interested in the character of the wolf) reflected that the wolf should be made into a playable character.

The app fostered all of the social learning dimensions of the MLAF (listening, building on ideas, supporting, effective collaboration, seeking assistance and feeding back). The app's designers intended that the app would afford social learning primarily through the provision of the 'Play' ('2–player') mode. To play productively in this mode, at least two children must understand the unique abilities of their playable characters and communicate with others about these. Technical difficulties meant children's engagements in '2–player' mode were not examined in the study. However, the game's other modes ('Create' and '1–player') themselves afforded social learning. The level of knowledge required in the game increases as players progress sequentially through its levels. A short visual and verbal tutorial at the beginning of each level provides some of the basic principles of the game. However, players must employ a trial and error approach to understand other principles. This factor appears to afford a good deal of social learning, as children discover and share strategies for success in meeting the progressively difficult challenges of the game. In the present study, children were observed using the app individually (one child per tablet) and in small groups (sharing a tablet). Children, and groups of children, were also observed playing on one device but sharing knowledge and strategies with another child or children. This knowledge was communicated verbally and physically. Children modelled strategies by showing other children on their own screens and by tapping each other's screens. EYPs also identified this phenomenon, with many noting that *LRRC* promoted collaboration in a relatively spontaneous and relaxed way without a great deal of overt intervention or guidance from adults. Many EYPs reported observing children supporting one another in their learning with the app, for example pointing out each other's mistakes and modelling the correct approaches. The play afforded by the app was thus associated with (and coded against) multiple creative dimensions of the MLAF, including S1: Listening and S2: Building on ideas.

It is worth noting that characteristics of playful learning, creative thinking and behaviour and early coding and knowledge skills were demonstrated across all four cases studies, across settings, genders and age groups. The app thus promoted these skills and characteristics in children as young as four. Notably, both girls and boys demonstrated good motivation and engagement in relation to *LRRC*. We now move to the conclusion, which highlights the most important findings of the study as well as some limitations and implications for future research and educators.

19.6 Conclusion

Engagement with the *LRCC* app promotes a variety of playful learning, creativity and early coding skills and knowledge in young children (four to six). All of the characteristics in the MLAF were observed, indicating children engaged in a range of playing and exploring, active learning, critical thinking, creativity and design and social learning. Additionally, all of the early coding skills and knowledge types were observed, with the exception of ECSK11: Identifies loops. In its present form, *LRCC* does not afford the creation of loops.

The A to E framework proved useful in conceptualising children's creativity with *LRRC*. It was clear that all four levels addressed by the framework (Product, Person, Place and Process) were important for understanding children's creativity in relation to an AR coding app. In terms of 'Process', children demonstrated a range of creative thinking and behaviours, including the six dimensions of creativity and design (the exploration of materials; the creative use of materials; trialling; developing workarounds; adjusting goals; and suggesting improvements) and other creative categories of the MLAF, e.g. exploration, the transformation of resources, being unafraid and many more (see Table 19.1).

In terms of 'Place', the present study identifies a range of findings relating to the unique affordances of *LRRC* as a digital context. Interestingly, different types of playful learning were afforded by the 'Create' and 'Play' ('1–player') modes. The 'Create' mode particularly supported aspects of engagement, critical thinking and creativity and design (e.g. exploration of materials and the creative use of materials). The 'Play' ('1–player') mode particularly supported early coding skills and knowledge types including sequencing, defining algorithms and de-bugging. The data suggest that, when learning early coding skills and knowledge in a digital context, children are enabled to be creative when equipped with both technical understanding of the conventions of coding and provided with contexts conducive to 'freeplay' and the production of their own digital texts and artefacts.

In terms of 'Person', whilst many of the skills discussed above were demonstrated by children in their solo or peer play with *LRRC*, others clearly required suitable pedagogical support from an adult. For example, CD6: Suggesting improvements, which was observed in only two of 90 clips. This aspect of creativity and design, which required a child to make suggestions about how an artefact could be improved, was only observed when an adult prompted children to critically reflect on the game. In terms of 'product', the children successfully defined and de-bugged lists of steps (algorithms) to complete tasks within the game. As Bers (2017, 2018) suggests, such processes can be considered intrinsically creative, enabling children to become creative producers. Children were creative producers of sequences and algorithms. The children also created otherwise, generating a range of novel texts and artefacts, including visual, on-screen assemblages and narrating short stories.

19.6.1 Limitations

The study had a number of limitations. In particular, the study was exploratory and small-scale in nature. Future work could extend this research across a wider range of settings. The reliability of the study would be improved by a second researcher coding all, rather than a subset, of the video clips.

19.6.2 Implications for Research and Practice

The study also has implications for further research and for educators. Further research into the relationship between the acquisition of early coding skills and knowledge and the creative deployment of these skills is needed. The unique affordances of AR in teaching early coding skills and knowledge also warrant further research. Educators are likely to be interested in the relationship between early coding skills and knowledge and creativity. The study emphasises that the inclusion of coding and computational thinking in early childhood education may not only be of value in relation to learning a particular defined skillset, but also in terms of making possible particular forms of creativity and creative thinking. It is recommended that educators might also pay attention to the finding that CD6: 'Suggesting improvements' was only observed in the data when facilitated by an educator. This suggests that this particular creative behaviour required more scaffolding than many of the others, which children exhibited independently in their interactions with the app.

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Chapter 20
Preparing Greek Pre-service Kindergarten Teachers to Promote Creativity: Opportunities Using *Scratch* and *Makey Makey*

Michail Kalogiannakis and Stamatios Papadakis

20.1 Introduction

Creativity is relevant in all aspects of life and is essential for adaptable and innovative thinking (Craft, 2005). Around the world, we see children thinking creatively, inquiring, and discovering STEM (Science, Technology, Engineering, and Mathematics) understandings and capabilities in their everyday activities and through their play (Murcia et al., 2018; Murcia et al., 2020). Torrance (1969) define creativity as a set of abilities, skills, motivation, and the ability to find solutions to confront challenging situations or difficulties. Creativity is a thinking ability that enables problem-solving in an innovative manner and the production of original and valuable products (Torrance, 1974). Samuelsson and Carlsson (2008) comment that pedagogy should not separate play and learning but draw upon the similarities in order to promote creativity in future generations.

Creativity has been identified as crucial to creative human potential in all disciplines, and it is evident that its influence dominates various spheres of life (Navarrete, 2013). Epistemologically, creativity in education is framed in one of two ways. Firstly, an instrumentalist perspective can be seen as a skill that should be developed as a route towards innovation and building a 'knowledge economy'. Secondly, it is often interpreted in education through the notion of romantic 'self-actualisation' tied in with a democratic ideal of creativity—that creativity is something that we are all capable of and that creativity is an essential part of childhood development (Gibson, 2005).

In recent years there has been growing recognition that creativity is an essential skill for the twenty-first century that can be nurtured and included in the curriculum

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from an early age (Beghetto, 2010; Said-Metwaly et al., 2017). In the past decade, concepts such as Computational Thinking (CT), algorithmic thinking, and coding have focused on research and teaching interest from the early years (Bocconi et al., 2016; Sáez-López et al., 2019). Many countries are developing or reviewing national policies to support children developing as computational creators and computational thinkers (Reisoğlu & Çebi, 2020; Resnick, 2017a, b).

Since the early days, children have used Logo programming language to guide a ‘turtle’ around the classroom; the scientific community has not ignored the challenges (Fessakis et al., 2019). There are ongoing attempts to make the coding world more accessible to novices by connecting it to the real world (Clarke-Midura et al., 2019). This linkage may be a great advantage when these processes are embedded into cognitive activity to introduce early young learners to computational thinking, algorithmic thinking, problem-solving and critical thinking (Cabrera et al., 2019; Piedade et al., 2020; Sáez-López et al., 2019; Walsh & Campbell, 2018). As a robotic kit, the *Makey Makey* provides functionality that falls into this category and has been used extensively in education (Fokides & Papoutsi, 2020; Pérez-Marín et al., 2019).

Preschool teachers do not view coding literacy similarly to universal reading and writing literacy (Bers, 2019). However, in the light of recent evidence, they will likely change their current view as new curriculum around the globe fosters the purposeful integration of coding and data literacy (Walsh & Campbell, 2018). When education systems worldwide identify CT and coding as a prerequisite even for young age children, preschool age educators will become responsible for introducing these concepts relative to CT, coding, and tinkering in early childhood education, even when they may have had little or no training in the specific domain (Walsh & Campbell, 2018). In any case, this will result in a change in practice, demanding from teachers to rapidly develop a series of skills to introduce CT concepts and coding skills in the classroom (Marín-Marín et al., 2020).

Several researchers have found that teachers’ training affects their ways of embedding technology into teaching practice and that teachers’ prior technical knowledge and relative positive perceptions could support or hinder technology integration in daily teaching practice (Alkhayat et al., 2020). The National Association for the Education of Young Children (NAEYC) and the Fred Rogers Center (2012, p. 4) roughly a decade ago highlighted the fact that “in the digital age, educators need pre-service and professional development opportunities to test new technology tools, learn about the appropriate use of technology, at the end gain the knowledge and skills to implement them effectively”. Stylianidou et al. (2018) also highlight the need for sufficient resources and facilities in schools to support practical inquiry and problem-solving in early science and opportunities for ongoing professional development.

At current, there are several educational resources at a low or moderate cost that allow for the introduction of coding activities at very young ages in the form of programmable toys, such as the *Roamer*, the *Pro-Bot* or the *Bee-Bot*® robotic kit (García-Valcárcel-Muñoz-Repiso & Caballero-González, 2019). Nevertheless, the pre-service teachers need to be equipped with digital and pedagogical competencies in their professional careers to include CT in schools actively (Marín-Marín et al., 2020). Robotics and coding, most underrated in the early childhood curriculum, provide early childhood teachers with the opportunity to integrate technology and research-based teaching (Turan & Aydoğdu, 2020). In this respect, pre-service training is essential to improve pre-service teachers' knowledge in this domain ((Reisoğlu & Çebi, 2020).

The research question this study sought to answer is:

> Can *Scratch* and *Makey-Makey* be considered as effective tools for introducing pre-service teachers to concepts related to both CT and programming during their training in institutions of higher education?

Chappell and Craft (2011) focused on wise, humanising creativity, emphasising collaborative and communal engagement with creativity's ethics. In summation, creative and intellectual minds will produce original products containing a social or personal value to enhance creativity to the users (Behnamnia et al., 2020). Effective development in science is a complex interrelationship between procedural skills, often grouped into phases linked to the inquiry process and conceptual understanding leading to scientific 'literacy.' Creativity is an inherent capability in all people and thus an essential part of childhood (Gibson, 2005). In this study context, the innovative product refers to the creation of game-based projects. For this purpose, a teaching intervention has been implemented to place our students at the centre of the knowledge discovery and construction processes to leverage their inherent curiosity to engage with content and seek answers through experiences and experiments. The intervention is presented in more detail in the following sections.

20.2 Visual Programming and Robots

Papert (1980), stated that the introduction of developmentally appropriate technology activities into the curriculum, based on a constructivist pedagogical approach, can help students internalise new knowledge via motivational aspects of learning and facilitate their future involvement in relative settings (Caballero-Gonzalez et al., 2019; Papert, 1980). Nowadays, CT and coding are recognised as critical twenty-first century skills (Bocconi et al., 2016). The expectation of introducing CT and coding skills at an earlier age triggers a shift in preschool teachers' professional identity. The introduction of CT and coding activities in preschool education represents a substantial change so that teachers must undertake new responsibilities and developing different forms of interactions with children to connect their activities to technology through fun and engaging activities (Walsh & Campbell, 2018). Banaji et al. (2006) focus on creative classroom discourse that they identify as widespread in play and creativity, emphasising playful, exploratory engagement. Digital technologies can foster children's creativity, such as gaming, connecting with others, and content generation in particular (Craft, 2010). The engagement of young children in science, seeking to build lifelong positive attitudes.

Developing creativity, one of the skills of the twenty-first century, is crucial to the future of children (Pan et al., 2018). Developing creativity also leads to other issues such as problem-solving, collaboration, and critical thinking (Hwang, H.W. et al., 2012; Shih et al., 2010). Digital activities in preschool education, based on CT and coding activities and focusing on elements such as fantasy, curiosity, and challenge, raise the interest and motivation of children (Hooshyar et al., 2018). This type of learning is based on curiosity to stimulate children to find new ways to solve problems and then to increase children's satisfaction (Shin et al., 2012).

The introduction of these new concepts and skills, especially in preschool education, requires developmentally appropriate tools and active learning practices to make programming simpler for young children. This approach is considered critical to accomplishing the goals of "low-floors, high ceilings, and wide walls" (Bocconi et al., 2016; Cabrera et al., 2019; Clarke-Midura et al., 2019; Resnick, 2017b), which describes something comfortable to get started on, yet has considerable growth potential.

The need to introduce CT concepts and necessary algorithmic and coding skills in preschool education has driven numerous commercial and research-based toys and kits. These products derive from the necessity to make technology and relative concepts more accessible to children via tangible things -touchscreen smartphones and tablets, wearable devices, and infrared sensors (Clarke-Midura et al., 2019). In all these new forms of technology, or just using the 'traditional' devices in laptops and desktop machines, educators can help novice programmers-children develop CT, coding, and digital skills (Piedade et al., 2020). Various authors (Kalogiannakis et al., 2021; Wang et al., 2010) have claimed that technology can support inquiry in various ways, including data collection, stimulating questioning, and supporting thinking. For example, several studies have explored mobile devices' use to support personal inquiry by allowing individuals to record and analyse information in the world around them (Kalogiannakis & Papadakis, 2017; Vlasopoulou et al., 2021).

Educational-based activities, along with creative components, enhance children's ability to solve learning and interaction problems and facilitate young students' learning. These kits serve as learning tools from kindergarten to K-12 to ensure the fun and engaging hands-on activities in a playful learning environment that helps novice programmers cultivate their curiosity, passion, and creativity (Cabrera et al., 2019; Sisman & Kucuk, 2019).

Nevertheless, developing coding skills is challenging for novice programmers of all ages, such as students and their non-computer science teachers. It demands a coherent theoretical understanding of specific concepts and a practical application of programming knowledge and other higher-level cognitive skills such as synthesis and evaluation (Piedade et al., 2020). Research on novice programmers has revealed that novices perceive block-based programming environments as more accessible, regardless of prior experience. They help them complete programming tasks more quickly and easily through a visual, drag-and-drop interface (Cabrera et al., 2019). While using a visual interactive programming environment, novices avoid syntax errors such as missing commas or incomplete parentheses that appear in conventional textual programming languages.

In general, novices creating programmes or projects, such as *Scratch*, with blocked-based environments are more comfortable and demand lower cognitive effort. Novice programmers, different from conventional textual programming languages, have to interact with coloured blocks similar to a jigsaw puzzle. Furthermore, when teachers combine block-based environments with educational robotics via educational interventions, students can learn and further develop applied methods while almost in real-time observe their projects' tangible results (Piedade et al., 2020). Research has revealed that students of all ages can create complex concepts by editing and manipulating code to control educational robots. Educational robots can help the teaching process acting as a factual basis for novices to carry out the learning-based activities with authentic and integrated learning experiences via interactivity and immediate feedback (Sáez-López et al., 2019). In the last decade, the educational community has taken advantage of better educational opportunities, as several educational robot kits are cooperating with block-based programming environments. This interaction can facilitate an accessible introduction of coding activities in primary education settings due to this interaction type (Piedade et al., 2020; Sáez-López et al., 2019).

20.3 The *Scratch 3* Visual Programming Environment

Scratch (https://scratch.mit.edu/) is maybe the most popular programming environment for novice programmers. Mitch Resnick, director of the Lifelong Kindergarten group at the MIT Media Lab, is the creator of this free block-based language. The scratchers, the *Scratch* users, can create projects by dragging and dropping visual blocks of commands on the screen. This coding method reduces the cognitive load to recall commands and strict syntax requirements (Clarke-Midura et al., 2019). *Scratch* supports seven different blocks (command) categories: motion, look, sound, control, sensing, operators, and variables (Sáez-López et al., 2019).

According to Resnick (2017b), *Scratch's* main advantage is how novice programmers learn to programme while creating their projects. While in most introductory educational coding activities, children have to make a character move around obstacles, with *Scratch*, the students focus on projects. In this way, children use their imagination and skills to create interactive stories, simulations, games, and animations based on their interests. Furthermore, they can easily share their projects with their classmates or an online community of scratchers worldwide (Resnick, 2017b).

Due to its popularity, people of all ages use it as it is easy for anyone to start developing their programming and problem-solving skills by creating their projects. *Scratch 3* runs on virtually any computer, with or without internet access. It runs on *Windows*, *macOS*, *Linux*, *Android*, or *iOS*. e.g., PCs, tablets, smartphones, and *Raspberry Pi*. By setting up an optional free account online, a scratcher can also copy and 'remix' other people's projects, which is a great way to learn and collaborate with other *Scratch* users worldwide.

20.4 The *Makey Makey* Educational Robotic Kit

Makey Makey is another robotic device used in the last years in the teaching and learning process. Its name comes from 'Make + Key' and can be used by young children of both genders (Castro-Araya et al., 2020). *Makey Makey* is a low-cost electronic board that plugs into any keyboard computer. Additionally, for enhanced experiences with the physical world, the *Makey Makey* device includes actuators and sensors. Unlike other robotic tools, the *Makey Makey's* potential lies in connecting familiar elements to this device like bananas or aluminium foil (see Fig. 20.1). All this favors people's interaction with the robotic kit, endorsing positive behaviours relative to programming with little cognitive effort (Marín-Marín et al., 2020). All a user needs to use *Makey Makey* is a standard keyboard-equipped computer with a USB port and some conductive materials (Aydogan & Aydogan, 2020). It works as soon as a user plugs it in - no special software or other preparation is needed. This connection helps a novice implement various educational activities, leading to excellent participation levels and a significant cognitive impact (Marín-Marín et al., 2020).

Makey Makey consists of several components. In front, there exists a USB port and the necessary components for the device control. On the other side, there is the motherboard based on *Arduino's* open-source platform. *Arduino* is an open-source electronics platform based on easy-to-use hardware and software. *Arduino* boards can read inputs—light on a sensor, a finger on a button, or a Twitter message—and turn it into an output—activating a motor, turning on an LED, publishing something online (Arduino.cc, 2021). There are also wiring and control clips connected in various slots, both on the front and the back (see Fig. 20.2).

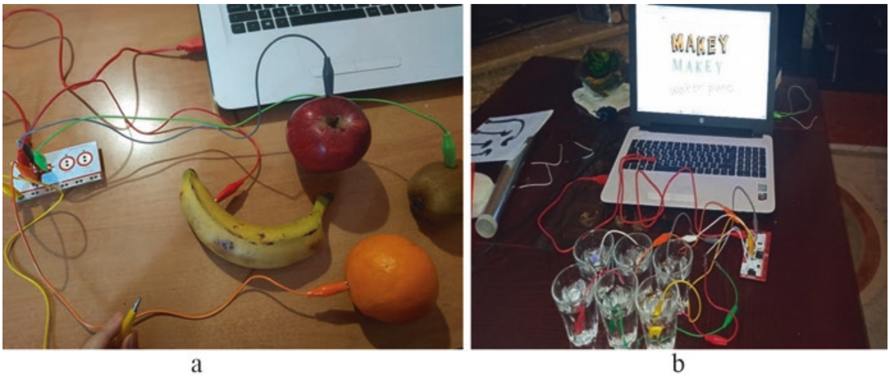


Fig. 20.1 (**a**, **b**) A fruit *PacMan* and a water piano with *Scratch 3* and *Makey Makey*

a b

Fig. 20.2 (**a**, **b**) *Makey Makey* components

20.5 Methods

20.5.1 Participants

The participants were 23 female pre-service early childhood teaching students (20–22 years old) who took a university course called 'ICT in Education' in the Department of Preschool Education of a major university, University of Crete, in Greece. The participants voluntarily attended the course, and they all planned to teach in kindergartens in their future careers.

20.5.2 Study Design

The study is part of the research programme of the department currently under development. The intervention focused on activities that strengthened computational thinking concepts, coding, and algorithmic connections to other concepts. These activities also focused on developing positive attitudes and behaviours in early pre-service childhood students based on educational robotics kits' problem-solving activities. The intervention's development was based on the *Makey Makey* device, a robotic invention kit, and *Scratch 3* as a free interactive visual block programming environment. The tools mentioned above complemented various daily use materials such as bananas, aluminium foil, plasticine, and water glasses.

As a pedagogical strategy, the intervention focused on project-based and inquiry-based learning, solving real problems with the teacher and peers' support (van Uum et al., 2017). The pedagogical actions carried out tried to support students by scaffolding their learning, which meant that they worked as a team.

The intervention approach was based on the assumption that learning occurs when the learner is actively involved in knowledge construction while having the freedom to decide for their projects to acquire knowledge and skills in new situations (Sáez-López et al., 2019). The different student teams (consisting of two or three members each) were free to choose their projects. Students created their projects to promote CT and digital-making skills, social interaction, imagination, and creativity. Students were encouraged throughout this process as their projects were taken into account for their evaluation for this course.

The course participants met three hours each week, and it lasted 13 weeks during the spring semester of the academic year 2018–2019. At the beginning of this course, the instructor focused on making the students familiar with *Scratch 3* and *Makey Makey* by introducing both tools. For instance, the instructor introduced the *Makey Makey* sensors, algorithms, *Scratch 3* interface, use of everyday objects, e.g., bananas) into the related activity. Accordingly, the students in groups had to design a simple project by following the instructor's steps. The project was based on an activity published on the *Instructables* website (https://www.instructables.com/Makey-Makey-in-the-Classroom/).

Throughout the whole learning procedure, the instructor assumed the observer's role and provided guidance only if needed and asked by the students. All participant groups completed five activities and one project according to their own choice for use in the kindergarten classroom.

20.5.3 Data Collection

The course evaluation included both cognitive (e.g., how effectively students have learned the skills taught) and affective (e.g., how enjoyable students found the intervention) factors. For this purpose, quantitative and qualitative data were collected and analysed by the researchers.

The study's quantitative part was conducted in a pre-test/ post-test comparison of a quasi-experimental design. Additionally, to analyse how the students developed CT and coding concepts, the researchers investigated students' projects to understand how students used *Scratch* elements and their projects' functionality and appearance. A short questionnaire and semi-structured interviews were used to explore students' views as part of the qualitative approach. These data were recorded in the form of field notes and were not audio-recorded. The researchers adapted this approach to evaluate three aspects:

- The potential of *Scratch/ Makey Makey* and relative activities as a learning support tool.
- The students' intention to introduce the course elements in their future daily teaching practice.
- The students' level of satisfaction during the course.

The data-collection techniques included open (yes/ no) and closed questions such as:

> What is your opinion of the combination of *Scratch* and *Makey Makey* as a supportive learning tool?
>
> What do you think regarding the introduction of CT and coding activities in your future daily practice?

20.5.4 Data Analysis

20.5.4.1 Project Analysis

The pre-test and post-test results were analysed to verify educational robotics activities' influence on the acquisition of computational thinking skills, distinguishing the dimensions: sequences of instruction, concepts such as variables, selection, repetition, and debugging. The dependent variable was the students' computational thinking and programming skills, considering seven dimensions, evaluated through *Dr. Scratch*.

Dr. Scratch (http://drscratch.org/) is a web-based tool for predicting users' performance in *Scratch* projects taking into account seven different dimensions expressing an opinion for each of them (Moreno-León & Robles, 2015). The dimensions are (1) logical thinking (LT), (2) data-information representation (IR), (3) user-interactivity (IN), (4) flow control (FC), (5) abstraction (AB), (6) parallelism (PA), and (7) synchronisation (SN). Each dimension is graded from zero to three, respectively. Depending on the level of project sophistication, project scores range from zero to 21.

The score depends on the project complexity in terms of sophistication, interactivity, etc. Thus, a total evaluation ranges from zero to 21 (seven dimensions multiplied by [zero to three]). The evaluated project scores ranged between ten and 20 (see Table 20.1).

Table 20.1 Modified TSECT instrument items

	Items
1	I feel confident in creating simple projects with *Scratch* and *Makey Makey*.
2	I know how to teach programming concepts with *Scratch* and *Makey Makey*.
3	I can encourage a positive attitude toward programming with *Scratch* and *Makey Makey* to my students.
4	I can act as a mentor teacher and support other teachers or students to use CT and coding as an interdisciplinary tool.
5	I am sure to implement CT concepts and coding as an educative tool within the preschool classroom.
6	I can share lesson plans, activity sheets based on CT, and coding as an educative tool within the preschool classroom.
7	I can create lesson plans using CT, algorithmic, and coding as an educative tool.

20.5.4.2 Students' Self-Efficacy Analysis

The *Teachers' Self-Efficacy in Computational Thinking* (TSECT) questionnaire (Bean et al., 2015) was used by the researchers to evaluate students' self-efficacy beliefs regarding CT concepts and coding skills in their future teaching practices (see Table 20.1). The first seven questionnaire items were used in the analysis based on a five-point Likert scale (from strongly disagree to agree strongly). The other questions were not compliant with this study scope.

The questionnaire was translated, adapted, and validated for use in the Greek pre-service teacher's community. After translation and before using the questionnaire for this study, it was pilot tested in two phases in an independent focus group of teachers and academics experienced in research. The pilot test aimed to minimise the difficulties in completing it and ensure it would be adapted, providing the best possible reliability and validity conditions.

The participants completed the questionnaire before and after the intervention. The statistical analysis was performed with *SPSS 23.0* for Windows.

20.6 Results

As might be expected, students' project analysis revealed issues regarding advanced computer science concepts such as parallelism and synchronisation. This observation complies with a similar study (Moreno-León et al., 2017). Additionally, only two projects used sophisticated elements (for novice programmers) such as random numbers and logical expressions. Indeed, the frequent use of flow control in conjunction with increased user interactivity reveals that the students -although novice programmers—tried to implement conditions and handle user interaction in their projects.

Dr. Scratch also categorises the user CT and coding skills in three domains: Basic, Developing, and Master. Students' project analysis reveals that only 30 per cent of their projects were categorised as 'Basic', while 70 per cent were categorised as 'Developing'. As was expected, there were no projects on the 'Master' level. The results of the *Dr. Scratch* evaluation are presented in Table 20.2.

The differences between the pre-test and post-test were analysed with a paired sample test and revealed a statistically significant increase from pre-test (M = 11.01,

Table 20.2 *Dr. Scratch* project score analysis

	Computational thinking dimensions						
Statistical measures	PA	LT	FC	IN	IR	AB	SN
Mean	1.92	1.62	2.1	1.98	1.75	0.65	1.64
Std. dev.	0.29	0.32	0.35	0.19	0.32	0.34	0.39
Minimum	1	1	1	1	1	1	1
Maximum	3	3	3	3	3	2	2

SD = 3.84) to post-test (M = 17.42, SD = 2.98), t(22) = 2.87, $p < .0001$. From this analysis, we can conclude that after the teaching intervention, the students felt confident enough to create projects with *Scratch* and *Makey Makey* and, more importantly, use them as an educative tool within the preschool classroom. It also seems that the students intend to use CT concepts and algorithmic and coding for instructional purposes in their future daily practice.

The workshop's final products show a wide variety of projects (see Fig. 20.3), where each group applies the learnings built in the course, practically applying CT and coding skills in their designs for the context of initial education-in turn, using low-cost resources such as food, plasticine, recycling materials, as presented in various videos and literature.

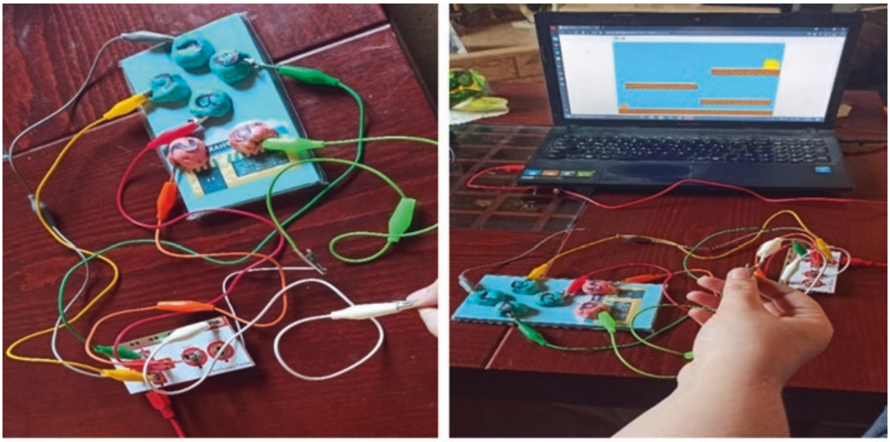
Moreover, after completing the course, the two researchers conducted the student focus group interviews using a semi-structured interview protocol. The interview included questions aiming to reveal students' satisfaction, challenge, motivation, creativity, and collaboration during the course activities. Some of the participants' answers were the following:

> I believe that these types of activities can be integrated into the preschool education curriculum. I believe that the CT and coding activities can be integrated into combination with other subjects, but they can also have the first role in teaching.

> There is not enough experience in STEM activities. However, from this course, we realised that it is a rather neglected object and is not examined in depth during our studies.

> Certainly, the preparation in the subject of STEM during our studies is not to a good degree, but after this course, we got the necessary knowledge to introduce these concepts.

> These kinds of activities will increase children's motivation as they will give them a more active role, i.e., to participate in the process themselves and be implemented by themselves.



a b

Fig. 20.3 (**a**, **b**) *Super Mario* game with *Makey Makey*, *Scratch 3*, and plasticine

All the students noted that they could handle the cognitive course effort, and they feel confident in introducing relative CT and coding activities in the preschool classroom. The students mentioned that they experienced a significant improvement in their representations towards CT or coding. Although the lack of CT and coding knowledge was a significant challenge before the teaching intervention, they mentioned that they do not consider themselves novices after the course completion. These students reflected on their intention to incorporate *Scratch* and *Makey Makey* activities in their future teaching career and their practice in the following semesters in kindergartens during their university studies. Convincingly, all students noted that the course helped them correct most of their misconceptions toward CT, algorithmic, and coding concepts. The participants' interviews revealed that most students could adequately explain CT and coding concepts taught in the course. This result complies with the high levels of interest and self-confidence in using educational robotics after the course completion.

Furthermore, it is also worth acknowledging that almost all the students noted that they would like to follow similarly or with more advanced CT and coding concepts during their university studies. Of particular note is that the students noted that they would recommend the programme as a valuable experience to other students. According to the *Analysing Children's Creative Thinking* (ACCT) framework, creativity and creative thinking can be identified through observable behaviours associated with three main areas: exploration, involvement and enjoyment, and persistence (Marsh et al., 2018). In this study, this was determined by the specific context in which a creative act occurred. Like other studies, this study combines a block-based programming environment and an educational robotic kit as an effective way to introduce young students and novice programmers to coding (Piedade et al., 2020).

20.6.1 Ethical Considerations

In this research context, national and international research ethics guidelines were followed (Petousi & Sifaki, 2020), such as the guidelines suggested by the *University of Crete Code of Ethics & Research Ethics Committee* (https://en.uoc.gr/el/research-at-uni/ethics/ethics-and-research.html). We obtained informed and voluntary consent from the teachers who participated in this study. We also informed potential participants of the importance of their participation and where any data collected would be stored.

20.7 Limitations

There are a few limitations related to this work that needed to be addressed. This study's findings are based on investigating female students' responses at just one Greek university. Although technology inclusion in education is increasing worldwide, complex cultural factors are always at play when studying attitudes and their effects (Alkhayat et al., 2020). Furthermore, this study is the first study of its kind from Greece and was a pilot; it was conducted with a relatively small sample and a short intervention, limiting statistical power. Thus, we note that the data are merely descriptive, constraining our ability to make strong claims about the intervention's effect on students' acquisition of CT concepts and coding skills.

Furthermore, we consider that projects can act as vehicles of creative inquiry. Projects must whether integrated into content-based courses, as standalone focused courses, or as co-curricular pursuits to provide the optimal framework for students and faculty to engage in creative inquiry. We hope to continue investigating this teaching intervention's effect with many participants from different departments within universities in future work. In the next academic year, the participants, as part of their pedagogical practice, plan to implement activities and knowledge learned during the course with actual classes of students in kindergartens. This implementation will increase the quantity and quality of the observations widening the scope and generalisation of the present study's conclusions (Caballero-Gonzalez et al., 2019).

20.8 Discussion—Conclusion

Given the increasing number of young children using apps that promote CT concepts and coding skills (*ScratchJr*) and the abundance of robotic toys or kits available for educational activities (e.g., *Blue-Bot*, *Makey Makey*), preschool educators are responsible for introducing these new forms of technology into the preschool learning experiences (Walsh & Campbell, 2018). Creativity nurturing novelty and science nurturing children's engagement with the content and process of bodies of knowledge, they share a recognition of the importance of hands-on and minds-on exploratory engagement, and a focus on inquiry and investigation, often driven by young learners' curiosity and questions. Simultaneously, most preschool educators have limited knowledge of introducing coding literacy in their daily teaching practice. This problem derives from the fact that most early childhood teacher education programmes do not include coding literacy training as part of their teachers' development programme (Walsh & Campbell, 2018).

With the pace of technology change, it is of paramount importance that preservice teachers be provided with training opportunities through their university studies that will intensely focus on CT pedagogy and coding literacy, which can be easily transferred to young age students with minimal difficulty (Alkhayat et al., 2020; Bocconi et al., 2016). The aim is to cultivate a positive ethos around digital technology use in the classroom, recognising CT and robotic technologies' affordances for children's learning (Levy & Kucirkova, 2017). Creativity motivates interest in computer science and supports CT acquisition (Dagiene et al., 2019), and motivation has a vital role in creativity.

For preschool educators to feel motivated and self-confident to teach coding with robotic technologies, they first need to learn CT concepts and coding basics.

Play-based exploratory contexts afford rich opportunities for supporting the development of both positive attitudes and motivation, which are critical constructs of the affective domain in science education (Koballa & Glynn, 2007). They also need resources that explain how teaching CT and coding skills dovetail with play-based learning experiences and other learning forms aligned with national policies (Walsh & Campbell, 2018).

In this case study, we have analysed 23 female pre-service early childhood teaching students as they worked with a robotic kit and a visual block programming language. The students who participated in the teaching intervention developed CT and coding skills using tangible objects (robots) based on project-based learning, consolidating this new knowledge and integrating it with previous knowledge (García-Valcárcel-Muñoz-Repiso & Caballero-González, 2019; Castro-Araya et al., 2020).

According to this study's findings, the participants actively engaged in learning coding through various activities. Most of them were also satisfied with the interaction they had with the other students and the instructor. Similar to other studies, it is considered that the *Makey Makey* is a versatile tool because it allows us to generate interaction with very diverse and low-cost conductive materials, to connect different objects to the computer (Castro-Araya et al., 2020). Besides, this study demonstrates that there can be an improvement in understanding the concepts of CT and coding as a literacy when students take part in teaching approaches that on cooperative, student-centered learning, while they actively participate and have fun in the process (Sáez-López et al., 2019; Sisman & Kucuk, 2019).

Children's creativity in the early years has mainly been characterised as problem finding and problem-solving, involving playful exploration that prompts individual, collaborative and communal engagement (Craft et al., 2012). We recommend integrating coding literacy in the pre-service teachers' professional development design based on the present investigation's results. Based on this study's results, we further recommend integrating robotics and visual block-based programming (such as *Scratch* and *Makey Makey*) as an effective way to train university students in CT concepts and coding activities (Sáez-López et al., 2019).

This study provides implications for the implementation of coding literacy in educational institutions. Given the importance of CT and coding skills, understanding how best to support pre-service teachers in meaningfully and successfully implementing coding literacy is of great importance. This study hopes to help inform future course design to help pre-service teachers acquire positive coding literacy experiences during their studies.

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